PEER REVIEW DRAFT

STAFF REPORT FOR THE KLAMATH RIVER BASIN TEMPERATURE, DISSOLVED OXYGEN, ORGANIC MATTER, AND NUTRIENT TOTAL MAXIMUM DAILY LOADS

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PEER REVIEW DRAFT
CHAPTER 1. INTRODUCTION

1.1 Overview

The purpose of this report is to present the Total Maximum Daily Loads (TMDLs) calculated by California to protect and restore beneficial uses of water downstream of the Oregon border. The California Klamath TMDLs are comprised of two distinct parts: the Staff Report and the Action Plan. This document is the Staff Report that contains information and findings to support the recommended Action Plan to the North Coast Regional Water Quality Control Board (Regional Water Board).

The Klamath River basin[1] is 12,680 square miles originating in southern Oregon and flowing through northern California to meet the Pacific Ocean at Requa in Del Norte County, California. Forty-four percent of the watershed lies within the boundaries of Oregon, while the remaining 56% of the basin lies within the boundaries of California. Figure 1.1 is a map of the Klamath River basin.

The Klamath River basin is of vital economic and cultural importance to the states of Oregon and California, as well as the Klamath Tribes in Oregon; the Hoopa, Karuk, and Yurok Tribes in California; the Quartz Valley Indian Reservation in California, and the Resighini Rancheria in California. It provides fertile lands for a rich agricultural economy in the upper basin. Irrigation facilities known as the Klamath Project owned by the U.S. Bureau of Reclamation support this economy as well as hydroelectric power provided via a system of five dams operated by PacifiCorp. It is the home spawning grounds of a once vast Tribal, sport, and commercial fishery and provides other aquatic resources of cultural significance to the local Indian Tribes. The watershed supports an active recreational industry, including activities that are specific to the Wild and Scenic portions of the river designated by both the states and federal governments in both Oregon and California. Finally, the watershed continues to support what were once historically significant mining and timber industries.

A decline in the fisheries has signaled deep impacts on the ecology of the basin. Congress passed Public Law 99-552 (Klamath Act) in 1986 to establish the Klamath River Basin Conservation Area Restoration Program with the intention of rebuilding the river's dwindling fish resources. Since that time, however, several of the fish species endemic to the basin have been listed by federal and state agencies as threatened or endangered. Impairments to water quality have been identified as one of the factors contributing to the continued decline of native fish populations. This has led to water quality assessments by the States of Oregon and California and the listing of the Klamath River as impaired under section 303(d) of the federal Clean Water Act (CWA).

The Oregon Department of Environmental Quality (ODEQ) and Regional Water Board are working cooperatively to develop TMDLs for the water quality impaired waterbodies in the Klamath Basin, including the Lost River, including Klamath Straits

[1] For the purposes of this report, the terms "basin" and "watershed" are synonymous and will be used to refer to the area that drains flows to the Pacific Ocean at Requa.

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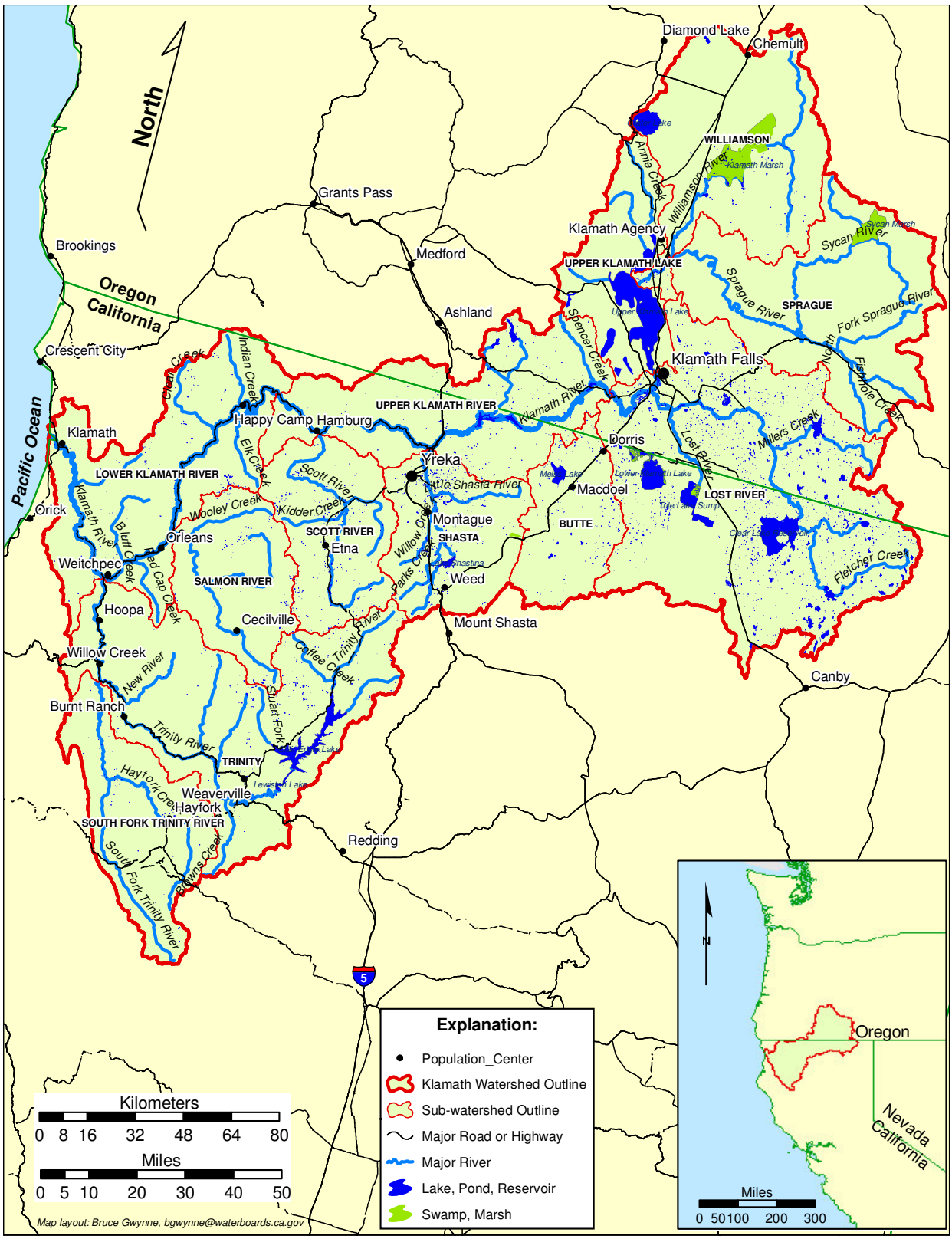

Figure 1.1: Klamath River Basin Showing Rivers, Lakes and Reservoirs, Population Centers, and Major Roads

Drain, and the Klamath River from Link River to the Pacific Ocean. The States of Oregon and California are responsible for calculating the TMDL of each of the pollutants of concern that can be discharged to the river and still protect the fisheries and other beneficial uses of the water within their respective jurisdictions.

California has listed the portions of the Klamath River within its jurisdiction (from the CA/OR Stateline to the mouth) for impairments due to elevated water temperatures, elevated nutrients, and organic enrichment/low dissolved oxygen. In addition, the portion of the Klamath River watershed downstream of the Trinity River, partially within the Yurok Reservation, is listed for sedimentation/siltation impairment. Finally, in March 2008, the U.S. Environmental Protection Agency (USEPA) added the reach of the Klamath River that incorporates Copco 1 and 2 and Iron Gate Reservoirs to the 303(d) List for the blue-green algae toxin microcystin. Table 1.1 summarizes the waterbody-pollutant combinations for the Klamath River in California as identified on the current section 303(d) List.

Table 1.1: Klamath River Water Quality Impairments in California

Hydrologic Area (HA)[2]	CalWater Watershed	Pollutant/Stressor(s)
Middle HA, Oregon to Iron Gate	10530000	Temperature Nutrients Organic enrichment/low dissolved oxygen
Middle HA, Copco 1 and 2 and Iron Gate Reservoirs	NA	Microcystin
Middle HA, Iron Gate Dam to Scott River	10530000	Temperature Nutrients Organic enrichment/low dissolved oxygen
Middle HA, Scott River to Trinity River	10500000	Temperature Nutrients Organic enrichment/low dissolved oxygen
Lower HA, Klamath Glen HSA, Trinity River to Pacific Ocean	10511000	Temperature Nutrients Organic enrichment/low dissolved oxygen Sedimentation/Siltation

A consent decree entered into by the USEPA in March 1997 (*Pacific Coast Fisherman's Association et al. v. EPA*) establishes the date by which TMDLs for 17 California northcoast watersheds must be completed. The Klamath River TMDLs for the listed temperature and nutrient impairments were scheduled for completion by 2007. Negotiations between USEPA and the plaintiffs resulted in an extension of that deadline to 2010.

The current TMDLs for the Klamath River in California reported here, address temperature, nutrient, and organic enrichment/low dissolved oxygen water quality

[2] Hydrologic Area (HA) is the terminology used in the CalWater watershed delineation system to identify a sub-unit of a watershed. Similarly, Hydrologic Sub Area (HAS) identifies a smaller hydrologic unit within a HA.

impairments for the Klamath River Hydrologic Unit, Middle HA (Oregon to Trinity River) and Lower HA, Klamath Glen HSA (Trinity River to Pacific Ocean). These TMDLs do not explicitly address the sedimentation/siltation impairments in the Lower HA, Klamath Glen HSA or the microcystin impairment in Copco 1 and 2 and Iron Gate Reservoirs.

Oregon and California have formed a technical team in conjunction with USEPA and their contractor Tetra Tech, Inc. to develop a uniform water quality model of the basin to ensure compatible TMDLs. However, the states will establish independently the TMDLs for those portions of the basin within their respective jurisdiction. Oregon is not bound by the deadlines associated with the above referenced consent decree.

California has listed separately several of the major tributaries to the Klamath River as impaired; they are identified in Table 1.2 below. Each tributary watershed is listed for its own site-specific list of pollutants but generally include: elevated water temperature, elevated nutrients, depressed dissolved oxygen and excess sediment. TMDLs for each of the major tributary watersheds have been developed and approved, with the exception of the Lower Lost River Nutrient TMDL which is still in progress.

Table 1.2: Status of TMDLs in the Klamath River Basin in California.

Subwatershed	TMDL(s)	Year	Agency
Upper Lost River	Temperature, nutrients	Delisted, 2006	-
Lower Lost River	Nutrients	Technical TMDL in progress	USEPA
	Temperature	Delisted, 2006	-
Shasta River	Temperature, dissolved oxygen	Final Technical TMDL and Implementation Plan, 2007	Regional Water Board
Scott River	Temperature, sediment	Final Technical TMDL and Implementation Plan, 2006	Regional Water Board
Salmon River	Temperature	Final Technical TMDL, 2005	Regional Water Board
	Nutrients	Delisted, 2006	-
Trinity River	Sediment	Final Technical TMDL, 2001	USEPA
South Fork Trinity River	Sediment	Final Technical TMDL, 1998	USEPA
Klamath River	Nutrients, temperature, dissolved oxygen	TMDL in progress	Regional Water Board

1.2 Report Organization

As noted above, this document is the Staff Report supporting the Action Plan. This report contains several standard elements (summarized below) including:

- Chapter 1 – Introduction
- Chapter 2 – Problem Statement
- Chapter 3 – Analytical Approach
- Chapter 4 – Pollutant Source Analysis
- Chapter 5 – Klamath River TMDLs -- Allocations and Numeric Targets

- Chapter 6 – Implementation Plan
- Chapter 7 – Monitoring Plan
- Chapter 8 – Adaptive Management Plan
- Chapter 9 – Antidegradation Analysis
- Chapter 10 – California Environmental Quality Act (CEQA) Environmental Analysis
- Chapter 11 – Economic Analysis
- Chapter 12 – Public Participation

Chapter 1 provides the regulatory framework for the Klamath River TMDLs, and presents an overview of the Klamath River basin. Chapter 2 provides the assessment framework for the TMDL, assesses water quality conditions in the basin, and documents impairment. Chapter 3 describes the TMDL model and its use in developing the source analysis and allocations for the TMDL. Chapter 4 provides an assessment of the sources of water quality impairment in the basin and their relative contribution to the overall load of pollutants. Chapter 5 assigns pollutant load and waste load allocations and established numeric targets consistent with water quality standards. Chapter 6 describes a program of implementation for these TMDLs and includes measures necessary to achieve the Klamath River TMDLs in California. Chapter 7 describes the monitoring necessary to assess the degree of success associated with the TMDLs and their implementation. Chapter 8 describes the process the Regional Water Board will take to review, reassess, and possibly revise the proposed TMDL Action Plan for the Klamath River basin. Chapter 9 briefly describes the state and federal antidegradation policies and how they apply to the Action Plan. Chapter 10 describes the steps Regional Water Board staff have taken to comply with CEQA, and presents the findings of the CEQA analysis. Chapter 11 analyzes the potential economic benefits and costs that may result from the adoption and implementation of the proposed Action Plan. Chapter 12 describes some of the opportunities that have been made available to the public for comment on and participation in the development of the Klamath River basin TMDL Staff Report and Action Plan.

1.3 TMDL Development and Adoption Process

Regional Water Board staff submit the draft Staff Report to an outside Science Review Panel for review of the technical elements associated with the TMDL. Staff revise the Staff Report accordingly and prepare it for submittal to the Regional Water Board. The Staff Report accompanies a draft Action Plan that summarizes the findings of the TMDLs and describes in detail the proposed plans for implementation, monitoring, and adaptive management. The draft Action Plan is presented before the Regional Water Board in a workshop and then a public hearing for the purpose of adopting the Action Plan as an amendment to the Basin Plan. The Regional Water Board receives public comments and staff prepare appropriate revisions and responses to comments received. Once the Regional Water Board has adopted the TMDL Action Plan, the State Water Resources Control Board (State Water Board) holds a workshop and hearing to confirm the decision of the Regional Water Board. California's Office of Administrative Law provides a final legal review before the TMDL Action Plan is forwarded to USEPA for its approval.

1.4 Regulatory Framework and Purpose of the TMDL

The quality of surface and ground waters in the North Coast Region of California is governed by the Water Quality Control Plan for the North Coast Region (Basin Plan) as developed and implemented by the Regional Water Board. The North Coast Region is defined as those waters draining into the Pacific Ocean from the California-Oregon state line southerly to the southerly boundary of the watershed of the Estero de San Antonio and Stemple Creek in Marin and Sonoma Counties. The Basin Plan identifies the existing and potential beneficial uses of water within the North Coast Region and the water quality objectives necessary to protect those uses. Together water quality objectives, beneficial uses, and the anti-degradation policy are known as water quality standards. The Basin Plan also prohibits certain activities and requires certain other activities as necessary to achieve water quality standards.

With respect to the Klamath River basin, the Basin Plan prohibits the discharge of pollutants from point sources to surface waters. Point sources are sources of pollutants discharged through a known conveyance, such as an outfall pipe. This prohibition does not apply to point source discharges of pollutants to land, such as discharges to evaporation or percolation ponds. Similarly, the prohibition does not apply to nonpoint source discharges which are the more dispersed flow of pollutants through stormwater runoff.

Under section 303(d) of the CWA, states are required to develop a list of water bodies where legally required pollution control mechanisms are not sufficient or stringent enough to meet water quality standards applicable to such waters. The 303(d) List also includes the pollutant/stressor causing the impairment and a time schedule for addressing the water quality impairment. Placement of a water body on the 303(d) List triggers the development of a TMDL, for each water body-pollutant/stressor combination. The specific requirements for TMDLs are described in the United States Code of Federal Regulations (CFR) Title 40, sections 130.2 and 130.7 (40 CFR § 130.2 and 130.7), and section 303(d) of the federal CWA.

A TMDL is in essence a planning and management tool intended to identify, quantify, and control the sources of pollution within a given watershed such that water quality objectives are achieved and the beneficial uses of water are fully protected. A TMDL is defined as the sum of individual waste loads allocated to point sources, load allocations assigned to non-point sources, and loads assigned to natural background conditions. Loading from all pollutant sources must not exceed the loading or assimilative capacity (TMDL) of a water body. To account for uncertainty, CWA section 303(d) requires that TMDLs are established with a margin of safety.

The USEPA has federal oversight authority for the CWA section 303(d) program and may approve or disapprove TMDLs developed by the states. Under the terms of the consent decree (*Pacific Coast Fishermen's Association, et. al. v. EPA*), if USEPA

disapproves the Klamath River TMDLs as developed by the Regional Water Board, then USEPA must itself establish the TMDLs by the date specified in the decree.

The Regional Water Board, under the state's Porter-Cologne Water Quality Control Act, has the obligation to establish an Action Plan by which TMDLs are implemented. Action Plans are adopted by the Regional Water Board and incorporated as an amendment into the Basin Plan. USEPA, on the other hand, does not have this obligation. TMDLs developed by USEPA include the technical analysis, only, and are then forwarded to the Regional Water Board for implementation. The States of Oregon and California utilize their authority to implement TMDLs by different methods. See <http://www.oregon.gov/DEQ/WQ/index.shtml> for information on Oregon's TMDLs and implementation planning methods.

The purpose of the Klamath River TMDLs is to estimate the assimilative capacity of the system with respect to the total loads of nutrients and organic matter that can be delivered to the Klamath River and its tributaries without causing an exceedance of the water quality objectives for nutrients and dissolved oxygen. The TMDLs must also establish the amount of protection from solar radiation and cold water withdrawals necessary to meet water quality objectives for water temperature.

Assessing the assimilative capacity of the system begins with an estimate of water quality under natural baseline conditions. Having simulated the natural baseline conditions, then, additional anthropogenic sources of nutrient and organic matter loads are incrementally added back into the models up until that point at which water quality objectives are achieved. A somewhat different but similar approach is used to assess the assimilative capacity of the river for solar radiation and cold water withdrawals. This then forms the basis for the TMDLs. The geographic scope of these TMDLs includes the entire Klamath River hydrologic area[3] (HA) in California, not including those reaches of the Klamath River that lie within the Hoopa Valley Indian Reservation and Yurok Reservation.

1.5 Other Ongoing Regulatory Processes in the Klamath River Basin

TMDLs must consider other ongoing regulatory processes in the basin. Of particular relevance to water quality are:

- The Tribal Trust responsibilities of the United States government to Tribes and individual Indians.
- The need for consultation under the Endangered Species Act with the National Marine Fisheries and U.S. Fish and Wildlife Service on projects affecting listed Klamath River fishes, and

[3] Hydrologic Area is the terminology used in the CalWater watershed delineation system to identify a sub unit of a watershed, involving a major river.

- The relationship between the TMDL process and the water quality certification process under section 401 of the Clean Water Act associated with the relicensing application submitted by PacifiCorp to the Federal Regulatory Energy Commission for the operation of hydroelectric facilities on the Klamath River mainstem.

1.5.1 Tribal Trust Responsibilities

The United States has a trust responsibility to protect and maintain rights reserved by, or granted to, federally recognized Tribes and individual Indians, by treaties, statutes, and executive orders. The trust responsibility requires that federal agencies take all actions reasonably necessary to protect trust assets, including the fishery resources of the Indian Tribes in the Klamath River basin. The Regional Water Board must consider federal Tribal Trust responsibilities in the Klamath River basin since TMDLs are subject to the approval of the USEPA. The Regional Water Board will fulfill Tribal Trust responsibilities by adopting an Action Plan that restores and maintains pollutant levels that are protective of anadromous fish and other beneficial uses related to the Tribes of the Klamath River in California, including the Hoopa, Karuk, Quartz Valley, and Yurok Tribes and the Resighini Rancheria to the degree that natural conditions allow.

1.5.2 ESA Consultation

The USEPA and Regional Water Board initiated an informal consultation process with the United States Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration Fisheries (NOAA Fisheries) on the Klamath River basin TMDLs in California. USEPA and Regional Water Board staff used this process to provide information and updates on the TMDLs in the Klamath River basin (e.g., the Salmon, Scott, Shasta, Lower Lost, and Klamath River TMDLs). USEPA has an obligation to consult with federal wildlife agencies on any action that may affect the wildlife trust responsibilities of these agencies. The Regional Water Board must consider the federal wildlife trust responsibility in the Klamath River basin since TMDLs are subject to the approval of the USEPA. The Regional Water Board will fulfill wildlife trust responsibilities by adopting an Action Plan that restores and maintains pollutant levels that are protective of anadromous fish, and other cold water species, and their habitat.

1.5.3 Water Quality Certification

PacifiCorp currently operates hydroelectric facilities on the Klamath River in southern Oregon and northern California. On February 23, 2004, PacifiCorp transmitted its application for a new 50-year license for the Klamath Hydroelectric Project to the Federal Energy Regulatory Commission (FERC). Associated with its application for a new license is the obligation to submit documentation under section 401 of the CWA to the State Water Board and ODEQ that demonstrates compliance of the proposed project with state water quality standards. The State Water Board then reviews the documentation and issues its water quality certification (401Certification) if the information indicates that water quality standards will be met. The certification can include conditions in order to

ensure that water quality standards are met. A certification is denied if water quality standards will not be met.

As a result of its review of the submitted documents, the State Water Board issued a letter on February 26, 2007 indicating that PacifiCorp had not adequately documented its assertion that water quality will be protected by the relicensing of the hydroelectric facilities. Additional studies of several areas of concern are required before 401 Certification can be issued and an environmental impact review under the CEQA is required before a certification can be issued. Another question under consideration in the certification review process is whether or not the proposed project will meet the TMDLs.

1.6 Physical Setting

It is useful to orient the reader to the physical setting within which the TMDLs for the Klamath River basin are developed as a way of establishing the background conditions influencing pollutant levels in the system. The topography of the basin, the bedrock geology, soils, vegetation and climate each play a role in the manner in which surface and ground water are expressed as hydrology. Similarly, these factors play a role in the fate and transport of instream pollutants. More detailed descriptions of the physical setting of the Klamath River basin have been reported extensively in numerous available publications.

1.6.1 Population and Land Ownership

The human population in the Klamath River basin was estimated in the 2000 US Census to be about 114,000 (United States Census Bureau [USCB] 2000). The largest population concentrations lie in the upper Klamath agricultural area, the Shasta River valley, and Scott Valley. The largest population center (19,462 people in 2000) is Klamath Falls in Oregon followed by Yreka, California (7,290 people). The Klamath River basin can generally be characterized as a rural watershed with limited population-related water quality issues.

More than two thirds of the Klamath River watershed is in federal ownership. Figure 1.2 shows, among other things, federal lands managed as National Forests, National Wildlife Refuges, and National Parks, in addition to Bureau of Land Management (BLM) land. The largest blocks of private ownership are agricultural areas in the upper Klamath watershed and agricultural and timber properties in Shasta and Scott Valleys. Also, much of the Klamath River valley near the mouth of the river is privately owned.

The Hoopa Valley Tribe owns land, 12 miles by 12 miles, primarily in the Trinity River watershed but intersecting with the Klamath River at Saints Rest Bar upstream of the confluence with the Trinity. The Yurok Reservation's lands extend from 1 mile on each side from the mouth of the Klamath River and upriver for a distance of 44 miles. The

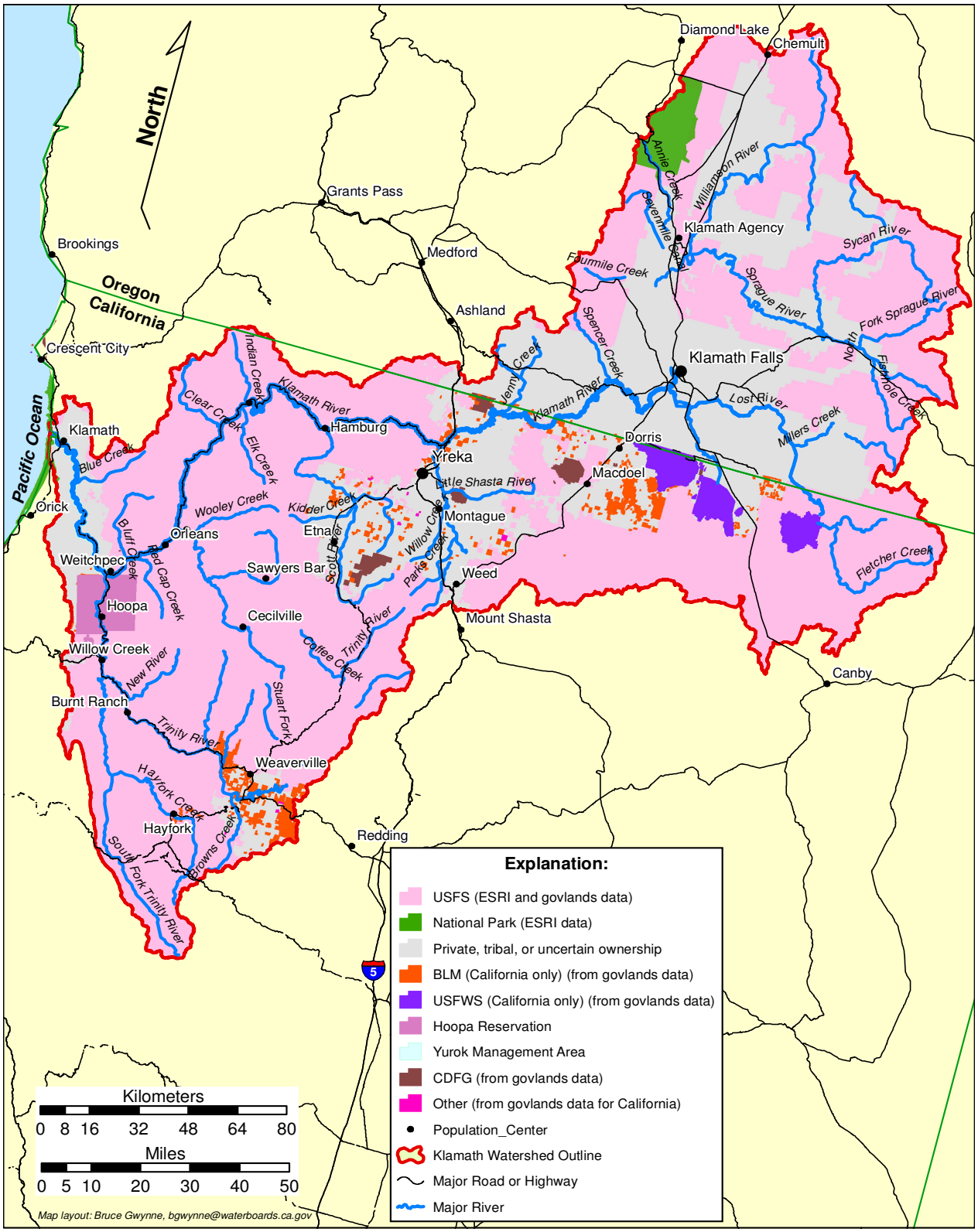

Figure 1.2: Land Ownership in the Klamath River Basin

Karuk Tribe owns 800 acres of tribal trust land along the Klamath River between Orleans and Happy Camp, and in Yreka, California. The Quartz Valley Indian Reservation is located near Fort Jones and encompasses 174 acres along the Scott River. The Resighini Rancheria spans 228 acres along the south shore of the mouth of the Klamath River.

1.6.2 Topography, Geology and Soils

Topography in the Klamath River watershed varies between steep mountains and flat and rolling valley bottoms with little in between (Figure 1.3). Elevations range from sea level at the river mouth to 14,179 feet at the summit of Mount Shasta. The Klamath River watershed crosses four recognized geomorphic provinces, each of which is defined and shaped by its unique geologic history. From east (upstream) to west (downstream) these provinces are the Modoc Plateau, Cascade Range, Klamath Mountains, and Coast Ranges (Figure 1.4). These geomorphic provinces, defined by Oakshott (1978), are the result of the different structure and composition of the underlying rocks and different times of uplift and volcanism.

Headwaters of the Klamath gather in the Modoc Plateau, an area of geologically young lava flows (Pliocene and Pleistocene – less than fifteen million years) and flat valleys punctuated by volcanic cones. The rolling valley bottoms are at about 4000 to 5000 feet elevation and the volcanic cones rise a thousand feet higher. While drainage in this young landscape is through-flowing, many depressions contain shallow lakes, most of which have been augmented by dams. Although rainfall is low, the flat and rolling valley bottoms of rich volcanic and organic soils combine with abundance of water entering from higher surrounding country to create historically vast freshwater wetlands. Much of these have been converted to farmland. The volcanic soils are naturally rich in phosphorus, a nutrient of concern in these TMDLs. Similarly, the conversion of wetlands to farmland and other land uses has exposed the nutrient and organic rich soils to oxidation, resulting in the release to the water column of nitrogen and phosphorus previously stored in the soil and wetland vegetation (Snyder and Morace, 1997).

The transition between the Modoc Plateau and Cascade Range provinces is not sharp, so that a line on a map is by necessity a bit arbitrary (Figures 1.3, 1.4). The Cascade Range province is a belt of mainly volcanic rocks that are younger than rocks of most of the Modoc Plateau and form higher relief. The Cascade Range is defined by a chain of active and potentially active volcanoes that stretches from Mount Lassen, east of

Redding, northward through Oregon and Washington into Canada. The most prominent mountain in the Klamath region is Mount Shasta, a composite volcano that rises at the head of Shasta Valley, and which last erupted about 1786. Crater Lake, in the northeast, fills the collapse crater of a volcano that erupted cataclysmically about 7,000 years ago.

The border between the Cascade province and the Klamath Mountains province is spanned by Shasta Valley and covered by a unique deposit. Most of the floor of this valley is disrupted rolling topography of small hillocks and closed depressions. Crandell (1989) recognized this landscape as the deposits formed by a huge avalanche and debris

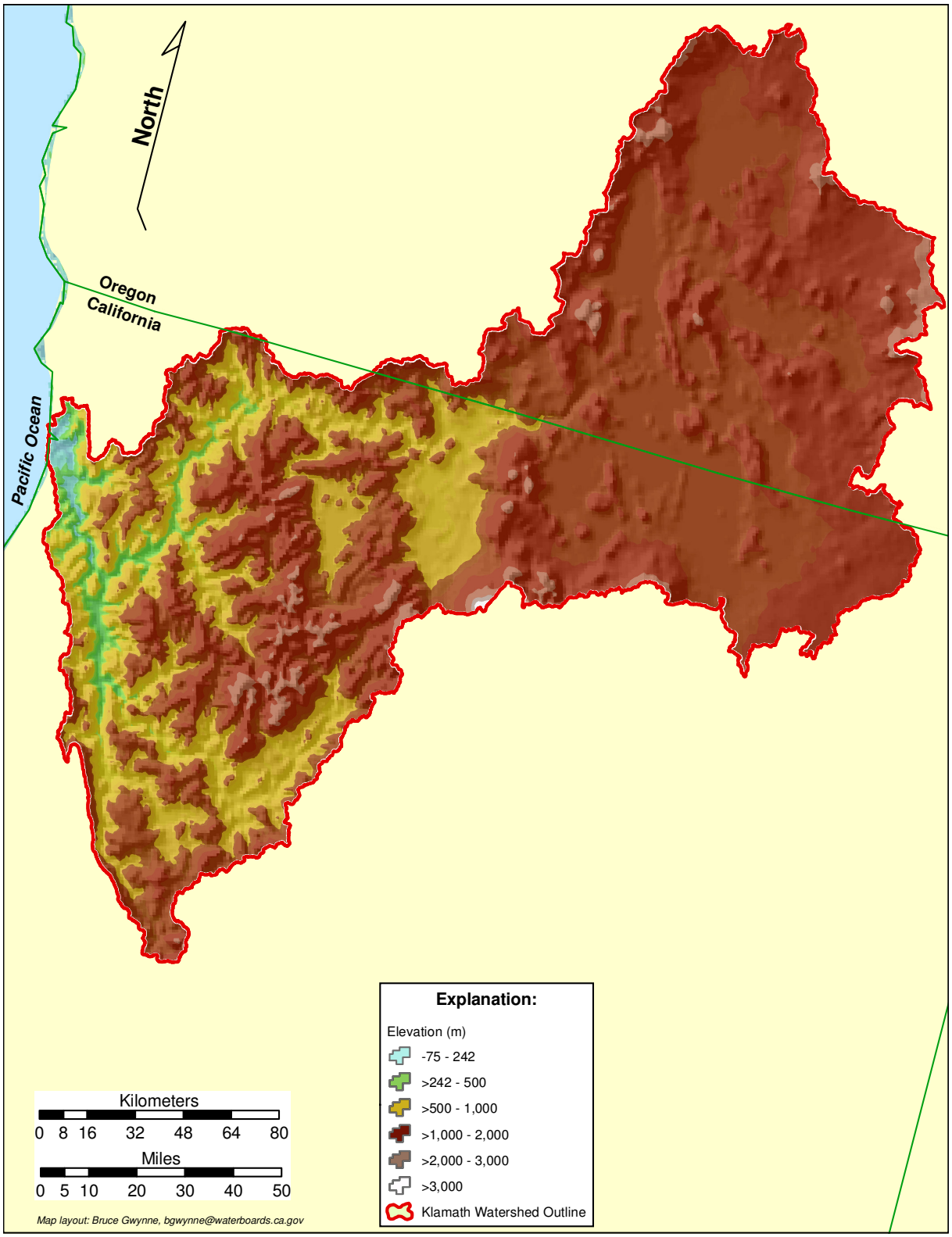

Figure 1.3: Land Elevation in the Klamath River Basin

Figure 1.4: Geomorphic Provinces in the Klamath River Basin
Source: Oakshott 1978

flow, or series of such events, shed off the north flank of Mount Shasta more than 300,000 years ago.

The Klamath Mountains province is very steep and rugged for the most part and in the Klamath River watershed consists of several irregularly oriented ranges – the Trinity Alps, Scott Bar Mountains, Siskiyou Mountains, and Marble Mountains. Shasta and Scott Valleys have broad flat valley bottoms that support agriculture, but other valleys are narrower and steeper and therefore less developed. Most of the land in the Klamath Mountains province is in federal ownership (Figure 1.2), and this rugged landscape lends itself more to timber harvest and cattle grazing than to crops.

The bedrock geology of the Klamath Mountains province is extremely varied and complex (Figure 1.5) and largely made up of ocean-floor igneous and sedimentary rocks of a large range in ages. Most of the igneous rocks in this province are dark colored mafic and ultramafic rocks of both intrusive and extrusive origin, most of which have been partly or wholly altered to serpentine and otherwise metamorphosed. Younger, light colored granitic rocks have been intruded in some places. Recent uplift has created a landscape of rapidly downcutting streams and steep slopes that are subject to rapid erosion and landsliding. The granitic rocks in particular weather to form loosely consolidated material that sloughs and ravels easily when disturbed.

The Coast Ranges province, the westernmost province (Figure 1.4), forms about 20 miles of the lower Klamath River valley and part of the west side of the valley of the lower Trinity River and South Fork Trinity River. These rivers have exploited the fault zone that forms the geologic boundary between the Klamath Mountains province and the Coast Ranges province. The Coast Ranges are steep, but are generally more rounded than and not as high as the mountains of the Klamath Mountains province. Bedrock is the Franciscan Complex, which is structurally deformed and highly varied. The mix of sedimentary rocks includes sandstone, siltstone, shale, conglomerate, greywacke, and chert. Parts of the complex have been metamorphosed and include blueschist and greenschist as well as low grade mica schist. Some areas are mélange, which is geologic terrane that has been deformed and mixed by prolonged and complex tectonic movement, and lacks continuity of structure, rock type, or age.

The gradient profile of the Klamath River is anomalous for a large river in that it is generally low gradient in the headwaters in the Modoc Plateau and steeper farther downstream (Figure 1.3). This unusual gradient is largely the result of geologic uplift in the upstream portion of the river basin in recent geologic time.

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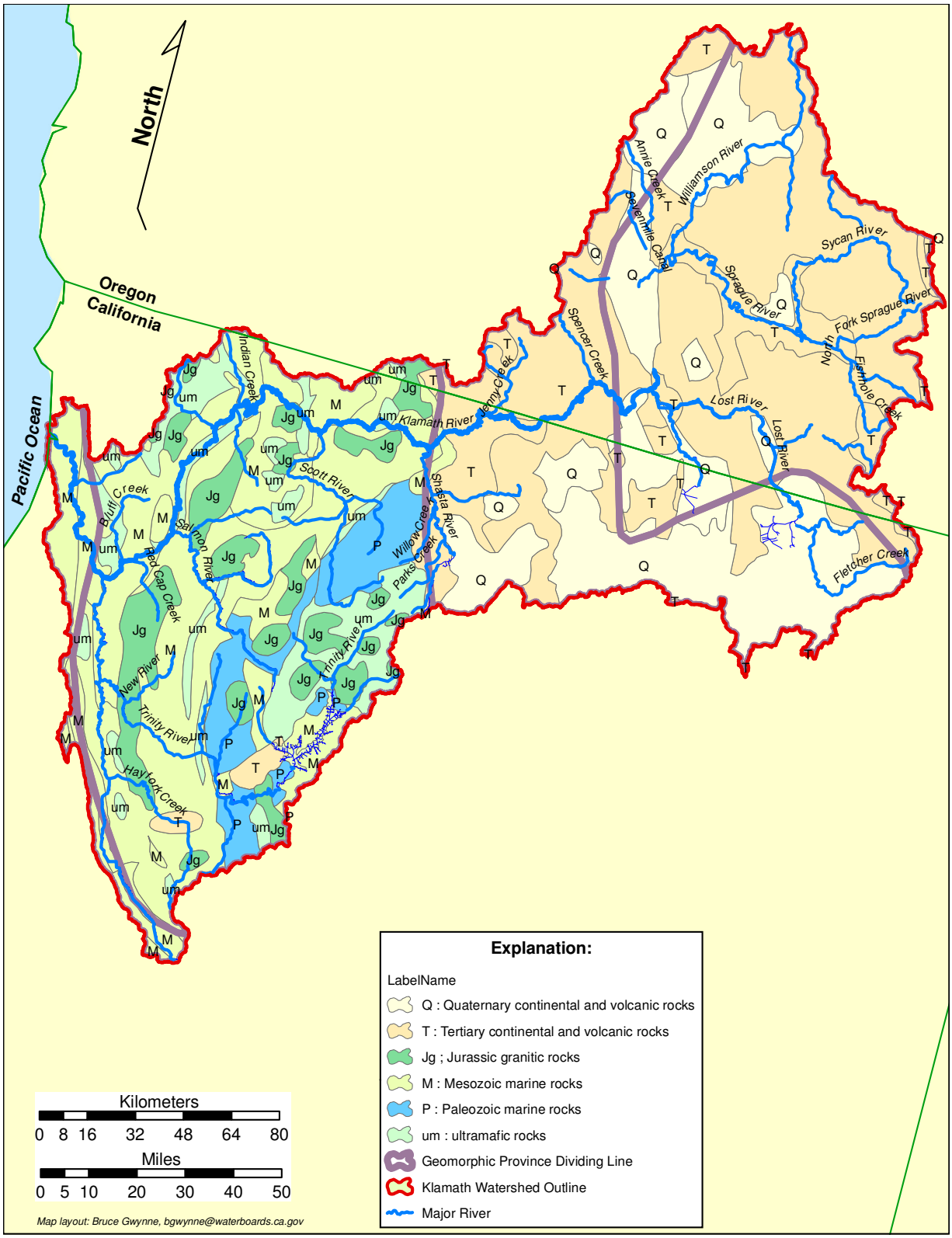

Figure 1.5: Geologic Map of the Klamath River Basin
Source: Modified from Schruben et al. (1997)

1.6.3 Vegetation

Vegetation in the Klamath varies greatly with elevation, precipitation, and degree of disturbance. Figure 1.6 shows the major classifications of vegetation (Thematic Mapper GIS database). Conifers dominate in the steep mountains and the higher elevations. Hardwood forest and shrubs are more abundant in the lower country, which tends to be warmer and dryer. In many parts of the region a transition zone of mixed conifer and hardwood separates areas classified as conifer forest and hardwood.

1.6.4 Climate

The great geographic extent and topographic relief of the Klamath River watershed combine to produce a wide variety of climate (Figure 1.7). On average, the climate is characterized by dry summers with high daytime temperatures and wet winters with moderate to low temperatures. About three quarters of the annual precipitation falls between October and March, producing a snowpack in the higher mountain ranges that feeds streamflow in many lower areas through the summer.

As major storms move in from the Pacific Ocean, the moisture-laden air rises over the coastal mountain ranges and condenses as rain and snow (California Department of Water Resources [CDWR] 1986). Further inland, in the valleys of major tributaries and over the lower terrain of the upper Klamath basin, a rain shadow effect is created, and less moisture falls (Figure 1.7).

Figure 1.8 provides a comparison of monthly precipitation values from Orleans, California in the mountainous country of the lower Klamath basin and Klamath Falls, OR in the broad valley of the upper Klamath basin as an illustration of rainshadow effect. The mean annual precipitation in the Klamath River watershed is about 32 inches (CDWR 1986); but, local averages range from more than 80 inches in the high elevations to 10 inches in the broad inland valleys (CDWR 1986; United States Forest Service [USFS] 1996).

In the 20th century the Klamath River watershed was characterized by a pattern of floods and droughts. This pattern is discussed by The Klamath River Basin Fisheries Task Force [KRBFTF] (1991, p. 2-3 to 2-7). During a drought in 1976-77, precipitation was only 20 percent of normal in the Scott River watershed and 40 percent of normal in the upper Klamath River basin. The largest floods occurred when relatively warm storm systems melted a pre-existing snow pack such as occurred in 1861, 1955, 1964, 1974 and 1997 (USFS 2000, p.3-3). Many areas of the Klamath River watershed, mostly in the middle third of the basin, are susceptible to these rain-on-snow events.

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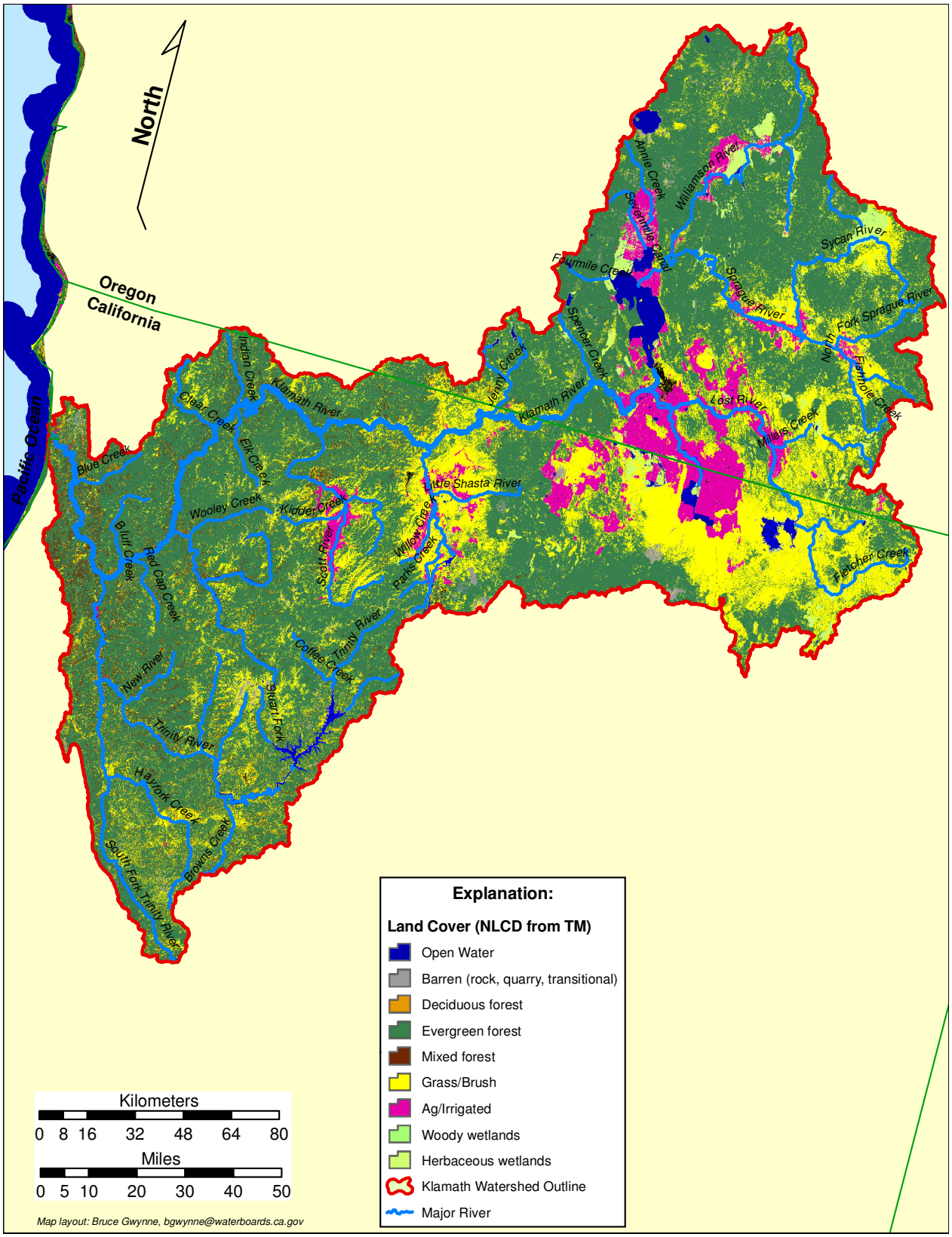

Figure 1.6: Vegetation and Land Cover of the Klamath River Basin

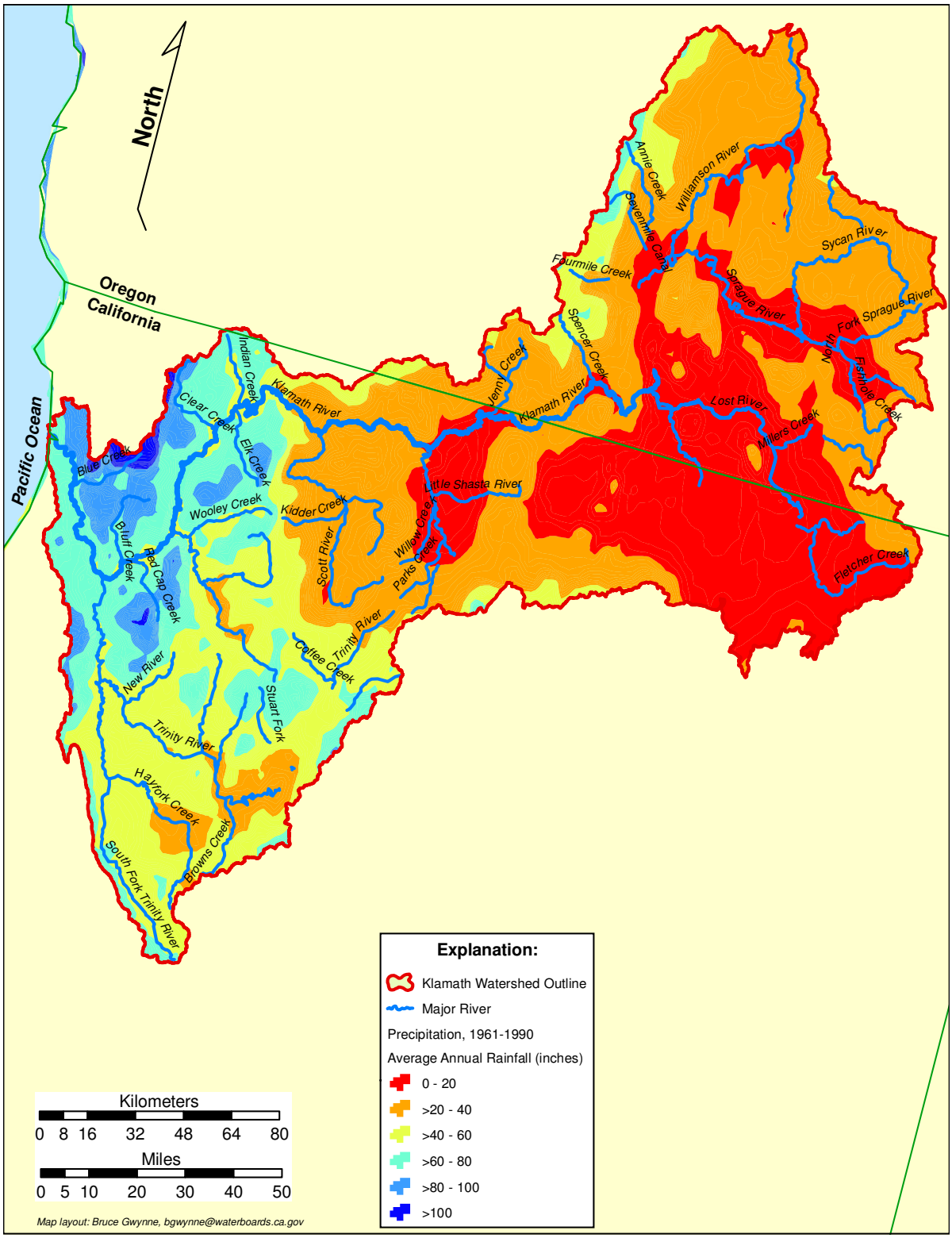

Figure 1.7: Average Annual Rainfall in the Klamath River Basin
Source: United States Department of Agriculture (USDA) Undated

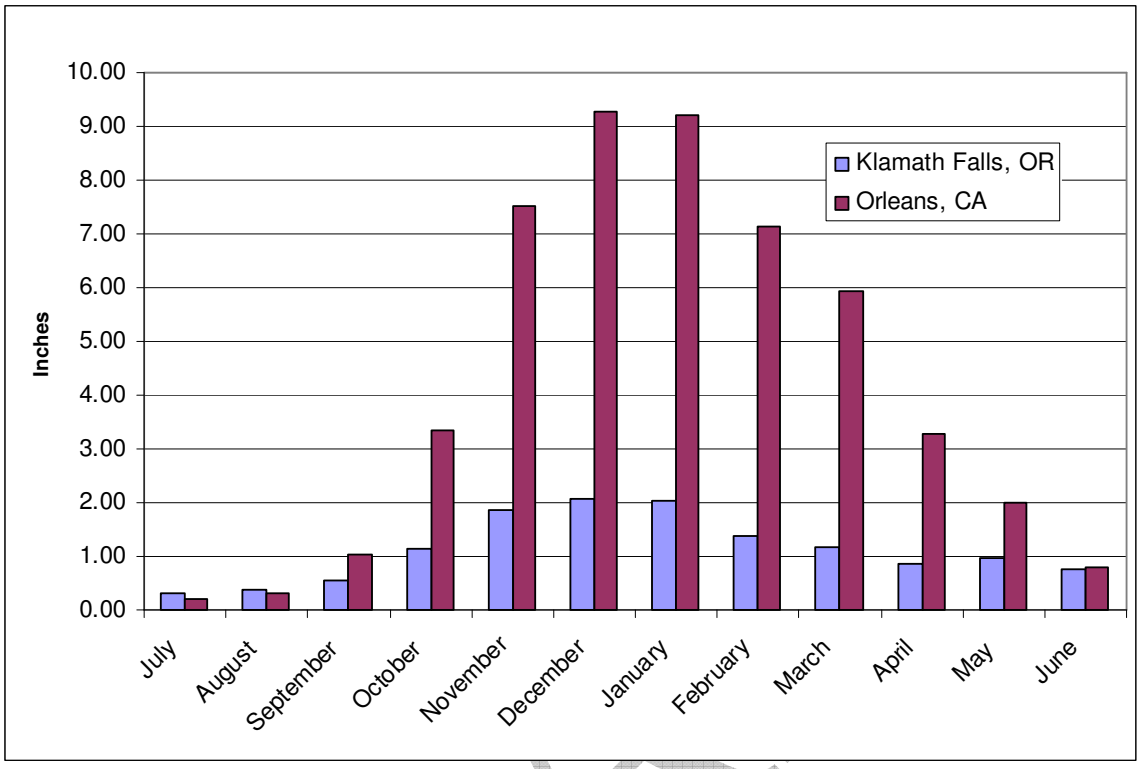

Figure 1.8: Average Monthly Precipitation, 1905-2003, in Klamath Falls, Oregon and Orleans, California
Source: California Data Exchange Center [CDEC] 2006; Oregon Climate Service [OCS] 2006

1.6.5 Hydrology

Drainage density in the Klamath River watershed is affected by rainfall, tectonics, and underlying bedrock. Figure 1.9 shows dense drainage networks in the steep, recently uplifted ranges to the west and in the volcanic mountains to the east. These are areas of recent mountain building and the increased rainfall associated with high topography. However, the lower, flatter county in the upper Klamath, in the region of Klamath Falls, has a much lower drainage density and is punctuated by lakes and wetlands associated with local tectonic subsidence. The pattern of drainage density is mirrored, of course, by a pattern of water yield. As illustrated in Figure 1.10, approximately half of the February flow measured in the lower watershed at Klamath, California is drained from that portion of the basin from Orleans, California to Klamath, California, representing about a third of the basin's area. Conversely, only 7 percent of the flow originates in the upper one third of the basin. This pattern is not as dramatic in the summer months when water yield is more generally proportional to drainage area.[4]

[4] It is important to recognize that the data presented in Figure 1.10 shows the pattern of flow associated with a history of consumptive use (e.g., Klamath Project in the upper basin) and altered flow timing (e.g., PacifiCorp's hydroelectricity generation). However, these factors do not affect the above observations with respect to winter flows.

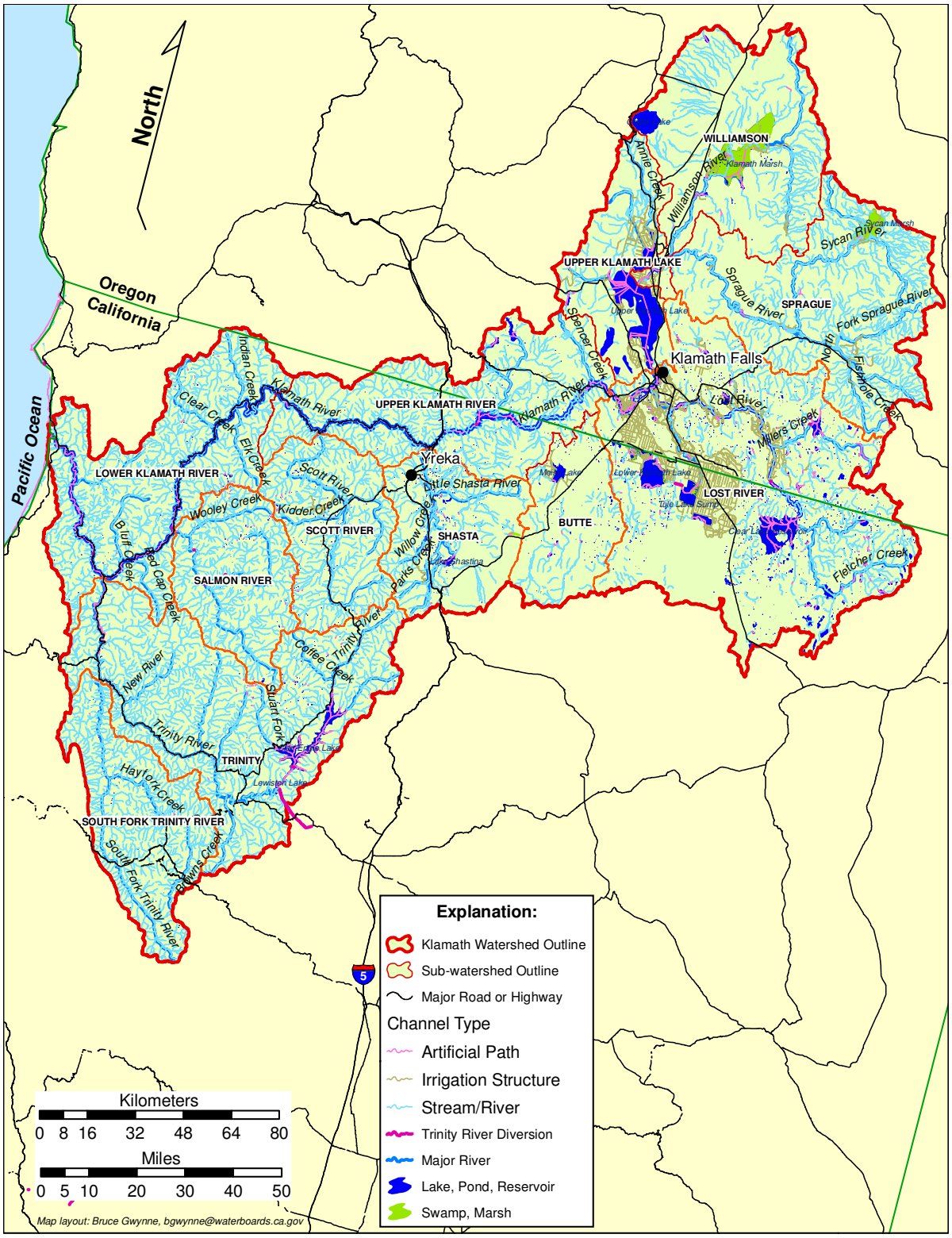

Figure 1.9: Map of Klamath River Basin Emphasizing Subbasins and Surface Drainage

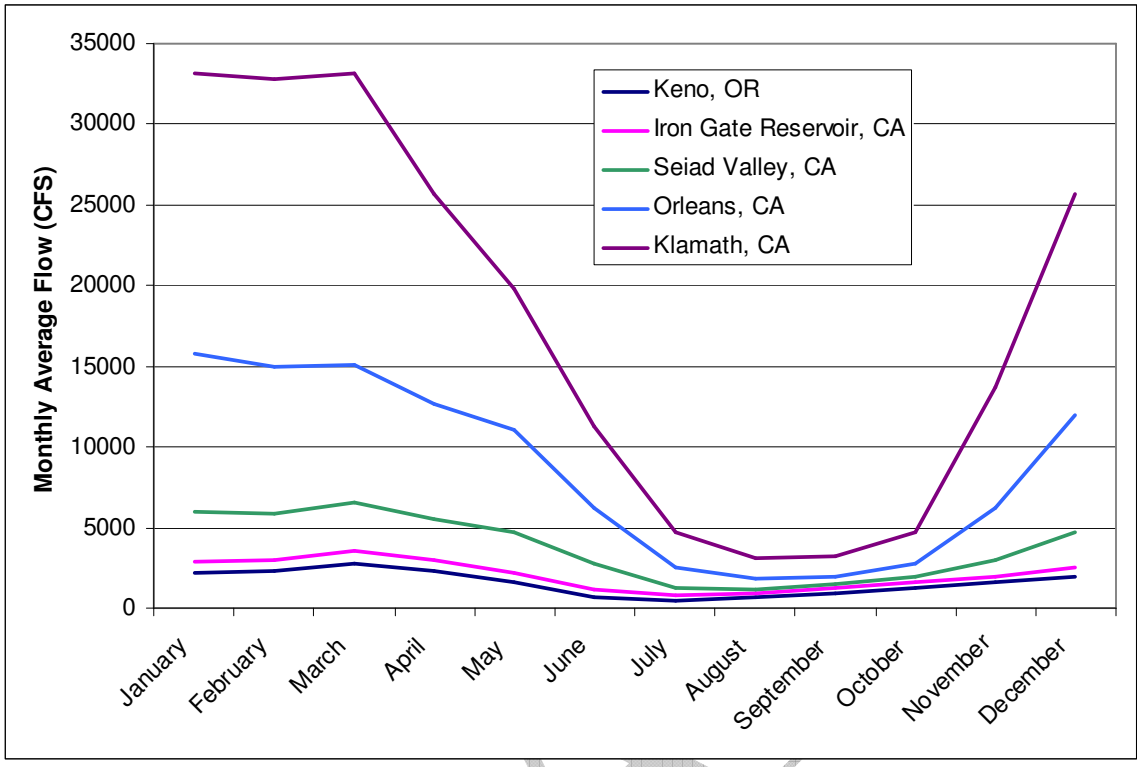

Figure 1.10: Monthly Average Flows at Five Klamath River Locations, Water Years 1963-2005
Source: United States Geological Survey [USGS] 2006

1.6.6 Water Use

There exist in the Klamath River basin numerous dams and diversions associated with power generation and irrigation. The history of many of these are well documented and the effects on water yield quantified. The effects of diversions granted under Riparian Rights and groundwater withdrawals, however, are not well understood. Beginning around 1850, small dams and diversion ditches were built on smaller tributaries for use in mining and irrigation. Starting out small and temporary in nature, some became more fixed as established use persisted. As early as 1930, these more permanent diversion structures were creating barriers to fish migration (KRBFTF 1991, p.2-40, 2-62). Among the mining dams, some were left in place after cessation of mining, creating additional barriers (KRBFTF 1991, p.2-62).

Beginning in the 1890s, hydroelectric power facilities were installed, first on the Shasta River, then on the Link River. California Oregon Power Company (COPCO) built Copco Number 1 Dam and Copco Number 2 Dam between 1917 and 1925. These comprise the first major hydroelectric project built on the mainstem of the Klamath River (KRBFTF 1991, 2-62 to 2-64).

Prohibition on the construction of any obstructions in the Klamath River downstream from the mouth of the Shasta River were enacted as a result of Proposition 11 passed in a

statewide election of 1924 (KRBFTF 1991, p. 2-64). This effectively ended the prospective efforts to build major hydroelectric and diversion projects in the Klamath River below the mouth of the Shasta River; though, no such protections were afforded the flows above the confluence with the Shasta. In 1958, J.C. Boyle (Big Bend) Dam went online just upstream of the California state line.

In 1962 Iron Gate Dam was built below Copco 1 and 2 at river mile 190. From this point to the ocean the river is protected as free flowing under the National Wild and Scenic Rivers System. Iron Gate Dam was originally built to attenuate flow variations caused by the operations of Copco 1 and 2 Dams. These dams were originally run as peak demand generation facilities but are now used in other ways

Most of the Klamath River water is used in the Klamath River basin, including the use of water for crop and pasture irrigation within the Williamson River, Sprague River, Lost River, Shasta River, Scott River, and South Fork Trinity River. Facilities built to support consumptive uses in California include the U.S. Bureau of Reclamation Klamath Project (construction began in 1906, first water delivered in 1907) and Lake Shastina (created by the construction of Dwinnell Dam on the Shasta River in 1928). A total of 240,412 acres of irrigable lands, including 235,667 acres of farmland, and 4,745 acres of residential, commercial, and industrial lands, are served by Klamath Project infrastructure.

In addition to in-basin use, however, there are also significant diversions out of the basin maintained for agriculture and power generation: The Lewiston and Trinity Dams were completed in 1964 on the Trinity River to enable a significant transfer of flow out of the Klamath watershed and into the Sacramento River system. An additional, smaller, out-of-basin diversion occurs from the upper tributaries in the Jenny Creek watershed in Oregon and into the Rogue River watershed in Oregon.

The pattern of water use, on the other hand, is nearly the opposite of the pattern in drainage density and water yield. That is, the majority of the diversions in the basin are upstream of Seiad Valley where the least amount of the water is produced. As demonstrated by Figure 1.10, some of the effects of this pattern of water use are to:

- Move the timing of the peak spring flows from mid-April to mid-March;
- Make steeper the decline in the spring hydrograph, thus reducing flows by roughly 30-45% in June and July and 20-25% in May and August;
- Lower the minimum summer flows; and
- Move the timing of the minimum summer flow from mid-September to mid-August.

The estimated unimpaired flows represented in Figure 1.11 illustrate the magnitude and pattern of flows that would be expected with natural flows in the Scott and Shasta Rivers

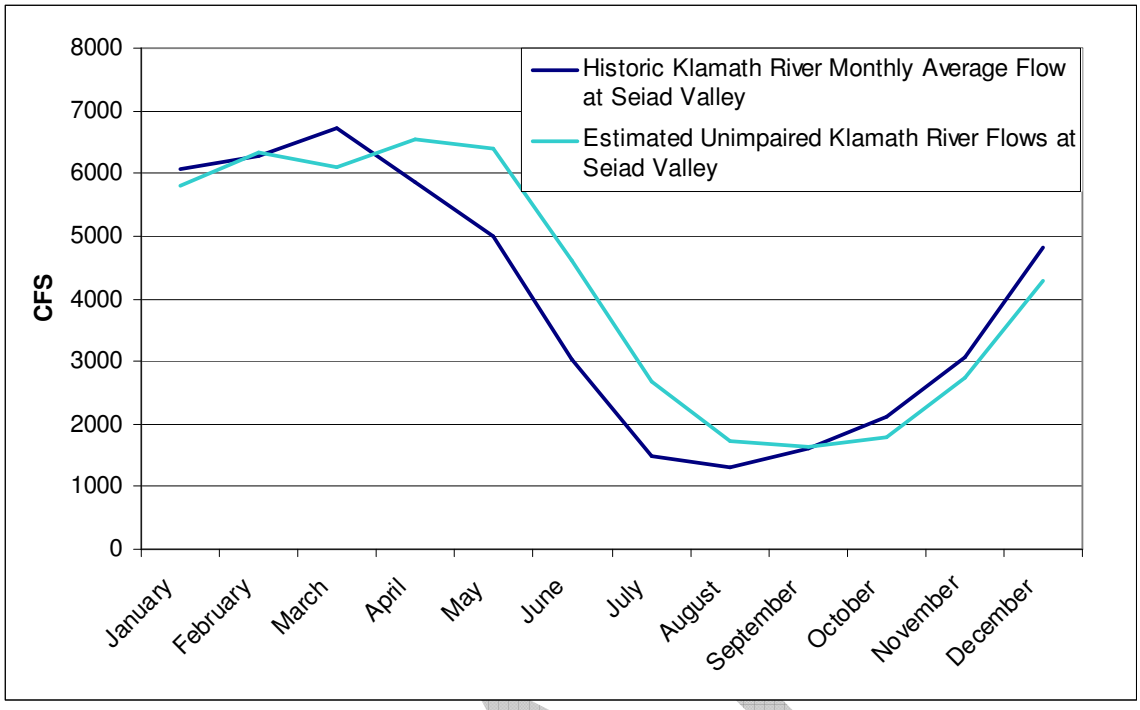

Figure 1.11: Estimated unimpaired Klamath River flows at Seiad Valley, California, and historic monthly average Klamath River flow at Seiad Valley, California; Water Years 1952-2004
Source: United States Bureau of Reclamation [USBR] 2005; USGS 2006

and without diversions upstream of Keno, Oregon. These data, however, should be viewed with caution because the estimated unimpaired flows are based on the estimated median monthly unimpaired flows at Keno, as reported by the United States Bureau of Reclamation [USBR] (2005), whereas the estimated natural Scott and Shasta River flows are reported as monthly means. Although the two types of data sets are different metrics, the data are useful for general comparison purposes.

1.6.6.1 Water Rights of the Klamath River Basin, California

Water rights within the State of California are administered by the State Water Resources Control Board, Division of Water Rights (Division of Water Rights) based on three general principles.

- All water belongs to the people of the state
- Water rights are a right to the use of water
- Water use must be reasonable and beneficial

Generally, the appropriative use of surface water after 1914 requires a permit through the Division of Water Rights. Permits identify the maximum amount of water allowed to the user, the timing of permitted use, and the place and purposes of the use. In times of drought, users with the oldest permits have the first priority to use. Permitting of water rights within the Klamath River basin in California began June 1916. Within California, there are a total of 1614 permitted water rights listed with the Division of Water Rights.

Once all the water within a stream or river has been permitted by the Division of Water Rights for withdrawal, the stream is declared fully appropriated either year-round or during specified months. Table 1.3 lists all the fully appropriated tributaries to the Klamath River in California, as well as the season during which they are determined fully appropriated. Additionally, the Klamath River itself is determined to be fully appropriated during the entire year.

The right to use water can under some circumstances be legal without a permit from the Division of Water Rights. Land owners with property adjacent to a waterbody have what is known as a "Riparian Right" by which they can use water on their river front parcel, so long as the use is reasonable with respect to other users of the waterbody. Groundwater use is also allowed without a permit from the Division of Water Rights. All water use in California is subject to a constitutional prohibition against waste and unreasonable use or method of diversion.

Table 1.3: Fully Appropriated Klamath River Reaches and Tributaries to the Klamath River in California

Stream	Tributary	Season Begin-End	Critical Reach
Klamath River	Pacific Ocean	01/01-12/31	From the mainstem about 100 yards below Iron Gate Dam to the Pacific Ocean.
Trinity River	Klamath River	01/01-12/31	The mainstem from 100 yards below Lewiston Dam to the river mouth at Weitchpec.
Salmon River	Klamath River	01/01-12/31	The Salmon River from Cecilville Bridge to the river mouth near Somes Bar.
Scott River	Klamath River	01/01-12/31	The Scott River from the mouth of Shackleford Creek west of Fort Jones to the river mouth near Hamburg.
Shasta River	Klamath River	05/01-10/31	From the confluence of the Shasta River and the Klamath River upstream.
Willow Creek	Klamath River	04/01-11/30	From the York Road Bridge located within Section 8, T46N, R5W, MDB&M upstream.
Seiad Creek	Klamath River	07/01-10/31	From the confluence of Seiad Creek and the Klamath River upstream.
McKinney Creek	Klamath River	03/01-11/30	About 1 ½ miles downstream from the point of diversion on McKinney Creek upstream.
Douglas Creek	Klamath River	06/01-10/31	From a point on Douglas Creek located within the NE 1/4, Section 19, T15N, R7E, MDB&M upstream.

Source: State Water Board 1998, p.8, 13, 56, 57, 58, 64.

Table 1.4 summarizes permitted water rights within the Klamath River basin in California, based on the Division of Water Rights, Water Right Information Management System (WRIMS). Table 1.4 groups water rights into reaches of the Klamath River in California including all tributaries. The Shasta, Scott, Salmon, and Trinity Rivers are summarized individually. Summer season (May through August) and winter season (September through April) water rights are summarized and the primary summer season water use is identified. Diversions for the purpose of storage are included in Table 1.4. Uses for stored water include domestic, fire protection, fish culture, irrigation, industrial,

incidental power, municipal, power, recreation, stockwatering, and fish and wildlife protection and/or enhancement. The season that water is diverted for the purpose of storage vary from permit to permit. Months of diversion for storage generally occur during the period of November through June. A small portion of permits include the right to divert water throughout the year and only a few allow diversion for storage during the summer months. All values represent the maximum permitted water use.

Table 1.4: Summary of Water Rights in the Klamath River Basin in California

Reach	Number of Permits	Primary Summer Use	Summer Totals (cfs)	Winter Totals (cfs)	Storage Totals (af)
Klamath River					
Iron Gate to Shasta River	50	Fish Culture	65	49	81
Shasta River to Scott River	76	Domestic	1084	1051	0
Scott River to Salmon River	143	Power	25	17	10
Salmon River to Trinity River	66	Domestic	0.006	0.006	160
Trinity River to Pacific Ocean	40	Power	2	2	0
Tributaries					
Tributaries to Iron Gate & Copco	34	Irrigation	72	16	0
Shasta River Watershed	121	Irrigation	982	82	9406
Scott River Watershed	272	Irrigation	255	157	387
Salmon River Watershed	86	Domestic	44	39	6
Trinity River Watershed	726	Municipal	818	593	4442

Source: WRIMS 2006
Note: Summer season is May through August and winter season is September through April.

Dates of permitted water use vary from permit to permit. Table 1.4 groups permitted water rights into summer and winter seasons. Water use permitted during the months of May through August are grouped into the summer totals. Water use permitted during the months of September through April is grouped into the winter totals. Water uses permitted for the entire year are accounted for once in the summer total and again in the winter total.

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DRAFT

CHAPTER 2. PROBLEM STATEMENT

2.1 Introduction

In the Klamath River in California increased water temperatures, elevated nutrient levels, low dissolved oxygen concentrations, elevated pH, potential ammonia toxicity, increased incidence of fish disease, an abundance of aquatic plant growth - high Chlorophyll-*a* levels (both planktonic and periphytic algae), and high concentrations of potentially toxigenic blue-green algae, particularly in the impounded reaches, decrease the quality and quantity of suitable habitat for fish and aquatic life, and have disrupted traditional cultural uses of the river by resident Tribes. These conditions contribute to the non-attainment of beneficial uses, including the most sensitive beneficial uses: those associated with the cold water fishery (specifically the salmonid fishery) in California, and those related to cultural uses and practices.

The purpose of the Klamath River basin TMDL problem statement is to:

- Provide an overarching assessment framework for the TMDL;
- Present a summary assessment of current water quality conditions; and
- Document beneficial use impairment.

The Klamath River numeric and narrative water quality objectives and beneficial uses that are the comparative benchmarks for the problem statement assessment are described in the Regional Water Board's *Water Quality Control Plan for the North Coast Region* (Basin Plan). Section 2.2 of the problem statement, Water Quality Standards, consists of a summary description of the Basin Plan and Tribal water quality standards, objectives, and beneficial uses addressed in the TMDL. The Basin Plan and Tribal water quality standards provide the regulatory context for the assessment that follows. Section 2.3 Numeric Targets presents the numeric water quality targets that represent attainment of applicable water quality objectives used in this TMDL.

Section 2.4 Water Quality Conceptual Models Overview, describes the technical approach used in the problem statement assessment. To ensure a comprehensive assessment and decision framework, the Regional Water Board has adopted the technical approach from the California Nutrient Numeric Endpoints (CA NNE) framework (Tetra Tech 2006). The CA NNE is used to assess and describe the water quality impacts associated with nutrient and organic enrichment and temperature alteration. The approach involves the development of conceptual models that illustrate how key factors and processes link the primary stressors (nutrients and organic enrichment, and altered temperature regime) with impacts on beneficial uses. In addition, the conceptual models can be used to identify key uncertainties and data gaps, provide lines of evidence for numeric targets and allocations, and are useful tools for adaptive management. The conceptual models for the Klamath River focus on water quality related impacts and provide perspective on other factors that contribute to impairment of beneficial uses within the Klamath River basin.

Section 2.5 Evidence of Water Quality Objective and Numeric Target Exceedances, as the title suggests, presents evidence of exceedances of water quality objectives. The Regional Water Board has compiled water quality monitoring data from several sources to support this analysis (e.g., dissolved oxygen, temperature, pH, nutrient enrichment) and CA NNE indicators (e.g., benthic algal biomass, chlorophyll-a, diurnal DO and pH patterns). The purpose of the analysis of water quality objectives and CA NNE indicators is to evaluate the risk of impairment to beneficial uses. The Section 2.4 analysis uses data from eleven stations along the length of the Klamath River from the Oregon border to its mouth at the Pacific Ocean.

As detailed in Section 2.6 Evidence of Beneficial Use Impairment, many designated beneficial uses are not being supported in the Klamath River. The purpose of Section 2.5 is to describe how poor water quality conditions are impairing beneficial uses in the Klamath River. The focus is on the status of the elements that are essential to each beneficial use. For example, to evaluate the Cold Freshwater Habitat (COLD) beneficial use, the historical and current status of the cold-water fishery is compared to demonstrate a significant degradation of fishery related beneficial uses.

Section 2.7 Problem Statement Synthesis, presents the problem statement conclusions regarding the status of Klamath River beneficial uses and the necessity for fully implementing the TMDL in a timely manner. The problem statement conclusions provide the focus for the TMDL pollutant allocations and implementation.

2.1.1 Non-TMDL Factors and Other Regulatory Processes

It is important to recognize that in the Klamath River basin there are factors that affect the condition of beneficial uses that are not directly addressed through the TMDL process. For the COLD beneficial use, a few of these factors include, but are not limited to:

- The presence of dams which impede passage of anadromous fish;
- Altered flow conditions that affect habitat conditions;
- The presence of hatchery raised fish with the potential for disease and genetic effects;
- Ocean and in-river fisheries harvest rates; and
- Global climate change.

The problem statement description is a required component of any TMDL, but in this case it takes on added importance because of other ongoing regulatory processes within the Klamath Basin that must be kept clearly distinct from the TMDL process. The other ongoing regulatory processes include:

- The 50-year Federal Energy Regulatory Commission (FERC) relicense for the five dams included in the Klamath Hydroelectric Project; and
- Endangered Species Act (ESA) consultation for several native species that have special federal and or state status, including but not limited to Coho salmon, shortnose sucker, Lost River sucker, and Bull trout.
- Tribal Trust responsibilities of the USEPA to Tribes and individual Indians.

The mention of these other non-TMDL factors affecting water quality and other ongoing regulatory processes that will address some of these factors is meant to underscore the need for a comprehensive solution to restore ecosystem integrity to the Klamath River basin. The TMDL process described in this document is only one component of a restoration and management program that must be implemented in the next few years to preserve Klamath River water resource related uses in an acceptable manner.

2.2 Water Quality Standards

The USEPA describes a water quality standard as consisting of four basic elements: 1) designated uses of the water body, 2) water quality criteria to protect designated uses, 3) an antidegradation policy to maintain and protect existing uses and high quality waters, and 4) general policies addressing implementation issues. More information is available at <http://www.epa.gov/waterscience/standards/about/>.

The Porter Cologne Water Quality Control Act (Porter Cologne)[4] modifies USEPA's language to refer to designated uses as "beneficial uses" and water quality criteria as "water quality objectives", which includes the state anti-degradation policy (Resolution 68-16). Porter Cologne also requires a "program of implementation" (Water Code section 13050(i)) for water quality protection in California. A "program of implementation" includes actions necessary to achieve objectives, a time schedule for the actions to be taken, and surveillance to determine compliance with objectives (see Water Code section 13242).

The Regional Water Board has adopted the *Water Quality Control Plan for the North Coast Region* (Basin Plan) in which it establishes the region's water quality standards, including the standards that apply to that portion of the Klamath River basin that falls under the jurisdiction of the state of California. The Basin Plan has been approved by the State Water Board and by USEPA and is in full force and effect.

Similarly, the Hoopa Valley Tribe has adopted the *Water Quality Control Plan for the Hoopa Valley Indian Reservation* that has been approved by USEPA and is in full effect. The Hoopa's standards apply to those portions of the Trinity and Klamath Rivers under the jurisdiction of the Hoopa Valley Tribe[5].

The Yurok and Karuk Tribes have also adopted water quality standards, as has the Resighini Rancheria. These water quality plans and standards have not yet been approved by USEPA, however, and the Regional Water Board will consider their content and use for guidance, as appropriate.

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[4] The Porter-Cologne Water Quality Control Act (Water Code §§ 13000 et seq.) is the act governing the water quality protection activities of the State Water Resources Control Board (State Board) and the nine regional boards within the state of California.

[5] The Hoopa Valley Tribe is a sovereign nation with land, 12 miles by 12 miles, primarily in the Trinity River watershed but intersecting with the Klamath River at Saints Rest Bar upstream of the confluence with the Trinity (www. Hoopa-nsn.gov).

The Quartz Valley Tribe, located along the Scott River, is in the process of developing a document on water quality standards for approval by its Tribal government.

2.2.1 Water Quality Control Plan for the North Coast Region

The Basin Plan (Regional Water Board 2007) is divided into 6 chapters. Of concern to this discussion are Chapter 2 (Beneficial Uses), Chapter 3 (Water Quality Objectives), Chapter 4 (Implementation Plans), and Chapter 5 (Plans and Policies).

2.2.1.1 Beneficial Uses

Chapter 2 of the Basin Plan identifies 28 beneficial uses of water within the North Coast region. Within the Klamath River basin, the following beneficial uses are identified as existing uses:

- MUN—Municipal and domestic supply
- AGR—Agricultural supply
- IND—Industrial service supply
- PRO—Industrial process supply
- GWR—Groundwater recharge
- FRSH—Freshwater replenishment
- NAV—Navigation
- POW—Hydropower generation
- REC1—Water contact recreation
- REC2—Non-contact water recreation
- COMM—Commercial and sport fishing
- WARM—Warm freshwater habitat
- COLD—Cold freshwater habitat
- WILD—Wildlife habitat
- RARE—Rare, threatened, or endangered species
- MAR—Marine habitat
- MIGR—Migration of aquatic organisms
- SPWN—Spawning, reproduction, and/or early development
- SHELL—Shellfish harvesting
- EST—Estuarine habitat
- AQUA-- Aquaculture
- CUL—Native American Culture

Of particular importance are those uses that are currently not fully supported due in part to degraded water quality. As detailed in Section 2.5, the Klamath River beneficial uses that are impaired include: COLD, RARE, MIGR, SPWN, CUL, COMM, REC1, REC2, and MUN. Subsistence fishing (FISH) is also listed in the Basin Plan as a beneficial use of the waters in the region. Although, the specific areas in which this use exists has not yet been designated in the Basin Plan, this does not alter the need to protect this existing beneficial use.

2.2.1.2 Water Quality Objectives

Chapter 3 of the Basin Plan identifies the water quality objectives deemed necessary to protect beneficial uses. Of concern to this TMDL are the water quality objectives concerning temperature, dissolved oxygen and nutrients. These are the parameters for which instream water quality data indicate exceedances and for which the Klamath River is listed on the 303(d) list as impaired[6]. Additionally, pH is discussed because high pH can be directly stressful to salmonids and it also influences nutrient related parameters such as ammonia toxicity. Toxicity is also discussed as nutrient and temperature

[6] The Klamath River downstream of the Trinity River is also on the 303(d) list for Sedimentation/Siltation, and Copco and Iron Gate Reservoirs are on the 303(d) list for the microcystin toxin.

impairment contributes to the presence of blue-green algae blooms and associated presence of algal toxins.

Temperature

The Basin Plan contains two separate water quality objectives for temperature. The first objective is the intrastate temperature objective. This objective applies to all waters of the state.

The intrastate temperature objective is a narrative objective with associated numeric criteria and reads:

> The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses.
>
> At no time or place shall the temperature of any COLD water be increased by more than 5°F above natural receiving water temperature.
>
> At no time or place shall the temperature of WARM intrastate waters be increased more than 5°F above natural receiving water temperatures.

The second water quality objective for temperature is the interstate temperature objective contained in the state wide *Water Quality Control Plan for Control of Temperature In the Coastal and Interstate Waters and Enclosed Bays and Estuaries of California* (Thermal Plan). The Thermal Plan, as adopted by the State Water Board, is incorporated by reference in the Basin Plan (see Appendix 3 of the Basin Plan). The plan designates the Klamath River as a "Cold Interstate Water". The "Cold Interstate Waters" objective is as follows:

> Elevated temperature waste discharges into cold interstate waters are prohibited.

"Elevated Temperature Waste" is defined as:

> Liquid, solid, or gaseous material including thermal waste discharged at a temperature higher than the natural temperature of receiving water. Irrigation return water is not considered elevated temperature waste for the purpose of this plan.

The interstate objective applies to waters that cross or define the state border. The interstate temperature objective augments, but does not supersede, the intrastate temperature objective.

The federal Clean Water Act (CWA) imposes a criterion for setting loads in addition to the water quality standards defined by the State. For waters impaired by temperature,

CWA section 303(d)(1)(D) requires that states estimate "the total maximum daily thermal load required to assure protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife."

Dissolved Oxygen

Chapter 3 (Water Quality Objectives) of the Basin Plan includes two sets of dissolved oxygen (DO) objectives. The first set of objectives is included on page 3-4.00 (Regional Water Board 2007) and describes the life cycle requirements of aquatic species occupying warm water and marine habitat, as well as habitat of inland saline seas. It also describes the life cycle requirements of aquatic species occupying cold water habitat, as well as the spawning and incubation needs of cold water species. These are given as ambient water quality objectives applicable as instantaneous minimum requirements.

The second set of objectives is included in Table 3-1 of the Basin Plan (Regional Water Board 2007) and describes the background conditions in individual waterbodies as defined by grab sampling studies conducted in the 1950s and 1960s. In the existing Basin Plan the objectives contained in Table 3-1 supersede the life cycle requirements for those waterbodies listed in Table 3-1 with site specific DO objectives.

For the Klamath River, numeric objectives are assigned in Table 3-1 of the Basin Plan for the following hydrologic areas: 1) upstream of the Iron Gate Dam, 2) downstream of Iron Gate Dam, 3) on tributaries of the Middle Klamath River, and 4) on tributaries of the Lower Klamath River. The Klamath River DO impairment applies only to the mainstem of the Klamath River.

Upstream of the Iron Gate Dam, the instantaneous minimum concentration of DO required is 7.0 mg/L. Half of the monthly mean DO values for the year must be 10.0 mg/L or greater.

Downstream of the Iron Gate Dam, the instantaneous minimum concentration of DO required is 8.0 mg/L. Half of the monthly mean DO values for the year must also be 10.0 mg/L or greater.

These DO objectives are the existing water quality objectives for the Klamath River as currently contained in the Basin Plan. *However*, Regional Water Board staff is currently developing a proposed revision to the DO objectives to better account for updates in the scientific literature regarding the DO requirements of cold water fishes, particularly salmonids. This will primarily be done by expanding the objectives to include 7-day average requirements. The proposed revision will also reverse the priority of the DO objectives so that the life cycle objectives supersede the background DO objectives.

In addition, the proposed revision is intended to update the background DO requirements as contained in Table 3-1 of the Basin Plan. This is particularly important because the existing daily minimum requirements as listed in Table 3-1 of the Basin Plan are based on grab sample data collected during day light hours in the 1950s and

1960s. Today's monitoring and analysis capabilities are such that compliance is often based on continuous data collected over 24 hours or longer. Because the minimum DO conditions in a waterbody are much more likely to occur during the pre-dawn hours than during day light hours, violations (i.e. concentrations below the minimum DO objectives) of the minimum Table 3-1 limits are possible.

The DO objectives applicable to the Klamath River will be revised prior to the Regional Water Board's consideration of the Klamath River TMDLs [7]. Staff will propose that the DO water quality objectives be revised by adding to the existing numeric objectives; for the protection of COLD a 7-day average of the daily mean[8] of 8.0 mg/L DO in the water column; and replacing the existing numeric objective for SPWN with a 7-day average of the daily mean of 11.0 mg/L DO in the water column and 8.0 mg/L DO intragravel, to be applied during embryo and larval stages. These criteria are derived from the USEPA 1986 guidance.

In those waterbodies identified as COLD but unable to meet the salmonid life cycle requirements due to natural conditions (e.g., the Klamath River), a minimum limit equal to 85% of the saturation concentration of DO, as calculated based on natural water temperatures, will be proposed. This will be proposed as a replacement of the background objectives contained in Table 3-1 of the Basin Plan—an alternative method of defining background DO conditions. Additionally, the proposed revision will state that in no case shall the DO fall below 6.0 mg/L as an instantaneous minimum.

The Klamath River TMDLs are being developed in accordance with the proposed DO objective of a minimum 85% DO saturation limit, calculated based on natural temperatures. As stated above, the DO objectives applicable to the Klamath River will be revised prior to the Regional Water Board's consideration of the Klamath River TMDLs, and the proposed DO objectives will undergo external peer review, separate from the peer review of the TMDL.

Nutrients

The nutrient objective is a narrative objective for controlling biostimulatory substances. Biostimulatory substances include nitrogen and phosphorus. The objective reads:

> Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.

Nutrient-Related Water Quality Objectives

The cycling of nutrients in an aquatic environment is strongly influenced by several factors. Depending on these factors, there is the potential for impacts to beneficial uses

[7] The proposed revisions to the DO objective are undergoing an external peer review, separate from the peer review of the draft Klamath River TMDLs.

[8] The daily mean is calculated from equally spaced values collected over a 24 hour period and including the day's minimum and maximum DO values. The 7-day average is applied as a moving average.

from secondary indicators of biostimulation such as algal biomass, chlorophyll-a, DO, and pH.

The Basin Plan does not contain numeric water quality objectives for algal biomass or chlorophyll-a. The Basin Plan does contain a set of numeric objectives for pH in the Klamath River. Minimum pH levels shall not drop below 7.0 and maximum pH shall not be raised above 8.5.

Other impacts closely related to excessive nutrient inputs but qualitatively different are ammonia toxicity and microcystin[9] toxicity. The Basin Plan does not include numeric objectives for ammonia toxicity or microcystin.

The Basin Plan includes a narrative objective for toxicity that reads:

> All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal, or aquatic life.

2.2.1.3 Antidegradation Policies

There are two applicable antidegradation policies pertinent to water quality in the North Coast Region – a state policy and a federal policy. The state antidegradation policy is titled the *Statement of Policy with Respect to Maintaining High Quality Waters in California* and is commonly known as "Resolution 68-16." The federal antidegradation policy is found at 40 CFR section 131.12. Both policies are incorporated in the Basin Plan for the North Coast Region. Although there are some differences in the state and federal policies, both require that whenever surface waters are of higher quality than necessary to protect the designated beneficial uses, such existing quality shall be maintained unless otherwise provided by the policies.

The state antidegradation policy applies to groundwater and surface water whose quality meets or exceeds water quality objectives, which may limit its direct applicability in impaired waterbodies. The state policy establishes a two-step process to determine if discharges that will degrade water quality are allowed. The federal antidegradation policy applies to both surface waters that meet or exceed water quality objectives, and those that do not meet the applicable water quality objectives (i.e., impaired waters). Under the federal policy, an activity or discharge would be prohibited if the activity will lower the quality of surface water that currently does not meet water quality standards (i.e., the water quality is not sufficient to support designated beneficial uses) with limited exceptions set forth in federal regulations.

2.2.1.4 Program of Implementation

Chapter 4 of the Basin Plan describes the program of implementation by which the beneficial uses and water quality objectives are applied and enforced. This chapter includes all the prohibitions, schedules of compliance, action plans, policies, and guidelines adopted by the Regional Water Board for that purpose.

[9] Microcystin is a toxin produced by a species of blue-green algae.

Chapter 6 of this TMDL staff report describes the proposed Implementation Plan for the TMDL, and will serve as the basis for the Action Plan for the Klamath River TMDL to be considered by the Regional Water Board as an amendment to Chapter 4 of the Basin Plan.

2.2.2 Tribal Water Quality Standards

The four Tribes in California with land along the mainstem Klamath River are the Hoopa Valley Tribe, the Karuk Tribe, the Resighini Rancheria, and the Yurok Tribe. As stated earlier, only the Hoopa Valley Tribe's water quality standards have been approved by the USEPA at this time. The water quality standards developed by the Yurok and Karuk Tribes and Resighini Rancheria will be used as guidance in developing the TMDL as appropriate.

2.2.2.1 Hoopa Valley Tribe Beneficial Uses

The *Water Quality Control Plan for the Hoopa Valley Indian Reservation* (Hoopa Valley Tribal Environmental Protection Agency [HVTEPA] 2008) identifies nine existing, four potential, and one historical beneficial uses of water within their jurisdictional reach of the Klamath River. Figure 1.2 identifies the location and boundaries of the Hoopa Valley Indian Reservation, as well as the Yurok Indian Reservation.

- AGR—Agricultural supply(P)
- COLD—Cold freshwater habitat(E)
- CUL—Ceremonial and Cultural Water Use(H)
- GWR—Groundwater recharge(E)
- IND—Industrial service supply(P)
- MGR—Fish Migration(E)
- MUN—Municipal and domestic supply(P)
- PROC—Industrial process supply(P)
- REC1—Water contact recreation(E)
- REC2—Non-contact water recreation(E)
- SPWN—Spawning, reproduction,
- and/or early development(E)
- T&E— Preservation of Threatened(E)
- W&S—Wild and Scenic(E)
- WILD—Wildlife habitat
- and Endangered Species(E)

2.2.2.2 Hoopa Valley Tribe Water Quality Criteria

The Hoopa Valley Tribe has established DO and nutrients criteria for the Klamath River as described below. The Tribe has not developed temperature criteria for the Klamath River.

Dissolved Oxygen

The dissolved oxygen (DO) criteria consists of 7-day moving averages of the daily minimum DO concentrations.

In areas of the Klamath River designated as COLD (year-round), the 7-day moving average of the daily minimum DO concentration required in the water column must be 8.0 mg/L or greater. Areas of the Klamath River designated as SPWN (whenever spawning occurs, has occurred in the past or has potential to occur) must have a 7-day moving average of the daily minimum DO concentration in the water column of the Klamath River of 11.0 mg/L or greater. The intragravel 7-day moving average of the

daily minimum DO concentration required in the Klamath River areas designated as SPWN (whenever spawning occurs, has occurred in the past or has potential to occur) must be 8.0 mg/L or greater. In the event that these 7-day moving averages of the daily minimum DO standards "are not achievable due to natural conditions, then the COLD and SPAWN standard shall instead be DO concentrations equivalent to 90% saturation under natural receiving water temperatures."

Nutrients

Nutrient criteria consist of several narrative criteria for controlling biostimulatory substances, nitrate and nitrite levels, and phosphate levels. Additionally, there are numeric objectives for nitrate, total nitrogen, ammonia, and total phosphorus.

The narrative criteria for biostimulatory substances reads:

> Waters shall not contain bio-stimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.

The narrative criteria for nitrates applies to all waterbodies except those designated as municipal or domestic supply (which have their own numeric criteria) and reads:

> …levels of nitrate shall not be increased by human related activity above the levels consistent with preservation of the specified beneficial uses.

The narrative criteria for nitrites reads:

> Levels of nitrites shall not be increased, in any body of water, by human related activity above the levels consistent with preservation of the specified beneficial use corresponding to that water body.

The narrative criteria for phosphates reads:

> In order to preserve the existing quality of water within the reservation boundaries from existing and to avoid potential eutrophication of phosphorous in any water body shall not be increased by human related activity above levels consistent with preservation of the specified beneficial uses. <sic>

Numeric nutrient criteria for the Klamath River are displayed below in Table 2.1. "If total nitrogen and total phosphorus standards are not achievable due to natural conditions, then the standards shall instead be the natural conditions for total nitrogen and total phosphorus (HVTEPA 2008, p.53)." As stated in a footnote within the Hoopa's Basin Plan, "Through consultation, the ongoing TMDL process for the Klamath River is expected to further define these natural conditions (HVTEPA 2008, p.53)."

Table 2.1: Hoopa Valley Tribe Numeric Nutrient Criteria

	Nitrate (mg/L)	Total N (mg/L)[1]	Ammonia (mgN/L)	Total P (mg/L)[1]
All Streams	-	0.2	-[2]	0.035
Domestic/Municipal supply	10	-	-	-

Source: HVTEPA 2008
[1] 30-day mean of at least two samples per 30-day period.
[2] Maximum one-hour and 30-day average concentrations linked to pH by a formula. Formula can be found in HVTEPA 2008.

Nutrient-Related Water Quality Criteria

In addition to the above narrative and numeric criteria for nutrients, the *Water Quality Control Plan for the Hoopa Valley Indian Reservation* contains narrative criteria for toxicity and Cyanobacterial scums, as well as numeric criteria for parameters which are closely related to excessive nutrient inputs and influence toxicity.

The toxicity narrative reads:

> All waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal or aquatic life.

The Cyanobacterial scums narrative reads:

> There shall be no presence of cyanobacterial scums.

Table 2.2 displays numeric criteria for algal biomass, pH, blue-green algae, and Microcystin.

Table 2.2: Hoopa Valley Tribe Numeric Nutrient and Toxicity Related Criteria

	Periphyton	Hydrogen Ion (pH)		Total Potentially Toxinogenic BGA Species[1]	*Microcystis aeruginosa* and Microcystin			
				Recreation Water	Drinking Water		Recreation Water	
	Max annual periphyton mg chl-a per m^2	Max	Min	cells/mL	cells/mL	Microcystin (µg/L)	cells/mL	Microcystin (µg/L)
All Streams	150	8.5	7.0	<100,000	<5000	<1	<40,000	<8

Source: HVTEPA 2008
[1] Includes: *Anabaena, Microcystis, Planktothrix, Nostoc, Coelosphaerium, Anabaenopsis, Aphanizomenon, Gloeotrichia,* and *Oscillatoria*.

2.2.2.3 Karuk Tribe, Resighini Rancheria, and Yurok Tribe Beneficial Uses

The Karuk Tribe[10], Resighini Rancheria[11], and Yurok Tribe[12], have identified the

[10] Beneficial Uses designated by the Karuk Tribe
[11] Beneficial Uses designated by the Resighini Rancheria
[12] Beneficial Uses Designated by the Yurok Tribe

following existing, potential, and historical benefical uses within their respective reaches of the Klamath River:

- AGR—Agricultural Supply
- ASQ—Aesthetic Quality [9]
- BIOL—Preservation of Areas of Special Biological Significance[9, 10]
- COL/COLD—Cold Freshwater Habitat [9, 10, 11]
- COMM—Commercial and Sport Fishing [11]
- CUL—Cultural [10, 11]
- CUL-1—Cultural Contact Water [9]
- CUL-2—Cultural Non-Contact Water [9]
- EST—Estuarine Habitat [11]
- FC—Fish Consumption [9]
- FRSH—Freshwater Replenishment [9, 11]
- GW—Groundwater Recharge[9,10, 11]
- IND—Industrial Service Supply[10]
- LIV—Livestock Watering [9]
- MGR/MIGR—Migration of Aquatic Organisms [9, 11]
- MGR—Fish Migration [10]
- MUN—Municipal and Domestic Supply [10, 11]
- NAV—Navigation [9, 11]
- PROC—Industrial Process Supply [10]
- PWR/POW—Hydropower Generation [10, 11]
- RARE/T&E—Rare, Threatened, or Endangered Species [9, 10, 11]
- REC-1—Water Contact Recreation [9, 10, 11]
- REC-2—Non-Contact Water Recreation [9, 10, 11]
- SPAWN—Fish Spawning [10]
- SPN/SPWN—Spawning, Reproduction, and/or Early Development [9, 11]
- WARM—Warm Freshwater Habitat[11]
- WLD/WILD—Wildlife Habitat[9,10, 11]

2.2.2.4 Karuk Tribe, Resighini Rancheria, and Yurok Tribe, Water Quality Objectives and Criteria

The Karuk and Yurok Tribes have established narrative water quality objectives for temperature, DO and nutrients. Additionally, the Tribes have created narrative objectives for toxicity and pH. The Resighini Rancheria has established narrative water quality criteria for temperature and nutrients, as well as toxicity. These narrative water quality standards are quoted in Table 2.3.

Table 2.3: Karuk Tribe, Resighini Rancheria, and Yurok Tribe Narrative Objectives and Criteria for the Klamath River in California

KARUK	
Objective	**Description**
Temperature	The natural receiving water temperature of intratribal waters shall not be altered unless it can be demonstrated to the satisfaction of the Department of Natural Resources that such alteration in temperature does not adversely affect beneficial uses. At no time or place shall the temperature of any cold freshwater habitat (COLD) water be increased by more than 5 degrees F above natural receiving water temperature.
Dissolved Oxygen	Dissolved Oxygen Concentrations shall not at any time be depressed more than 10 percent from that which occurs naturally.
Nutrients	Biostimulatory Substances: Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.

Table 2.3 (cont.): Karuk Tribe, Resighini Rancheria, and Yurok Tribe, Narrative Objectives and Criteria for the Klamath River in California

KARUK (cont.)	
Objective	**Description**
Toxicity	All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal or aquatic life. Where appropriate, additional numerical receiving water standards for specific toxicants will be established as sufficient data become available, and source control of toxic substances will be encouraged.
pH	Changes in normal ambient pH levels shall not exceed 0.5 units within the range specified in fresh waters with designated COLD or WARM beneficial uses.
RESIGHINI RANCHERIA	
Objective	**Description**
Temperature	The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Business Council that such alteration in temperature does not adversely affect beneficial uses. At no time or place shall the temperature of any water be increased by more than 5 degrees F above natural receiving water temperature.
Nutrients	Biostimulatory Substances: Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.
Toxicity	All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal or aquatic life.
YUROK	
Objective	**Description**
Temperature	The temperature of waters within the Yurok Indian Reservation shall not be increased by human caused activity by more than 5 degrees Fahrenheit above the background level at any time or place. If a background level has not been determined, the temperature upstream of a project impacting the receiving water will be considered the background level.
Dissolved Oxygen	Dissolved oxygen concentrations shall not be altered by human caused activities that could cause a barrier to salmonid fish migration or adversely affect the water to support specified beneficial uses.
Nutrients	Ammonia: Levels of ammonia shall not be increased, in any body of water, by human related activity that could cause a nuisance or adversely affect the water to support specified beneficial uses. Biostimulatory Substances: Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses. Nitrites: Levels of nitrites shall not be increased, in any body of water, by human related activity that could cause a nuisance, or adversely affect the water to support specified beneficial uses. Phosphates: Levels of phosphorous in any water body shall not be increased by human related activity above the levels that could cause a nuisance, or adversely affect the water to support specified beneficial uses.
Toxicity	All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal, or aquatic life.
pH	Changes related to human caused activities in normal pH levels shall not exceed 0.5 pH units.

Sources: Karuk Tribe of California 2002, Resighini Rancheria Environmental Department 2006, and Yurok Tribe Environmental Program (YTEP) 2004

In addition to the narrative criteria, the Karuk Tribe, Resighini Rancheria, and Yurok Tribe have established numeric criteria for water quality parameters including temperature, DO, nutrients, and other criteria related to nutrients and toxicity as displayed in Table 2.4, Table 2.5, and Table 2.6.

Table 2.4 Karuk Tribe Numeric Water Quality Objectives

	Temperature (°C)		**Dissolved Oxygen (mg/L)**		**Hydrogen Ion (pH)**	
	MWAT[1]	**Max**	**Min**	**50% lower limit[2]**	**Max**	**Min**
All Streams	15.5	21	-	-	8.5	7.0
Klamath River	-	-	8.0	10.0	-	-
Other Streams	-	-	7.0	9.0	-	-

Sources: Karuk Tribe of California 2002
[1] MWAT is the maximum 7-day average temperature within a given time period.
[2]50% lower limits represent the 50 percentile values of the monthly means for a calendar year. 50% or more of the monthly means must be greater than or equal to the lower limit.

Table 2.5 Resighini Rancheria Numeric Water Quality Criteria

	Dissolved Oxygen (mg/L)	**Hydrogen Ion (pH)**		***Microcystis aeruginosa* and Microcystin**			
				Drinking Water		**Recreation Water**	
	7-DAMin[1]	**Max**	**Min**	**cells/mL**	**Microcystin (µg/L)**	**cells/mL**	**Microcystin (µg/L)**
COLD water column	8.0	-	-	<5000	<1	<50,000	<10
SPAWN intergravel	8.0	8.5	7.0	-		-	
SPAWN water column	11.0	8.5	6.5	-		-	

Source: Resighini Rancheria Environmental Department 2006
[1] 7-DAMin is the minimum 7-day average dissolved oxygen concentration within a given time period.

Table 2.6: Yurok Tribe Numeric Water Quality Objectives

	Temperature (°C)		**Dissolved Oxygen (mg/L)**		**Nutrients**		**Hydrogen Ion (pH)**	
	MWAT[1]	**Max**	**Min**	**50% lower limit[2]**	**Nitrate (mg/L)**	**Ammonia (mgN/L)**	**Max**	**Min**
All Streams	15.5	21.0	7.0	9.0	-	-[3]	8.5	6.5
Domestic/Municipal supply	-	-	-	-	10	-	-	-

Source: Yurok Tribe Environmental Program (YTEP) 2004
[1] MWAT is the maximum 7-day average temperature within a given time period.
[2]50% lower limits represent the 50 percentile values of the monthly means for a calendar year. 50% or more of the monthly means must be greater than or equal to the lower limit.
[3] Maximum one-hour and 30-day average concentrations linked to pH by a formula. Formula can be found in YTEP 2004.

2.3 Numeric Targets

Numeric targets are the numeric water quality conditions that represent attainment of the applicable water quality objectives for a TMDL. In some cases numeric targets can equal a numeric water quality objective. In other cases, numeric targets are a numeric interpretation of the conditions that meet a narrative water quality objective. In all cases numeric targets are used in the calculation of a TMDL. Presented here are the numeric targets applied for the development of these Klamath River TMDLs.

2.3.1 Temperature

The numeric temperature targets are expressed as monthly average temperatures and are calculated from the estimated natural temperature regime of the Klamath River. The approach and assumptions applied in estimating the natural temperatures and calculating the numeric targets at select compliance locations are detailed in Chapter 3. The specific numeric temperature targets for select TMDL compliance locations are presented in Chapter 5.

2.3.2 Dissolved Oxygen and Nutrient-Related

The numeric DO targets are expressed as monthly average and monthly minimum DO concentrations calculated at 85% DO saturation under natural temperatures. The approach and assumptions applied to estimating the natural temperatures and associated DO concentrations are detailed in Chapter 3. The specific numeric DO targets for select TMDL compliance locations are presented in Chapter 5.

The DO targets are the primary target associated with the nutrient and organic matter TMDLs and associated load allocations. However, additional numeric targets are associated with these TMDLs, and are used to reflect compliance with the narrative biostimulatory substances and toxicity objectives. These additional numeric targets are set for benthic algae biomass, suspended algae chlorophyll-a, *Microcystis aeruginosa* cell density and microsystin concentration.

2.3.2.1 <u>Benthic Algae Biomass</u>

The benthic algae biomass numeric target is 150 mg chlorophyll-a/m^2. During the summer season dense mats of attached algae form on the rocky substrate of many reaches of the Klamath River. This vegetative mass is referred to variously in the literature as periphyton, macroalgae, macrophytes, and attached benthic algal biomass. For this assessment we have adopted the term benthic algal biomass. Because of the limited amount of benthic algae data that has been collected in the Klamath River, Regional Water Board staff used various lines of evidence to develop a numeric target for this assessment. The lines of evidence include:

- The California Nutrient Numeric Endpoints (CA NNE) framework (Tetra Tech 2006) sets a benthic algal biomass target for the boundary between Beneficial Use Risk Category II (potentially impaired) and III (presumptively impaired) for streams with a cold-water fishery use (COLD) at 150 mg chlorophyll-a/m^2,

interpreted as a maximum biomass in time averaged over a reach (i.e., it does not apply to single point measurements). The CA NNE boundary target is based on a review of both regional and international studies and the recommendation of university and regional experts. The CA NNE also recommends the evaluation of other lines of evidence for each waterbody to ensure the appropriateness of this boundary condition. Because of the natural continuum of conditions from the Klamath headwaters (eutrophic) to its mouth (mesotrophic), the Regional Water Board considered other information for benthic algae biomass target determination.

- The Regional Water Board and EPA Region IX sponsored a *Nutrient Numeric Endpoint Analysis for the Klamath River, CA* (Tetra Tech 2008 [Appendix 1]) in 2008. The study made use of the CA NNE scoping tools (described in Chapter 3) to assess benthic algal biomass targets under both existing conditions and natural background scenarios. The scoping tool provided very close estimates of existing benthic algal biomass using existing nutrient concentrations and information from other factors (e.g., accrual period). Using natural background concentrations at four locations along the mainstem Klamath River below Iron Gate Dam, the scoping tool estimated reach-averaged maximum benthic algal biomass densities of 109 to 157 mg chlorophyll-a/m^2 with a mean across the four stations of 141 mg chlorophyll-a/m^2.
- The Hoopa Valley Tribe Basin Plan includes a criterion of 150 mg chlorophyll-a/m^2 for the reach of the Klamath River within the Hoopa Valley Indian Reservation.

Based on these three lines of evidence, a benthic algal biomass numeric target of 150 mg chlorophyll-a/m^2 is set for this TMDL. This is a reach-average benthic algal biomass target.

2.3.2.2 Suspended Algae Chlorophyll-a, *Microcystis aeruginosa*, and Microcystin Toxin

In addition to the benthic algae biomass target, the following nutrient-related numeric targets are set for the Klamath River TMDLs:

- Suspended algae chlorophyll-a = 10 µg/L;
- *Microcystis aeruginosa* cell density = 20,000 cells/mL; and
- Microcystin = 4 µg/L.

The selection of each of these targets is discussed below.

Chlorophyll-a is a key indicator for the Klamath River reservoirs, and is a surrogate measure of suspended algae (phytoplankton) biomass. Chlorophyll-a is a response variable to both water quality stressors (e.g. nutrients) and to impoundment conditions. High levels of suspended algae chlorophyll-a indicates an aquatic ecosystem subject to biostimulatory effects due to physical conditions and/or high concentrations of nutrients. Consistently high or episodic chlorophyll-a concentrations indicate the occurrence of

algal blooms, which can be harmful to aquatic organisms. Prolonged conditions of high levels of chlorophyll-a are typical of hyper-eutrophic water bodies.

Water quality impacts associated with high chlorophyll-a concentrations in the Klamath River reservoirs include:

- Extreme diurnal variation in DO and pH;
- Low DO conditions due to the decay of organic matter resulting from algal blooms;
- Aesthetic impacts, both visual and aroma, due to nuisance algal blooms; and
- Increasing dominance of toxigenic blue-green algal species at higher concentrations of chlorophyll-a.

The CA NNE framework sets a suspended algae chlorophyll-a target of 10 µg/L as the boundary between Beneficial Use Risk Category II (potentially impaired) and Beneficial Use Risk Category III (presumptively impaired) for support of the COLD beneficial use (Tetra Tech 2006). This concentration target was selected in part due to the rapidly increasing likelihood of nuisance algal blooms when chlorophyll-a concentrations are above this concentration (Walker 1985). In addition, as chlorophyll-a levels increase above 10 µg/L, blue-green algal species tend to begin to dominate the algal species assemblage (Downing et al. 2001). That is, the likelihood of blue-green algal biomass dominance rapidly increases as chlorophyll-a concentrations move above the target threshold. With blue-green algal dominance there is an increased risk of algal toxin production under elevated biomass of blue-green algae, creating a potential public risk hazard for people, livestock, and wildlife.

The CA NNE impairment boundary value of 10 µg/L of chlorophyll-a was developed from studies that included information from a large number of reservoirs from temperate climate locations (Walker 1985). Because a large amount of data has been collected at several stations along the Klamath River including Iron Gate and Copco Reservoirs it is possible to evaluate the site-specific relationship between high concentrations of chlorophyll-a and blue-green algal dominance.

Klamath River monitoring since 2005 has documented elevated levels of the blue-green algae (a.k.a. cyanobacteria) *Microcystis aeruginosa* (MSAE) and the blue-green algae toxin microcystin. Microcystins are a class of toxic chemicals produced by some strains of the blue-green algae *Microcystis aeruginosa* that are released into waters when blue-green algal cells die or cell membranes degrade. These chemicals are a human health risk, capable of inducing skin rashes, sore throat, oral blistering, nausea, gastroenteritis, fever, and liver toxicity (World Health Organization [WHO] 2003). Microcystin toxins have also been shown to produce effects on animals including acute livestock poisoning and tumor production in fish guts and liver (de Figueiredo et al. 2004, Lehman et al. 2005, and Xie et al. 2005). Microcystin can thus potentially impair a number of beneficial uses of a waterbody.

The targets for low risk exposure to *Microcystis aeruginosa* and microsystin come from the World Health Organization (WHO) and are 20,000 cells/mL and 4 µg/L respectively (WHO 2003).

When health advisories are issued by agencies concerned that cyanotoxins are present in waterbodies at levels that may pose a health risk, they are often issued based on "guidelines" or "risk levels." These guidelines are derived from analytic thresholds and field observations, and are established by the WHO. The WHO guidelines are largely accepted by nations and territories world-wide (WHO 1999, p. 171-175; WHO 2003, pp. 149-154). The presence of extensive blue-green algal water discolorations and scum accumulations are often used as triggers to assess the relative health risk to humans and other organisms from possible cyanotoxin exposures.

The Regional Water Board has not established numeric water quality objectives for microcystin toxins. However, the Basin Plan narrative objective for toxicity does apply. There are numeric translators for the narrative criteria for both *Microcystis aeruginosa* and microcystin that can be used as the basis for an impairment assessment and to develop numeric targets for the TMDL. The primary source for numeric assessment endpoints comes from the Blue Green Algae Work Group of the State Water Board, Department of Public Health (DPH), and Office of Environmental Health and Hazard Assessment (OEHHA) (Blue Green Algae Work Group), who developed guidance that is described in *Cyanobacteria in California Recreational Water Bodies: Providing Voluntary Guidance about Harmful Algal Blooms, Their Monitoring, and Public Notification* (State Water Board 2008). From this guidance the Regional Water Board has developed the following 303(d) impaired waters listing criteria:

Tissue Listing Criteria:

For the protection of human health from tissue contaminated with microsystin:

- Composite or three or more individual samples with microcystin edible tissue concentration $\geq$ 26 ng/g (OEHHA 2008)

Water Column Impairment Listing Criteria:

From grab sample or fixed station trend monitoring sites, three or more samples that exceed of any of the following numeric listing criteria for the protection of human health and aquatic life:

- Microsystin concentrations $\geq$ 8 µg/L
- *Microcystis aeruginosa* cell densities $\geq$ 40,000 cells/mL
- **Or** if a waterbody is posted based on photographic documentation of surface scums containing *Microcystis aeruginosa*. The photographic record must be compiled as part of a monitoring program that has an approved Quality Assurance Program and staff that have been trained in recognizing *Microcystis aeruginosa*

scums, as per the posting guidelines established by the Blue Green Algae Work Group (State Water Board 2008).

The following figures are from Kann and Corum (2009) presented in a technical memorandum to the Karuk Tribe of California Natural Resources Department. The data illustrated in Figures 2.1 through 2.6 was collected by the Yurok Environmental Program, Karuk Tribe of California, and PacifiCorp in 2005, 2006, and 2007.

The relationship illustrated in Figure 2.1 indicates that as chlorophyll-a concentrations reach 10 µg/L and above there is a sharp increase in *Microcystis aeruginosa* cell density above 20,000 cells/mL. That is, within the Klamath River and Iron Gate and Copco Reservoirs the dominance of toxigenic blue-green algal species rapidly increases above CA NNE target of 10 µg/L. Figure 2.2, which uses the same data as 2.1, demonstrates that the same relationship exists between chlorophyll-a and microcystin. As chlorophyll-a concentrations exceed 10 µg/L concentrations of microcystin rapidly increase above 4 µg/L. Taken together these relationships provide site-specific support the use of the CA NNE impairment boundary target of 10 µg/L of chlorophyll-a.

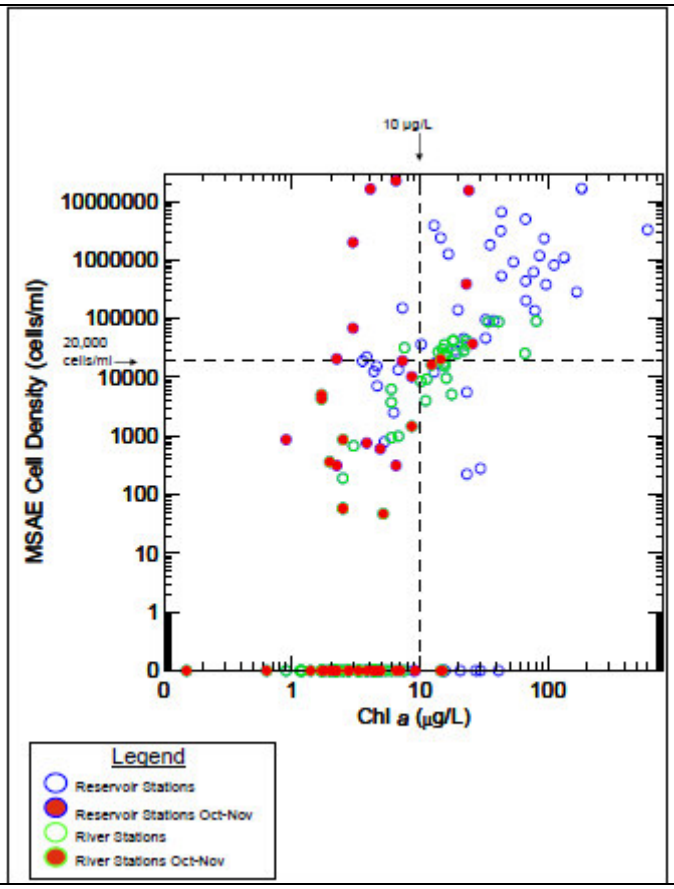


Figure 2.1: Relationship of chlorophyll-a and *Microcystis aeruginosa* (MSAE) cell density at monitoring stations along the Klamath River (2005-2007) from above Copco Reservoir to the lower Klamath River estuary.

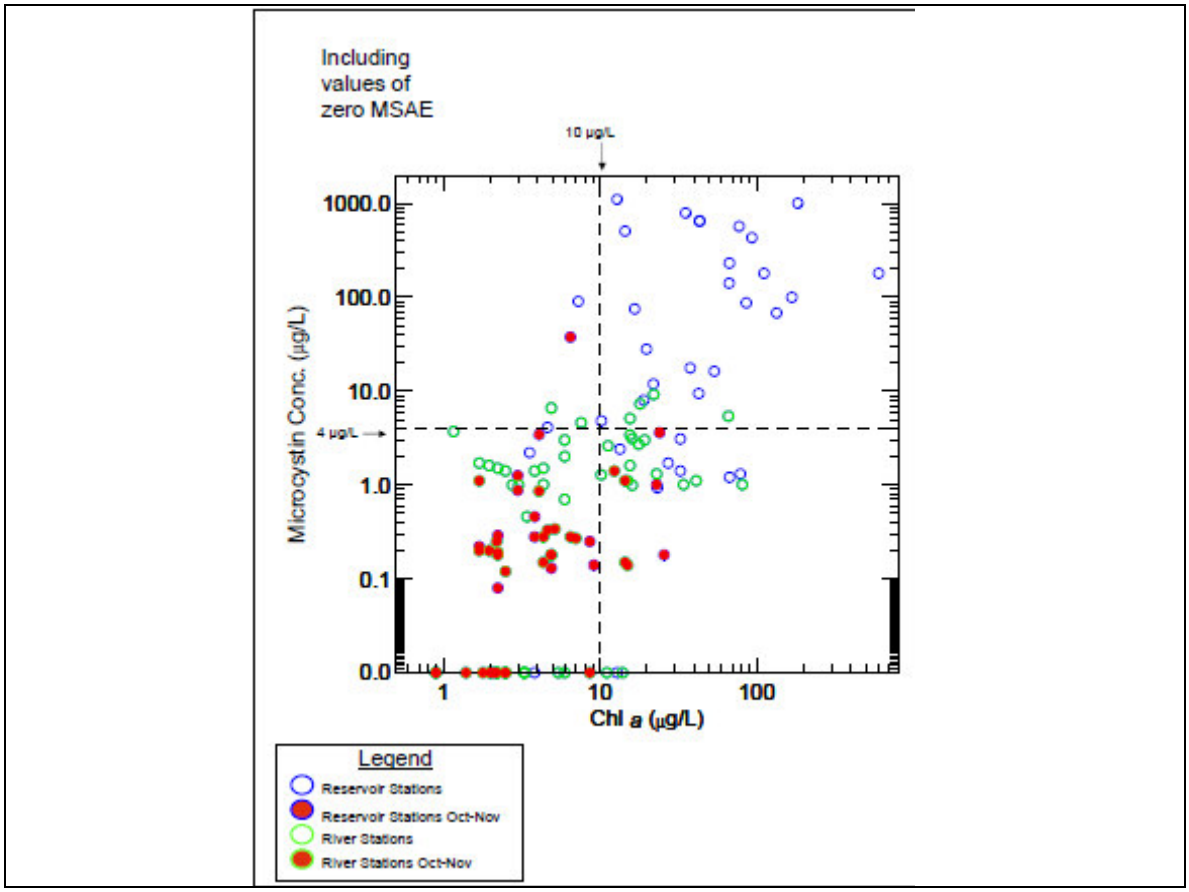


Figure 2.2: Relationship of chlorophyll-a and microcystin at monitoring stations along the Klamath River (2005-2007) from above Copco Reservoir to the lower estuary.

The probability of exceeding three critical *Microcystis aeruginosa* cell density levels at the chlorophyll-a target of 10 µg/L can be computed from nonparametric cross-tabulation probability models developed for Iron Gate and Copco Reservoirs (Kann and Corum 2009 – the computational methodology is explained in Kann and Smith 1999). The probability plots from this analysis are illustrated in Figure 2.3 using *Microcystis aeruginosa* cell density critical values of 20,000 cells/mL (red), 40,000 cells/mL (blue), and 100,000 cells/mL (green). The probability of *Microcystis aeruginosa* cell density exceeding the critical values of 20,000 cells/mL (red), 40,000 cells/mL (blue), and 100,000 cells/mL (green) at a chlorophyll-a concentration of 10 µg/L (dashed line) are approximately 32%, 13%, and 10% respectively. The exceedance probabilities for the critical values increases rapidly above 10 µg/L. For Iron Gate and Copco Reservoirs the chlorophyll-a target of 10 µg/L is a reasonable threshold top protect against conditions with unacceptable *Microcystis aeruginosa* cell densities.

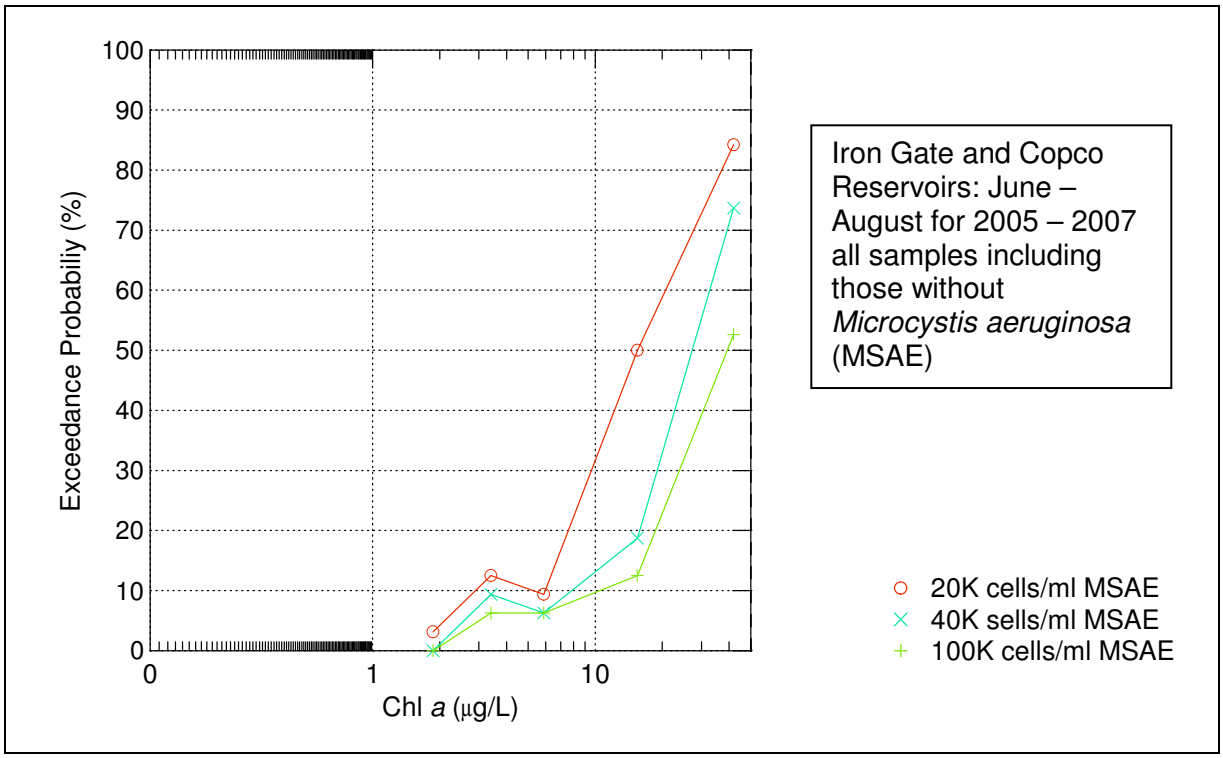


Figure 2.3: *Microcystis aeruginosa* (MSAE) cell density exceedance probability plotted as a function of chlorophyll-a concentration (10 µg/L) for Iron Gate and Copco Reservoirs using data collected by the Karuk Tribe of California for the years 2005, 2006, and 2007 during peak growing season (June – August). The probability plot includes all samples, including those with no *Microcystis aeruginosa* present.
Note: 20K = 20,000, 40K = 40,000, and 100K = 100,000

The same plots can be generated for the growing season (June – September) relationship between surface and/or 1 m chlorophyll-*a* and microcystin for Iron Gate and Copco Reservoirs for the period 2005-2007 with data collected by the Karuk Tribe of California Natural Resources Department. The probability plots from this analysis are illustrated in Figure 2.4 using microcystin concentrations critical values of 4 µg/L (red), 8 µg/L (blue), and 20 µg/L (green). The probability of microcystin concentrations exceeding the critical values of 4 µg/L (red), 8 µg/L (blue), and 20 µg/L (green) at a chlorophyll-a concentration of 10 µg/L (dashed line) are approximately 30%, 18%, and 13% respectively. The exceedance probabilities for the critical values increase rapidly above 10 µg/L. For Iron Gate and Copco Reservoirs the chlorophyll-a target of 10 µg/L is a reasonable threshold top protect against conditions with unacceptable microcystin concentrations.

Figure 2.5 illustrates *Microcystis aeruginosa* cell density during 2006-2007 for all stations from upper Copco through the lower estuary on the X axis with their associated microcystin concentration on the Y axis. The measurements in upper right hand quadrant in the chart are those measurements where cell count exceeds 20,000 cells/mL and the microcystin concentration exceeds 4 µg/L of microcystin. In regards to the relationship

being evaluated measurements in this quadrant of the graph are often referred to as true positives. The lower right hand quadrant includes those measurements that would be labeled false positives. That is, where you would expect a microcystin concentration higher than 4 µg/L, but was measured at a lower concentration. The lower left hand quadrant represents the true negative results. That is, with cell counts less than 20,000 cells/mL you would expect microcystin concentrations less than 4 µg/L and that is the case. Measurements in the upper left hand quadrant are the false negative measurements. This is the quadrant that would represent the risk to public health with adoption of a numeric target of 4 µg/L of microcystin and a cell density of 20,000 cells/mL of *Microcystis aeruginosa.* That is you have a higher concentration of microcystin than you would expect given the measured cell density. Because this is the low effects level and the low number of measurements in the false negative quadrant the proposed numeric target represents a reasonable level of protection. The high level of correlation between cell count and microcystin concentration makes it possible to calculate the percent probability that a desired level of microcystin concentration will be exceeded at a particular cell density. The final results of this analysis will be available in the near future (Kann and Corum 2009).

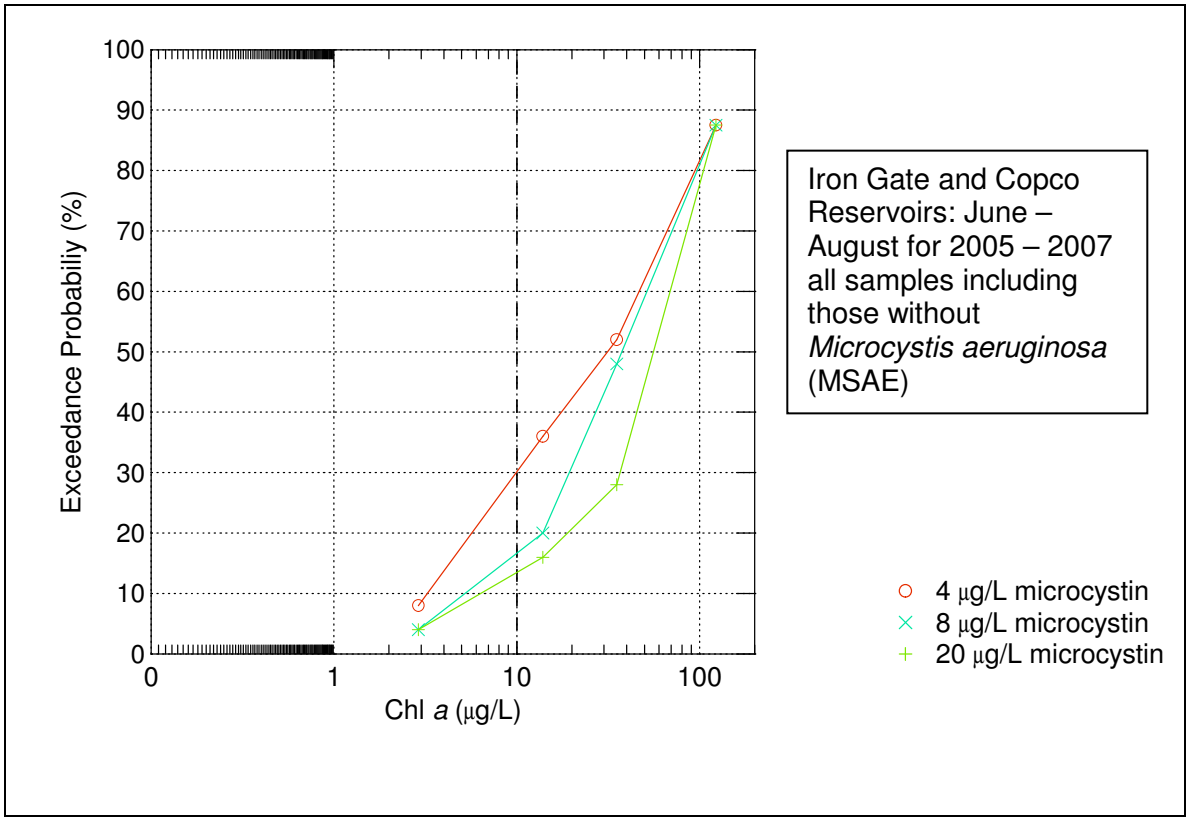


Figure 2.4: Microcystin concentration exceedance probability plotted as a function of chlorophyll-a concentration (10 µg/L)for Iron Gate and Copco Reservoirs using data collected by the Karuk Tribe of California for the years 2005, 2006, and 2007 during peak growing season (June – August). The probability plot includes all samples including those with no *Microcystis aeruginosa* present (Kann and Corum 2009).

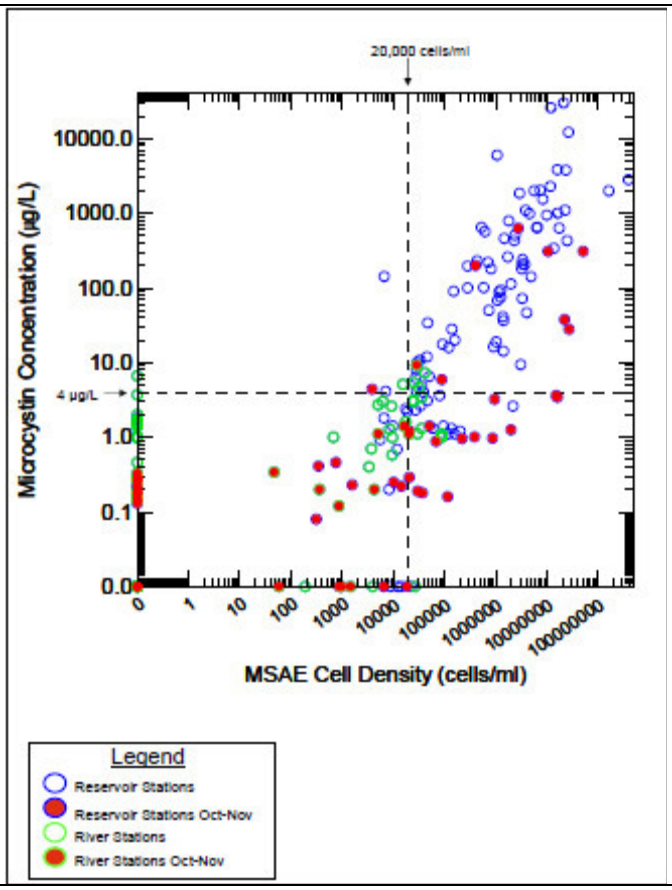


Figure 2.5: Relationship of *Microcystis aeruginosa* (MSAE) cell density and microcystin concentrations for stations along the Klamath river from above Copco to the lower estuary for the years 2006 and 2007 (Kann and Corum 2009). Data from Yurok Environmental Program, Karuk Natural Resources, and PacifiCorp.

The probability of exceeding three critical level microcystin concentrations at a *Microcystis aeruginosa* cell density level of 20,000 cells/mL can be computed from nonparametric cross-tabulation probability models developed for Iron Gate and Copco Reservoirs (Kann and Corum 2009). The probability plots from this analysis are illustrated in Figure 2.6 using microcystin concentrations of 4, 8, and 20 µg/L as critical values. These concentrations represent WHO health effects levels of low, moderate, and high respectively. The probability of microcystin exceeding the critical values of 4 µg/L (red), 8 µg/L (light blue), and 20 µg/L (green) at a *Microcystis aeruginosa* cell density of 20,000 cells/mL (dashed line) are approximately 47%, 8%, and 0% respectively. Therefore at a cell density target of 20,000 cells/mL there is less than a 50% probability that microcystin concentrations will exceed the low health effects threshold of 4 µg/L.

In addition to these numeric water quality targets, monitoring targets are also identified and included in the Monitoring Plan (Chapter 7) and in Chapter 5.

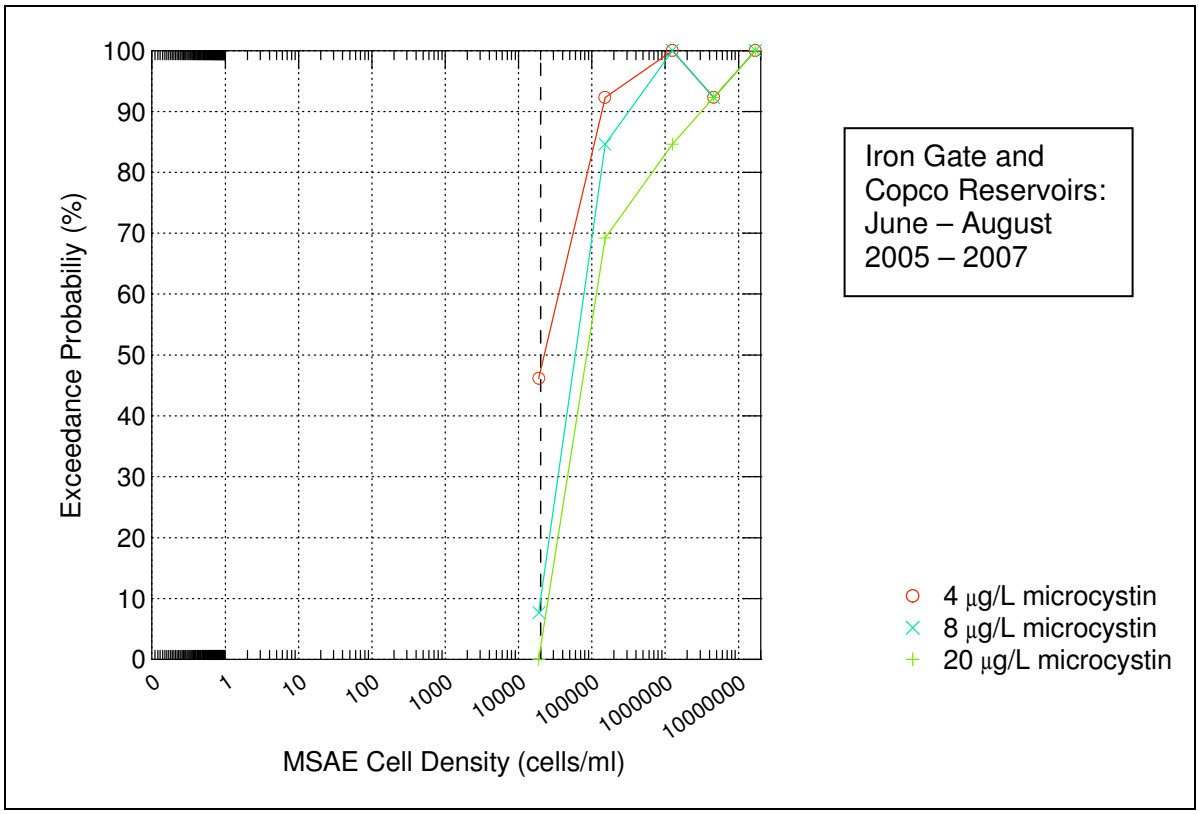


Figure 2.6: Microcystin exceedance probability plotted as a function of *Microcystis aeruginosa* cell density for Iron Gate and Copco Reservoirs using data collected by the Karuk Tribe of California Natural Resources Department and PacifiCorp for the years 2005, 2006, and 2007 during peak growing season (June – August).

2.4 Water Quality Conceptual Models Overview

There are numerous overlapping physical, chemical, and biological factors that are currently contributing to impairment of water quality standards in the Klamath River. The purpose of this section is to describe these factors and discuss how they are .contributing to impairment.

The challenge associated with the Klamath River TMDL problem statement is to develop a clear roadmap between the TMDL listing parameters of nutrients, temperature, and DO and their impacts on beneficial uses. There are several issues that must be addressed as part of this challenge. Nutrients and temperature often interact together and with other watershed factors to influence intermediate processes within the aquatic ecosystem that then impact ecological elements that are closely associated with Klamath River beneficial uses. With multiple factors impacting multiple ecosystem components, impacts on beneficial uses can be cumulative and involve effects from several different pathways. The Klamath River problem statement is based on the California Nutrient Numeric Endpoints (CA NNE) framework that incorporates an ecological risk assessment (ERA) process to clearly identify and evaluate impacts on beneficial uses from multiple concurrent stressors.

An ERA evaluates the likelihood that adverse ecological impacts may occur in response to one or more stressors. Keys to a successful ERA are identifying (1) the pathways by which stressors cause ecological effects and (2) informative and representative assessment endpoints. Assessment endpoints are the link between scientifically measurable endpoints and the objectives of stakeholders and resource managers (Suter 1993). Endpoints should be ecologically relevant, related to environmental management objectives, and susceptible to stressors (USEPA 1998). For the Klamath River problem statement evaluation, nutrients and temperature are the primary stressors and separate conceptual models have been developed for each. There are a total of thirty-three assessment endpoints included in the Klamath River nutrient conceptual model, and thirty-one assessment endpoints in the temperature conceptual model. The Klamath River problem statement evaluation includes DO as a secondary indicator in the pathway analysis. The management objectives for the Klamath River conceptual models are the beneficial uses designated to the Klamath River in the Basin Plan.

A supporting tool of the ERA process is development and evaluation of a conceptual model, and corresponding selection of assessment endpoints. A conceptual model is a graphical and narrative description of the physical, chemical and biological stressors within a system, their sources, and the pathways by which they are likely to impact multiple ecological resources (Suter 1999) and contribute to beneficial use impairment. The conceptual model is important because it links exposure characteristics such as water quality conditions with the ecological endpoints important for describing the beneficial uses.

Conceptual models consist of two general components (USEPA 1998): (1) a description of the hypothesized pathways between human activities (sources of stressors), stressors, and assessment endpoints; and (2) a diagram that illustrates the relationships between human activities, stressors, and direct and indirect ecological effects on assessment endpoints. The conceptual model consolidates available information on ecological resources, stressors, and effects, and describes, in narrative and graphical form, relationships among human activities, stressors, and the effects on valued ecological resources (Suter 1999). A conceptual model provides a visual representation for the cases where multiple stressors contribute to water quality problems. With the conceptual model, some attribute or related surrogate (termed an "indicator" in both the watershed approach [USEPA 1995] and the TMDL program) provides a measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality (USEPA 1999a).

2.4.1 Klamath River Nutrient and Temperature Conceptual Models

Figure 2.7 and Figure 2.8 present the nutrient and temperature conceptual models developed for the Klamath River TMDL problem statement. The components of the Klamath River nutrient and temperature conceptual models are described below.

- Driver/Stressor (A) – The primary risk element being evaluated (nutrients and temperature). There is one element, increased nutrient loading, included in this category for the nutrient conceptual model, and five elements in this category for the temperature conceptual model.

- Environmental Conditions (B) – Water quality processes directly impacted by the stressor. These conceptual model "elements" are linked to response/outcome ecosystem elements (e.g., fish populations) that are more directly linked to aspects of the beneficial use. Environmental Condition elements are secondary indicators, providing an intermediate measure (prior to primary impact) of beneficial use condition. There are 12 elements in this category for both the nutrient and the temperature conceptual models respectively.

- Risk Cofactors (C) – In the nutrient conceptual model, these are related conditions or stressors that affect how nutrients are processed in the ecosystem. The nutrient risk cofactors listed in category C can magnify or mitigate the negative impacts linked to nutrients as biostimulatory substances. In the temperature conceptual model, the risk cofactors are processes or factors which are affected by the environmental conditions (category B) caused by an altered natural temperature regime. There are eight nutrient risk cofactors and four temperature risk cofactors identified.

- Response/Outcome - Fish and Aquatic Life (D_a) – The elements included in Category D_a involve some measure of the health of the Klamath River fish populations and associated impacts to Native American culture and commercial and sport fishing. Other forms of aquatic life could be included in this category, but the cold water fish are considered most sensitive to water quality conditions resulting from increased nutrient loading and altered temperature regimes. There are 11 elements in this category for both the nutrient conceptual model and temperature conceptual models.

- Response/Outcome - Human Health and Aesthetics (D_b) – Beneficial uses linked to the human related assessment endpoints are included in category D_b. Risk related to close human contact or conditions that prohibit contact are potentially impacting long standing ceremonial practices of Tribes along the Klamath River and disruption of recreational activities. There are four assessment endpoints for this category.

- Beneficial Use Impairment (E) – Category E includes all of the beneficial uses that the Regional Water Board has determined to be impacted by water quality conditions in the Klamath River basin, and their restoration will be the primary focus of the TMDL implementation plan. There are 11 beneficial uses identified as impacted in the nutrient model and seven beneficial uses identified in the temperature conceptual model.

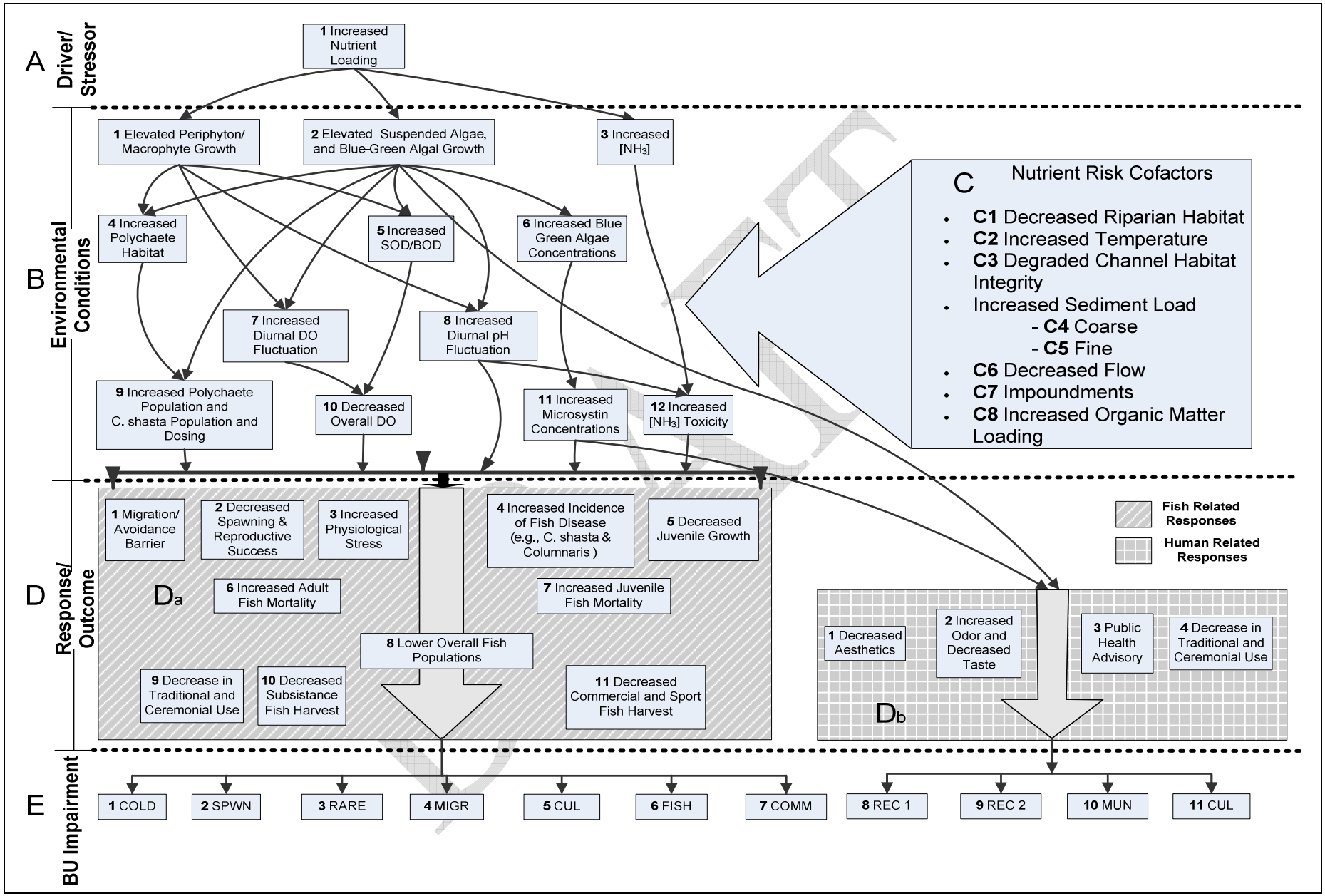


Figure 2.7: Nutrient Conceptual Model for the Klamath River in California

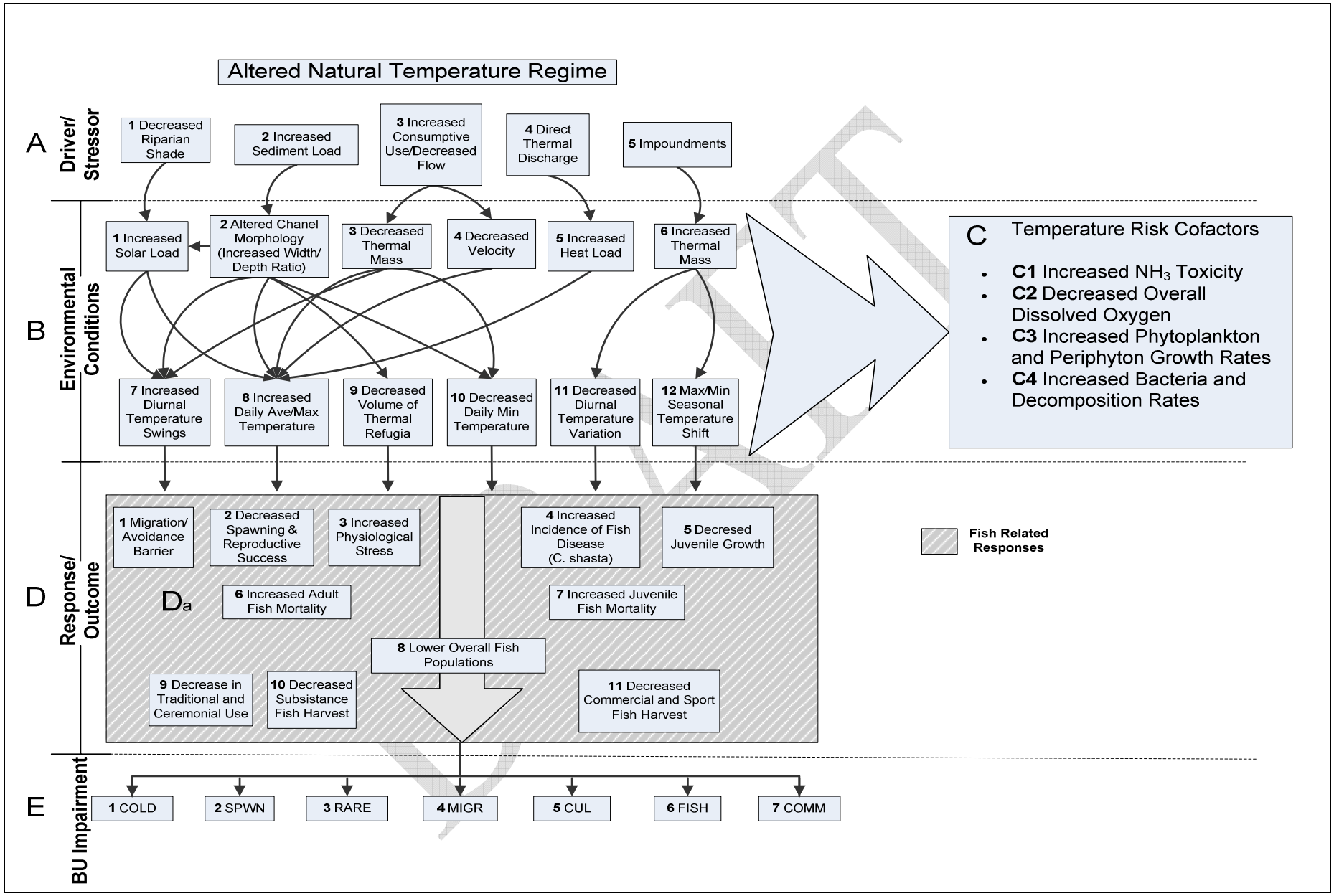


Figure 2.8: Temperature Conceptual Model for the Klamath River in California

It is not the purpose of the conceptual models developed for the Klamath River TMDL to provide a comprehensive description of all ecosystem elements and pathways. Rather the focus is on identifying assessment endpoints that either should be managed or measured as indicators of water quality condition for attaining and maintaining water quality standards in the Klamath River. The following sections describe the assessment endpoints and the linkages between the assessment endpoints that contribute to impairment of water quality standards in the Klamath River.

In the following sections, when components of the nutrient conceptual model are being discussed they will be referenced with the letter "N", and when the temperature conceptual model is being discussed it will be referenced with the letter "T". For example, a discussion related to the environmental condition of increased SOD/BOD from the nutrient conceptual model is referenced as "NB5", and a discussion of the environmental condition of increased solar loading in the temperature conceptual model is referenced as "TB1".

2.4.2 Nutrient Conceptual Model Environmental Conditions and Cofactors

The Klamath River prior to anthropogenic impacts was likely a highly productive ecosystem, in part driven by relatively high background loading of nutrients. More recently, anthropogenic impacts have resulted in increased levels of nutrient and organic loading and altered nutrient dynamics that have amplified the risk associated with **increased nutrient loading (NA1)** throughout the basin.

2.4.2.1 Nutrient Related Effects on Productivity

Increased nutrient loading (NA1) can result in increased primary productivity in waterbodies. Ecologically, an increase in primary production can increase the production of invertebrates and fish in streams (MacDonald et al. 1991). However, **elevated periphyton[13] and suspended algae growth (NB1, NB2)** result in high levels of algal biomass, and through algal respiration and photosynthesis can significantly **increase diurnal DO and pH swings (NB7, NB8)** and result in **decreased overall DO (NB10)** (Welch and Jacoby 2004). In their investigation of water quality conditions on the North Umpqua River, Anderson and Carpenter (1998, p.12) describe the process that occurs in rivers that have significant periphyton communities:

> Photosynthesis, a light driven process (Graham et al., 1982; Wooton and Power, 1993), consumes carbon dioxide (CO_2) and produces oxygen (Equation 1). Respiration by aquatic plants and animals, which occurs at all times, consumes oxygen and produces CO_2. Diel changes in pH are caused by shifts in the carbonate equilibrium (equation 2) as the algae utilize CO_2. (or bicarbonate, HCO3-) during photosynthesis (Wetzel, 1984) faster than atmosphere inputs can equilibrate. Streams with significant periphyton communities often have supersaturated DO

[13] For the purposes of the Klamath River TMDL Problem statement the term periphyton refers primarily to plants that are attached to the substrate (mainly benthic algae). However also included are heterotrophic organisms that are also attached to stream substrate such as bacteria and other benthic macroinvertebrates.

concentrations and high pH values late in the day and minimum DO and pH values in the early morning (for examples see Kuwabara, 1992 or Tanner and Anderson, 1996). However the solubility of DO is inversely proportional to the water temperature, which rises in response to solar radiation and thereby decreases DO solubility during daylight hours, and is also impacted by physical reaeration. In effect, stream temperature, reaeration, photosynthesis and respiration compete for control of DO and pH in streams.

Equation 1: $6CO_2 + 6H_2O \underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} C_6H_{12}O_6 + 6O_2$

Equation 2: $CO_2 + H_2O \longleftrightarrow HCO_3^- + H^+ \longleftrightarrow CO_3^{2-} + 2H^+$

The Klamath River has relatively low alkalinity (<100 mg/L) which means that it is a weakly buffered system that is susceptible to photosynthesis driven changes in pH. DO is incorporated into the Klamath River nutrient conceptual model as an assessment endpoint, and not included as a driver/stressor, because DO is an intermediate parameter that responds to the stressors. The actual concentration of DO in water depends not only on saturation concentration (temperature and barometric pressure dependent) but also on oxygen sinks and sources. Two of the primary oxygen sinks are **sediment oxygen demand (SOD) and biochemical oxygen demand (BOD) (NB5)** of substances in the water. When organic matter, such as periphyton and suspended algae, are broken down by microorganisms in the stream this process consumes oxygen and results in **decreased DO concentrations (NB10)**.

The pathways that have resulted in major documented fish mortalities in the Klamath River in the last several years ~~is~~ are illustrated as follows: **increased nutrient loading (NA1) → elevated periphyton/macrophyte growth (NB1)** and **elevated suspended algae and blue-green algal growth (NB2) → increased polychaete habitat (NB4) → increased polychaete population and *Ceratomyxa shasta (C. shasta)* population and dosing (NB9)**.

Ceratomyxa shasta (*C. shasta*) is thought to be indigenous to the Klamath River, and is the primary fish health issue in the Klamath River (Bartholomew et al. 2007). The lifecycle of *C. shasta* is complex because the parasite changes form and the lifecycle involves two hosts, a freshwater polychaete (worm) and a salmonid (Figure 2.9). One of the limiting factors for the presence of *C. shasta* appears to be the presence and abundance of the polychaete in the Klamath River (Bartholomew and Bjork 2007). Mat-forming epilithic algae (*Cladophora*) and sand embedded with fine benthic organic matter (FBOM) substrates are the primary microhabitats for the polychaete (Stocking and Bartholomew 2007).

In 2003 a study by Stocking and Bartholomew (2004) found the highest densities of the polychaete living in periphyton (commonly made up of *Cladophora*). Study results from

2006 at sites located between Iron Gate Dam and Interstate-5 in California revealed that polychaete populations at habitat locations identified in 2004 and 2005 were not present in 2006, or were present in numbers too low to be considered significant (Stocking and Bartholomew 2007). According to Stocking and Bartholomew (2007), the substrate at these locations was new in 2006 and devoid of periphyton (*Cladophora)*, most likely due to scour caused by winter flushing flows. It appears that the lack of available habitat for the polychaete in 2006 led to their absence from these locations in the Klamath River.

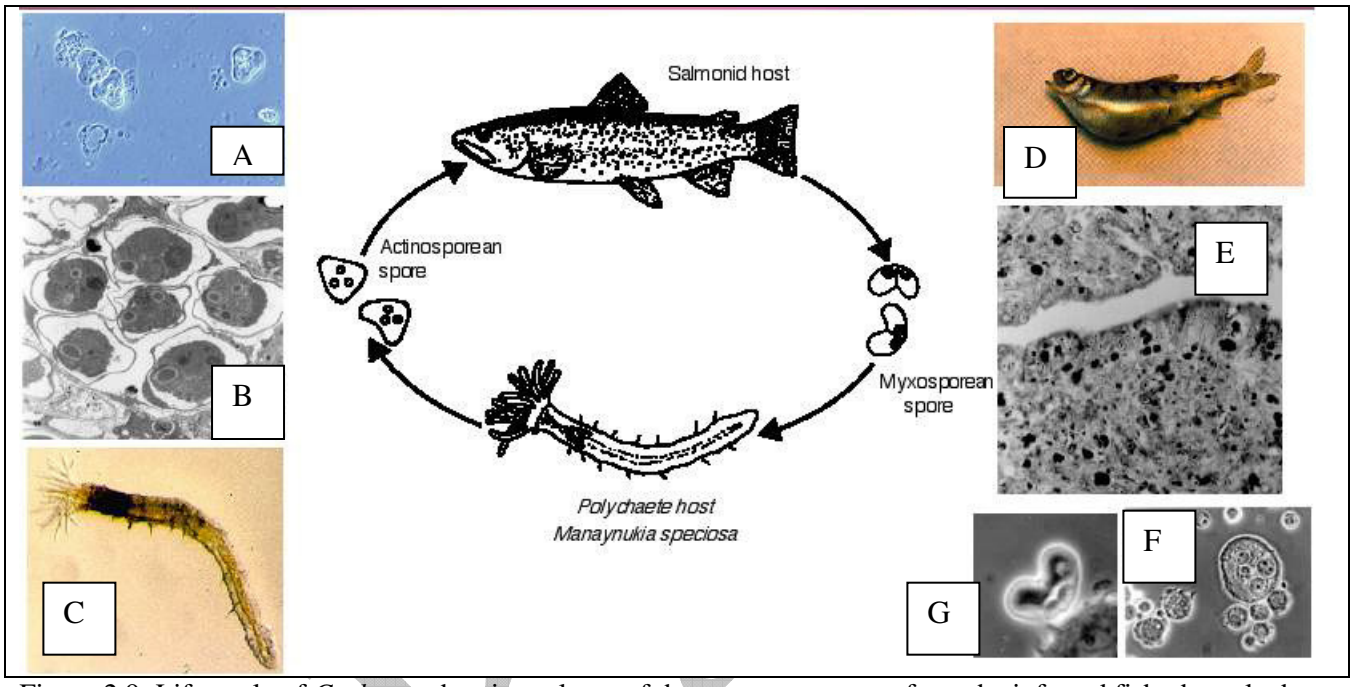


Figure 2.9: Life cycle of *C. shasta* showing release of the myxospore stage from the infected fish, the polychaete alternate host, and release of the alternate actinospore stage from the polychaete. A: released actinospores, B: electron micrograph of actinospores in the polychaete, C: polychaete, D: infected fish, E: histological section of infected intestine, F: trophozoite stages, G: myxopsore
Source: Bartholomew et al. 1997 as cited by Stocking and Bartholomew 2004

Studies have found that the primary habitat of the polychaete also includes sand embedded with fine benthic organic matter (FBOM) (Stocking 2006). FBOM is derived from the breakdown products of particulate organic matter, including periphyton and suspended algae.

Based on the above information there may be a linkage between the proliferation of *C. shasta* in the mainstem Klamath River and elevated nutrient concentrations. **Elevated nutrient concentrations (NA)** result in **increased periphyton (NB1) and increased suspended algae and blue-green algal growth (NB2)** in the river, which have been identified as prime habitat for the polychaete. **Increased habitat (NB4)** leads to an **increased abundance of the polychaete (NB9)**, which in turn leads to a high infectious spore load in the river. This results in a high probability that adult and juvenile salmonids migrating and rearing in the river will be infected by *C. shasta*.

An additional factor that is potentially shifting the balance toward increased parasite concentrations is the **elevated suspended algae and blue-green algal growth (NB2)** in Iron Gate Reservoir, which contributes to **increased polychaete populations (NB9)** in the mainstem Klamath River below the reservoir. The polychaetes are filter feeders and feed on fine organic detritus, as well as various forms of suspended algae and most preferably diatoms. **Elevated nutrient loading (NA)** leads to prolific amounts of diatoms and other suspended algae growth in the reservoir. The diatoms get released into the Klamath River as water flows out of Iron Gate Dam, thus creating an abundant food source for the polychaete, which may contribute to increasing their numbers (USFWS 2006).

Figure 2.10 was presented at the 2008 Klamath River Fish Health Conference to illustrate how the balance between parasite, hosts, and the environment has shifted to favor the increased abundance of parasites. There is an emerging consensus among those conducting research on these relationships in the Klamath River basin that the changes in the environmental conditions identified in the nutrient conceptual model, in association with other risk cofactors, provides a reasonable explanation of the shift to an increasing abundance of parasites (and spores) and higher levels of infection among salmonids in the Klamath River.

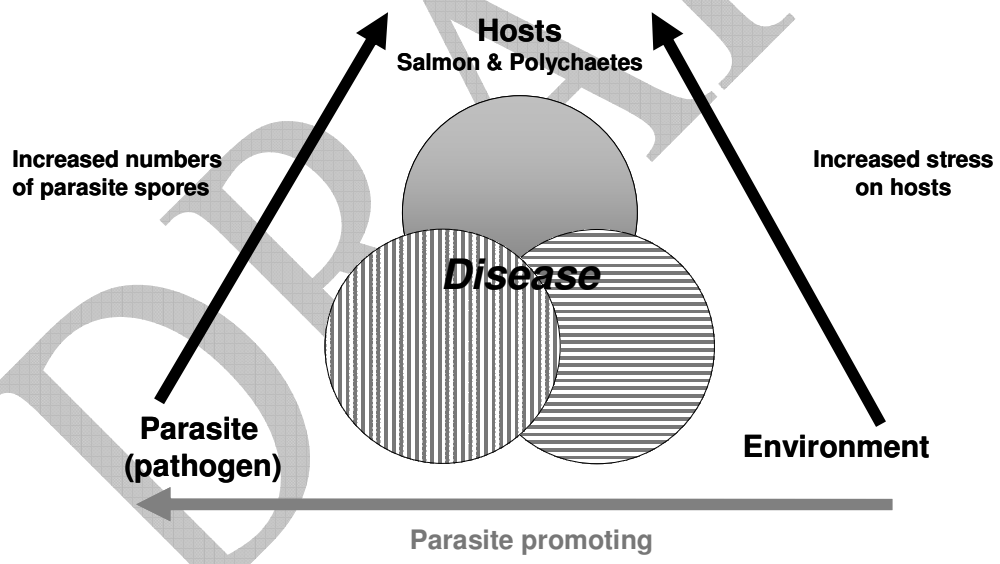


Figure 2.10: Severity of *Ceratomyxosis* in Klamath River suggests a shift in the host/parasite balance towards *C. shasta*
Source: Bartholomew personal communication 2008

The increase in the prevalence of parasite infection and related mortality is a very complex issue and it is likely that other environmental factors are also contributing to the proliferation of *C. shasta*. For example, the existing near-constant summer flow regime has not only reduced the frequency of periodic scouring flows, but has also eliminated extreme low flows which could cause the desiccation of the periphyton and resident polychaete populations. An example of the parasite promoting factors included in the

conceptual model above is that high densities of salmonids trapped in the reach below Iron Gate leads to increased shedding of the myxosporean spore which then infects the polychaete population in the dense periphyton present downstream of the dam. While these potential factors are not addressed explicitly in the conceptual model, they should be included in any comprehensive assessment and mitigation plan to address this issue.

The Klamath River basin has also been subject to **excessive suspended algae and blue-green algae growth (NB2)**. Blue-green algae grow and thrive in slow-moving to stagnant waterbodies such as ponds, lakes, and low gradient river reaches that usually have high nutrient loads accompanied by adequate sunlight. These conditions are found in Copco and Iron Gate Reservoirs, coupled with elevated nutrient concentrations, which promote nuisance **blooms of blue-green algae (NB6)**; the most common are *Microcystis aeruginosa*, *Anabaena flos-aquae, Anabaena flos-aquae,* and *Gleotricia echinulata*.

All four of these species are capable of producing cyanotoxins; however, the strain of *Aphanizomenon flos-aquae* found in Upper Klamath Lake, and subsequently transported downstream to the Klamath River, has not yet been shown to produce any toxins (Carmichael et al. 2000; Li et al. 2000). Cyanotoxins produced by these blue-green algae include dermatotoxins (cause contact dermatitis and stomach-intestinal disorders), neurotoxins (cause nervous system poisoning), and hepatotoxins (cause liver poisoning) (WHO 1999, p. 57). **Microcystin (NB11)** is a hepatotoxin produced by *Microcystis aeruginosa*, which has been measured in Copco and Iron Gate and detected in slow moving portions of the river downstream of Iron Gate dam, as well as in Klamath River fish tissue (Fetcho 2006, Kann 2006).

2.4.2.2 Nutrient Related Effects on Ammonia Toxicity

Nutrient loading to a waterbody can contribute directly to **increased ammonia concentrations (NB12)** through the addition of nitrogen to the system. The pH of the water column influences the concentration of un-ionized ammonia (NH_3) and ammonium ion (NH_4^+). As pH increases, un-ionized ammonia concentrations increase and ammonium ion concentrations decrease. These speciation relationships are important to ammonia toxicity because un-ionized ammonia is much more toxic to aquatic species than ammonium ion (USEPA 1999b). The **increased diurnal pH (NB8)** swings result in higher pH levels in the water column, and can result in **increased ammonia toxicity (NB12)**. The analysis of the potential for ammonia toxicity in the Klamath River is described below in Section 2.5.7.

2.4.2.3 Nutrient Risk Cofactors

Generally, nutrient concentrations alone do not impair beneficial uses. Rather, in combination with other factors nutrients cause indirect impacts through aquatic plant growth, low DO, high pH, and other related impacts. Nutrients are one factor in the impairment equation that must be present with other risk cofactors to express an impairment. Each of these risk cofactors contribute to the degraded conditions that exist in the Klamath River basin today. Any watershed scale recovery plan must address the potential effect of the following nutrient risk cofactors:

- Reduced riparian habitat (NC1) and associated reductions in shading by vegetation increases the amount of sunlight that reaches the stream that can drive photosynthesis of both suspended algae and periphyton. The increased solar radiation also causes **increased temperature (NC2)** of the water column which reduces oxygen saturation potential, and accelerates SOD and BOD processes. Also, reduced riparian habitat can impede riparian functions such as filtering and uptake of pollutants in runoff. These conditions are often associated with **degraded streambank and stream channel conditions (NC3).**

- Degraded Channel Habitat Integrity (NC3) through sediment filling, incidental anthropogenic channel disturbance (e.g., grazing), channelization, or diking repairs can impair natural river processes that retain or remove permanently from the water column nutrients through denitrification, growth of attached algae, and the settling of organic matter. The result of these types of impacts in the upper Klamath River basin is higher downstream nutrient loading than would have occurred historically. Bernot and Dodds (2005) describe several restoration techniques for reversion to historical channel sinuosity, channel complexity, and connectivity to riparian wetlands with the objective of restoring nitrogen retention and removal characteristics.

- Increased sediment load (NC4, NC5) includes both the fine and coarse components that can originate from different sources (roads versus mass wasting debris flow), but both have similar impacts on the stream ecosystem. Increased sediment load can result in stream channel aggradation, filling in pools and deeper portions of the stream channel (i.e., thalweg), creating a shallow concave channel cross-section that facilitates accelerated growth rates of periphyton and suspended algae. The transport of sediment into the water column is also a primary mechanism for nutrient loading.

- Altered flow conditions (NC6) covers a wide range of flow impacts including: reduced flow that is more susceptible to high temperature drivers; persistent flow during normally dry conditions which can promote excessive macrophyte and algal growth; reduced scouring flows that can increase periphyton accrual time; and reduced flows can lead to increased rate of deposition of sediment and organic matter in the stream channel.

- Impoundments (NC7) are a significant nutrient risk cofactor because of multiple potential linkages:
    - Empirical data and model predictions indicate that the Copco and Iron Gate impoundments have a small net retention of nutrients, but they play a role in changing the form and timing of nutrients delivered downstream, which may contribute to late season periphyton growth. In addition, under anoxic conditions (i.e., in bottom waters during summer stratification) nutrients delivered to the reservoirs in an organic particulate form can be converted to a dissolved inorganic form that is readily available for algal uptake (Welch and Jacoby 2004). There is

also an ongoing evaluation of whether reservoirs or free flowing river reaches have a higher nutrient retention/assimilative capacity as discussed in Appendix 2, *Nutrient Dynamics in the Klamath River* (Butcher 2008). Due to incomplete year round monitoring it is not currently possible to perform the nutrient mass-balance analyses required to address this issue with an adequate level of certainty.

- Impoundments create an environment that is more favorable to nuisance blooms of both green and blue-green algae (Kann and Asarian 2005; (Wetzel 2001).
- As described in section 2.4.2.1, recent studies have resulted in the hypothesis that the high density of the polychaetes below Iron Gate Reservoir (which in turn supports high densities of the parasite *C. shasta*) may be attributed to altered habitat conditions (i.e., dense communities of macroalgae) and waters rich in preferred algal species (diatoms) for the filter feeding polychaetes (Stocking and Bartholomew 2007).
- Dams typically halt the downstream transport of gravel, resulting in more coarse substrates (Biggs 2000). The Klamath Hydroelectric Project has had this effect on the Klamath River below Iron Gate Dam (FERC 2007). Larger substrates like cobble and boulder require higher flows to scour them than smaller substrates like gravel and sand. These coarse substrates are more stable, increasing the amount of periphyton and aquatic macrophytes that can grow (Biggs, 2000; Anderson and Carpenter 1998).

- Increased Organic Matter Loading (NC8) is a risk cofactor in a direct manner by contributing additional nutrients to the Klamath system and by exacerbating stressful DO conditions through SOD and BOD. The increased loading of organic matter is also a risk cofactor in a less direct manner due to its contribution to the formation of anoxic conditions that will alter nutrient dynamics increasing the abundance of dissolved inorganic nutrients contributing to increased algal productivity.

2.4.3 Temperature Conceptual Model Environmental Conditions and Cofactors

2.4.3.1 Thermal Processes Related to Solar Loading

Direct solar radiation is the primary factor influencing stream temperatures in summer months. The energy added to a stream from solar radiation far outweighs the energy lost or gained from evaporation or convection (Beschta et al. 1987; Johnson 2004; Sinokrot and Stefan 1993). At a given location, incoming solar radiation is a function of position of the sun, which in turn is determined by latitude, day of the year, and time of day. During the summer months, when solar radiation levels are highest and streamflows are low, shade from streamside forests and vegetation can be a significant control on direct solar radiation reaching streams (Beschta et al. 1987). Because shade limits the amount of direct solar radiation reaching the water, it provides a direct control on the amount of heat energy the water receives. At a workshop convened by the state of Oregon's

Independent Multidisciplinary Science Team, 21 scientists reached consensus that solar radiation is the principal energy source that causes stream heating (Independent Multidisciplinary Science Team 2000).

Shade is created by vegetation and topography; however, vegetation typically provides more shade than topography. The shade provided to a water body by vegetation, especially riparian vegetation, has a dramatic, beneficial effect on stream temperatures. The removal of vegetation **decreases shade (τA1)**, which **increases solar radiation levels (τB1)**, which, in turn, **increases both average and maximum stream temperatures (τB8)**, and leads to **large daily temperature variations (τB7)**. Additionally, the removal of vegetation increases ambient air temperatures, can result in bank erosion, and can result in changes to the channel geometry to a wider and shallower stream channel, all of which also increase water temperatures.

2.4.3.2 Thermal Processes Related to Sediment Load

Increased sediment loads (τA2) and associated changes in channel morphology can affect stream temperature conditions in multiple ways. These effects can manifest at both large (watershed-wide) and small (individual reach) scales. Sediment is defined as any inorganic or organic earthen material, including but not limited to: soil, silt, sand, clay, and rock (Regional Water Board 2007). The sizes of sediment that present a temperature concern are those that may result in pool filling, increased width, decreased depth, and/or a reduction of intergravel flow.

Increases in sediment loads may lead to a **wider and shallower wetted channel (τB2)**. In a study of stream channel geometry at twelve gauging stations throughout northwest California, Lisle (1982) described channel widths increasing by as much as one hundred percent, bars becoming smaller, and pools filling in response to increases in sediment supply. Channel widening associated with increased sediment loads can also result in the destruction of riparian canopy and consequent increases in solar loading.

A wider and shallower channel gains and loses heat more readily than a narrow and deep channel. This principal is true for any stream. A stream's width-to-depth ratio influences stream heating processes by determining the relative proportion of the wetted perimeter in contact with the atmosphere versus the streambed. Also, wide and shallow channels have a greater surface area per unit of volume than a narrower, deeper channel. Water in contact with the streambed exchanges heat via conduction. Conductive heat exchange with the streambed has a moderating influence, reducing daily temperature fluctuations. Water in contact with the atmosphere exchanges heat via evaporation, convection, solar radiation, and long-wave radiation. Heat exchange from solar radiation far outweighs heat exchange from evaporation, convection, and long-wave radiation, unless the stream is significantly shaded. The net effect of changes in width-to-depth ratios is that streams that are wider and shallower heat and cool faster than streams that are narrower and deeper (Poole and Berman 2001).

The effects of a wider and shallower channel are similar to the effects of increased solar loading. Both changes lead **to increases in daily average and maximum temperatures**

(τB8), **increase diurnal fluctuations (τB7)**, and may **decrease daily minimum temperatures (τB10).**

Morphological changes associated with increased sediment loads can also eliminate or result in a **decreased volume of thermal refugia (τB9)** in a stream or river and impede access to thermal refugia provided by tributaries. Refugial volume can be reduced or eliminated when deep pools fill with sediment, when side channels are buried, or when cold tributary flows percolate into aggraded tributary deltas or gravel bars before entering the river. Similarly, access to refugial tributaries can be reduced or eliminated when sediment loads result in aggradation and cause a tributary to percolate before entering the mainstem or become too shallow for fish to swim. Aggradation has impacted the mouths of Hunter, Terwar, Independence, Walker, Oneil, Portuguese and Grider Creeks, as well as 14 of 17 small Lower Klamath tributaries surveyed by the Yurok Tribe (De La Fuente and Elder 1998; Kier Associates 1999). Finally, refugia can be eliminated when tributary temperatures increase beyond salmonid thresholds due to the effects of increased sediment loads.

Increased sediment loads may also reduce heat exchange associated with hyporheic processes through simplification of the bed topography and reduced permeability due to increases in fine sediment deposition. Several published studies describe effects of sediment on stream channel morphology and stream channel characteristics related to thermal refugia. Vaux (1968) demonstrated that hyporheic exchange is dependent on the topographic complexity of the bed surface and permeability of the sediments. Wondzell and Swanson (1999) similarly demonstrated that simplification of stream channel geometry decreases intra-gravel exchange rates and suggested that loss of pool-step sequences related to channel disturbances could result in decreased intra-gravel exchange.

The complexity of the streambed (e.g. side channels, deep pools, topographic relief) can also influence stream heating processes by affecting the amount of intra-gravel flow, and can lead to the existence of pockets of cold water through stratification of deep pools and hyporheic-fed side channels. Stream channels with greater complexity have deeper pools, more prominent riffles, and back-watered side-channels. The amount of water passing through the gravels of a stream bed is proportional to the elevation change from the point the water enters the gravel to the point it leaves the gravel. Thus, streams with prominent pool-riffle morphology exchange more heat via conduction than flat, simplified stream channels.

2.4.3.3 Thermal Processes Related to Flow

Surface water diversions (τA3) decrease the volume of water in the stream, and thereby decrease a stream's capacity to assimilate heat. When water is removed from a stream the **thermal mass (τB3)** and **velocity (τB4)** of the water is decreased. Thermal mass refers to the ability of a body to resist changes in temperature. Basically, less water heats or cools faster than more water. Decreases in velocity increase the time required to travel a given distance, and thus increases the time heating and cooling processes can act on the water. These principles are true for any stream.

The increase in the rate of heating that accompanies a decrease in the volume of flow in a stream can have significant temperature effects. A decrease in thermal mass results in **higher daily high and lower daily low temperatures (тB7, тB8, тB10)**, as well as **higher daily average temperatures (тB8)**. Reduced velocities also result in **higher daily average temperatures (тB8)**.

2.4.3.4 Thermal Processes Related to Direct Thermal Discharges

Direct thermal discharge (тA4) is the discrete addition of heat to a waterbody. Direct thermal discharges occur when water is used in a cooling process, such as in power generation or industrial settings, or when warm materials are placed in a waterbody. In the Klamath basin the main source of direct thermal discharges is related to irrigation tailwater return flows.

Flood irrigation is a common irrigation practice in parts of the Klamath basin, including the Klamath Project area and the Shasta River watershed. When irrigation water is applied to a field in this manner, it generally flows across the field as a thin sheet or in shallow rivulets. As the irrigation water runs across the ground it absorbs heat. When irrigation flows return to a stream, they carry with them the **increased heat load (тB5)** added as they pass through the irrigated lands. Regional Water Board staff deployed temperature monitoring devices at several Shasta Valley locations with irrigation return flows. Upon review of the monitoring results, it was very difficult to determine when the temperature monitoring probes were exposed to irrigation return flow versus when they were exposed to the air, indicating that the temperature of the tailwater return flows were generally at equilibrium with the air temperature.
The net effect of direct thermal discharges is an **increase in both daily average and maximum temperatures (тB8)**.

2.4.3.5 Thermal Processes Related to Impoundments

The water stored behind a **dam (тA5)** functions as **thermal mass (тB6)**, storing heat. Because larger volumes of water heat and cool slower than smaller volumes, the large volume of water behind an impoundment acts as a temperature buffer, **reducing daily temperature variations downstream (тB11)**. Similarly, large volumes of water resist **seasonal changes in temperature (тB12)**, and thus delay seasonal temperature changes, resulting in colder temperatures in the spring and warmer temperatures in the fall. In the Klamath River, these effects may extend downstream to the Pacific Ocean under certain conditions (Bartholow et al. 2005). The effects are most pronounced immediately downstream of Iron Gate Dam, diminishing in the downstream direction.

The expected biological implications of the changes in diurnal temperature patterns caused by dams are mixed. The **decreased diurnal temperature variation (тB11)** associated with dams lead to reduced peak temperatures, thereby reducing the most acutely harmful temperatures. Conversely, the increased daily low temperatures associated with dams could reduce the time available for fish to leave thermal refugia to feed. Also, higher daily low temperatures may lead to higher temperatures at the bottom of thermally stratified pools (Nielsen et al. 1994).

The **seasonal temperature changes (τB12)** caused by the dams may also have biological implications. Bartholow et al. (2005) evaluated the thermal effects of the Klamath River dams on downstream reaches and determined that the dams delay the seasonal temperature patterns by approximately 18 days on an annual basis. The physical implication of an 18 day shift in the seasonal temperature pattern is that the river is cooler in the springtime when juvenile salmonids are migrating to the ocean, and warmer in the fall when adults are migrating upstream and spawning, and eggs are incubating in the gravels. Cooler temperatures are known to reduce juvenile salmonid growth rates; however this effect may be mitigated by the benefit gained by reduced incidence of stressfully high temperatures during outmigration. Warmer temperatures in the summer period may reduce the nocturnal feeding opportunities of juvenile salmonids that persist at thermal refugia, thereby reducing their ability to withstand stressfully high daytime temperatures (National Research Council of the National Academies [NRC] 2004). Warmer temperatures in the fall may delay adult migration or lead to stressfully high temperatures when adults are present or eggs are incubating in gravels. More discussion of this topic can be found in Section 2.5.2.1.

2.4.3.6 Temperature Risk Cofactors

Adverse temperature conditions may combine with other factors to further impair beneficial uses beyond the primary effects of high temperatures. Temperature is a physical factor that affects chemical concentrations and biological growth rates of other factors that affect habitat and water quality. These factors are described below. Each of these risk cofactors contribute to the degraded conditions that exist in the Klamath River basin today. Any watershed scale recovery plan must address the potential effect of the following temperature risk cofactors:

- Increased NH_3 Toxicity (τC1) – The concentration of un-ionized ammonia (NH_3) in water increases with higher temperature, higher pH, and higher concentration of ionized ammonia (NH_4^+). In waterbodies that have high concentrations of ionized ammonia and frequent excursions of high pH, such as the Klamath River, an increase in temperature can result in the formation of un-ionized ammonia, which is toxic to fish and other organisms.

- Decreased Overall Dissolved Oxygen (τC2) – The concentration of DO in water is partly a function of the temperature of the water. Colder water can absorb more DO than warm water, if all other factors are equal. Higher temperatures reduce the DO saturation concentration, increasing the risk that other factors that cause a decrease in DO will result in concentrations less than the criteria concentrations needed to support beneficial uses.

- Increased Suspended algae and Periphyton Growth Rates (τC3) – Algal growth rate is partially dependent on the temperature at which they grow. Generally, higher temperatures result in higher rates of growth (up to a limiting temperature), if all other factors are equal.

- Increased Bacteria and Decomposition Rates ($_{T}C4$) – The rate at which bacteria grow and decay is partially dependent on the temperature of the water they are in. Higher temperatures result in higher rates of growth and decay, if all other factors are equal, resulting in greater oxygen demand within the surrounding water column.

2.4.4 Responses/Outcomes

The driver/stressors and environmental conditions discussed in the previous sections have resulted in the response/outcomes identified in Section D of the Nutrient and Temperature Conceptual Models. Many of these have been well documented and are discussed in the following sections, which describes impacts to Klamath River beneficial uses. The current conditions of many of the indicators described in this section will be presented in Section 2.5 to better assess their actual impact on beneficial uses within the Klamath River basin. Additional information on the effects of an altered natural temperature regime and the secondary effects of elevated nutrient levels on salmonids is available in Appendix 3, *Effects of Temperature, Dissolved Oxygen/Total Dissolved Gas, Ammonia, and pH on Salmonids* (Carter 2008).

2.4.4.1 Migration/Avoidance Barrier (D_a1)

High water temperatures can inhibit or block upstream migration of adult salmonids. One study specific to the Klamath River was conducted by Strange (2007) and evaluated the association between water temperature in the mainstem Klamath River and adult fall Chinook migration. Utilizing radio telemetry to track the movements and monitor the internal body temperatures of adult fall Chinook salmon during their upriver spawning migration in the Klamath basin, Strange (2007) found that fall Chinook will not migrate upstream when mean daily temperatures are $\geq$22°C. Strange also noted that adult fall Chinook in the Klamath basin will not migrate upstream if temperatures are 21°C or above and rising, but will migrate at temperatures as high as 23°C if temperatures are rapidly falling.

The upstream migration by adult salmonids is typically a stressful endeavor. Sustained swimming over long distances requires high expenditures of energy and therefore requires adequate levels of DO. Migrating adult Chinook salmon in the San Joaquin River exhibited an avoidance response when DO was below 4.2 mg/L, and most Chinook waited to migrate until DO levels were at 5 mg/L or higher (Hallock et al. 1970). The swimming performance of migrating salmonids is also impacted by reduced concentrations of DO (Bjornn and Reiser 1991).

2.4.4.2 Decreased Spawning and Reproductive Success (D_a2)

There is evidence that fish that oversummer in stressfully high temperatures and low DO concentrations experience reduced reproductive success (Coutant 1987). A study by Coutant (1987) demonstrates that fish experiencing the combination of high temperatures and low DO are subject to physiological harm that persists well after the fish are exposed to these water quality conditions. Persistent effects of high temperature and low DO include a reduction in female spawning success and poor embryo survival.

2.4.4.3 Increased Physiological Stress (D_a3)
Increased temperature and the secondary effects of nutrient loading can result in physiological stress on salmonids. The metabolic processes of salmonids are directly related to temperature. When water temperatures are above the optimal metabolic range for salmonids, the resting metabolic rate increases dramatically. This results in reduced feeding rates, swimming speed, growth, reproduction, and resistance to environmental extremes (USEPA 2001, p.39). Also, if temperatures are high, much of the energy assimilated from food is lost as excessive metabolism (USEPA 2001, p.85). High incubation temperatures may create a metabolic energy deficit for pre-emergent salmon that increases mortality (Heming 1982, as cited by USEPA 2001, p.31). Further, the stressful impacts of water temperatures on salmonids are cumulative and positively correlated to the duration and severity of exposure. The longer the salmonid is exposed to thermal stress, the less chance it has for long-term survival (Ligon et al. 1999).

As the metabolic rates of salmonids increase there is an increased physiologic demand for oxygen. Low DO concentrations (<4-5 mg/L) result in decreased size of newly hatched salmonids (WDOE 2002a, p.14), as well as decreased juvenile salmonid growth and food consumption (Bjornn and Reiser 1999, p.118; Herrmann et al. 1962; and USEPA 1986, p.5-8), and decreased food conversion efficiency (ODEQ 1995, p.A-6). When DO levels are extremely low (2-3 mg/L) weight loss can occur due to decreased food consumption (Herrmann et al. 1962). Low DO concentrations also adversely affect swimming performance in both adult and juvenile salmonids (Bjornn and Reiser 1999, p.85, 118, 119; WDOE 2002a, p.46).

Concentrations of ammonia acutely toxic to fishes may cause loss of equilibrium, hyperexcitability, increased breathing, cardiac output and oxygen uptake, and, in extreme cases, convulsions, coma, and death. At lower concentrations ammonia has many effects on fishes, including a reduction in hatching success, reduction in growth rate and morphological development, and pathologic changes in tissues of gills, livers, and kidneys (USEPA 1986, p.17).

The pH of freshwater streams, lakes, and reservoirs is also important for adult and juvenile salmonid development, and is influenced by the respiration of benthic algae and suspended algae. Chronic effects from low pH can occur at levels that are not toxic to adult fish but that impair reproduction including altered spawning behavior, reduced egg viability, decreased hatchability, and reduced survival during early life stages when salmonid development is most vulnerable to low pH (Jordahl and Benson 1987). Chronic high pH levels in freshwater streams can decrease activity levels of salmonids, create stress responses, decrease or cease feeding, and lead to a loss of equilibrium (Murray and Ziebell 1984; Wagner et al. 1997). Additionally, high temperatures can exacerbate the effects of high pH levels on salmonids, and if pH reaches extremely low or high levels, death can occur (Wagner et al. 1997).

2.4.4.4 Increased Incidence of Fish Disease (*Ceratomyxa shasta* and Columnaris) (D_a4)
The USFWS California-Nevada Fish Health Center has identified *C. shasta* as the primary fish health issue in the Klamath River, and Columnaris is the second biggest fish

health threat (Foott 2005). Disease has been cited as the ultimate cause of death in most of the adult and juvenile fish kills which have occurred in the Klamath River from Iron Gate Dam to the mouth (CDFG 2000; CDFG 2004; Deas 2000; Engbring 2004; Foott 2000; Foott et al. 2002; Hannum 1997; Hendrickson 1997; KFHAT 2005; Klamt and Carter 2004; USFWS 1997; USFWS 2003a; USFWS 2003b; Williamson and Foott 1998). On more than one occasion the outbreak of disease was termed an "epizootic" (the equivalent of an epidemic in humans), and in all cases the disease outbreaks were exacerbated by a combination of poor water quality conditions including high water temperatures, low DO levels, sediment deposition, and high ammonia concentrations (CDFG 2000; CDFG 2004; Deas 2000; Engbring 2004; Foott 2000; Foott et al. 2002; Foott 2005; Hannum 1997; Hendrickson 1997; KFHAT 2005; Klamt and Carter 2004; USFWS 1997; USFWS 2003a; USFWS 2003b; Williamson and Foott 1998).

The USEPA (2003) and Washington Department of Ecology (WDOE 2002b, p.115) report that as water temperatures increase, the risk and severity of a disease outbreak increases. The infectivity of *C. shasta* and Columnaris increases with increasing temperature, and the lifecycle of these diseases shorten with increasing temperature, making outbreaks more likely. WDOE (2002b) expresses the temperature thresholds that are likely to prevent or exacerbate disease outbreaks as a Maximum Weekly Maximum Temperature (MWMT), which is the maximum seasonal or yearly value of the daily maximum temperatures over a running seven-day consecutive period. The Washington Department of Ecology (WDOE 2002b, p.115) conducted a review of studies on disease outbreak in salmonids and estimate that a MWMT of less than or equal to 14.4°C (midpoint of 12.6-16.2 range) will virtually prevent warm water disease effects. According to WDOE (2002b, p.115), to avoid serious rates of infection and mortality the MWMT should not exceed 17.4°C (midpoint of 15.6-19.2 range), and that severe infections and catastrophic outbreaks become a serious concern when the MWMTs exceed 21.0°C (midpoint of 18.6-23.2 range). In a summary of temperature considerations, USEPA (2003) state that disease risks for juvenile rearing and adult migration are minimized at temperatures from 12°C to13°C, elevated from 14°C to 17°C, and high at temperatures from 18°C to 20°C. Additionally, the crowding of salmonids in thermal refugia increases the likelihood of fish-to-fish transmission of Columnaris.

When the infectious spore load of *C. shasta* in the Klamath River is low or juvenile salmonids are exposed for less than 24 hours, they can successfully rear at temperatures as high as 21°C (Foott 2006). However, if the infectious spore load in the river is high or juvenile salmonids are exposed for long periods of time (2-4 days), mortality occurs at temperatures as low as 16°C (Foott 2006).

As discussed in Section 2.4.2.1 there may be a linkage between the proliferation of *C. shasta* in the mainstem Klamath River and elevated nutrient concentrations. Elevated levels of nutrients and organic matter allow for the proliferation of prime polychaete habitat (periphyton and pockets of fine benthic organic matter) and thus large numbers of polychaetes and high infectious spore load in the river. This can lead to an increased probability of *C. shasta* infections.

2.4.4.5 Decreased Juvenile Growth (D_a5)
Low dissolved oxygen levels and elevated temperatures can result in decreased juvenile fish growth, including salmonids.

> Hutchins (1973 [as cited by WDOE 2002a]) reported that at 15°C growth of juvenile coho salmon fed to repletion and held at velocities between 1.2 and 3.6 l/sec (lengths per second) at an oxygen level of 3 mg/L for 10 to 12 days was reduced by 20 and 65 percent from that of a control salmon held at respective velocities in air-saturated water (9.5 mg/L). At the intermediate oxygen concentration of 5 mg/L, growth rates of salmon were reportedly reduced by 0 and 15 percent over controls, respectively.
>
> Herrmann et al. (1962 [as cited by WDOE 2002a]) found that juvenile coho salmon (age class 0) held at 20°C and fed to repletion twice daily experienced declines in growth with reduction of oxygen from a mean of about 8.3 to 6 and 5 mg/L, and declined more sharply with further reduction of oxygen concentration, suggesting further that concentrations near 4 or 5 mg/L can be exceedingly detrimental. The authors estimated a reduction of both percent weight gain and the rate of food consumption by about 11 percent with reduction of oxygen concentration from 8.3 to 5.0 mg/L, and by at least twice as much with reduction of oxygen concentration to 4 mg/L.

Elevated water temperature has a detrimental effect on juvenile salmonid growth. Banks et al. (1971 as cited by WDOE 2002b) found that growth was similar at 15.6°C and 18.3°C, however temperatures above 19°C were associated with reduced feeding and growth, as well as increased problems with disease. Marine and Cech (2004) found that growth was substantially reduced at 21-24°C when compared to 13-16°C.

2.4.4.6 Increased Fish Mortality and Lower Overall Populations (D_a6, D_a7, D_a8)
The effects of altered temperature, decreased DO, and increased nutrient loading can have a significant impact on salmonids. In the Klamath River basin, the impacts of high water temperature directly, and in combination with other factors, have likely resulted in both adult and juvenile fish mortality and contributed to lower overall fish populations.

Bartholow (1995, p.19) states, "…water temperatures in the Klamath basin are marginal at best for anadromous salmonids, squeezing their thermal resources in both space and time." The National Research Council of the National Academies (NRC) state that various factors including decreased flows and increased water temperatures in the Klamath River basin have contributed to declining salmonid populations during the 20th century (NRC 2004, p.284). Salmonid populations in the Klamath River basin have declined sharply since the early 1900's. In 1931, Snyder (1931, p.9, 121) wrote that the fishery of the Klamath River basin is very important because with proper management it can be maintained, although he also states that depletion of the Klamath salmon is apparent and occurring at an "alarming rate" which artificial propagation alone may not

remedy. The NRC (2004, p.284) reports that virtually all Klamath River basin populations of salmonids have declined considerably from their historical abundances, and note the significant link between the decline in coho, spring Chinook, and summer steelhead to the "verge of extinction" and their dependence on cool summer water temperatures. The NRC also notes that the Klamath River has become inhospitable to juvenile coho due to high water temperatures, and although the Klamath River is still important for rearing Chinook and steelhead, further increases in temperatures may make it unsuitable even for those species (NRC 2004, p.284). NRC (2004, p.268) state that in some respects, "…it is remarkable that fall-run Chinook salmon in the Klamath River are doing as well as they seem to be. Both adults migrating upstream and juveniles moving downstream face water temperatures that are bioenergetically unsuitable or even lethal." In 1991, the Klamath River Basin Fisheries Task Force (KRBFTF) identified increased stream temperatures in the lower Klamath River as impeding the recovery and posing threats to coho, winter steelhead, and late run fall Chinook (KRBFTF 1991, p.4-29). A discussion of how temperature and other water quality factors are contributing to fish mortality and salmonid population decline can be found in Section 2.6.1.

2.4.4.7 Impacts to Cultural and Harvest-Related Activities (D_a9, D_a10, D_a11)

The reduction of overall salmonid populations impacts the availability of fish for commercial, sport, and subsistence fish harvesting, as well as traditional and ceremonial uses. All of these activities require robust fish populations for long-term sustainable use of the resource. Thus, water temperatures, DO, pH, and ammonia toxicity outside the range of salmonid suitability can significantly impact these activities. Evidence of temperature and nutrient related impairment to harvest related activities is presented in Sections 2.6.2 and 2.6.4.

2.4.4.8 Impacts to Municipal Supply, Recreation, and Traditional/Cultural Use (D_b1, D_b2, D_b3, D_b4)

Elevated nutrient concentrations in the Klamath River basin have contributed to nuisance blooms of the blue-green algae *Microcystis aeruginosa*, which produces the cyanotoxin microcystin. Exposure routes of cyanotoxin poisoning can be via direct water contact, ingestion of contaminated water, breathing of aerosolized toxin bearing water, and possibly secondarily through the ingestion of infected fish or other vertebrates, invertebrates, and plant matter. As detailed in Section 2.5.4 this toxin has been detected in Copco and Iron Gate Reservoirs at levels which are considered dangerous for contact or consumption, leading to the posting of public health warnings at the reservoirs and various locations along the river.

The Klamath River Tribes utilize the river for traditional and ceremonial uses including bathing, plant gathering, ingestion, and other activities discussed in Section 2.6.2. The presence of microcystin in the lower river presents a potential human health risk for the Tribes. Further, mats of suspended algae in the reservoirs and river are an aesthetic nuisance impacting the public's ability to enjoy the natural beauty of these waters. Additionally, taste and odor problems are associated with high densities of blue-green algae, and these compounds are difficult and costly to remove from water supplies (Welch and Jacoby 2004, p.172).

2.5 Evidence of Water Quality Objective and Numeric Target Exceedances

This section presents observed water quality conditions and evaluates the data with respect to the relevant water quality objectives or surrogate thresholds.

2.5.1 Temperature and Nutrient Data Sources

Stream temperature data used for this analysis were provided by the US Forest Service, Yurok Tribe, Karuk Tribe, Forest Science Project, US Fish and Wildlife Service, Salmon River Restoration Council, and PacifiCorp. In addition, Regional Water Board staff collected temperature data.

For the DO and nutrient analyses Regional Water Board staff compiled monitoring data from several sources including the US Fish and Wildlife Service, US Geological Survey, PacificCorp, Karuk Tribe, Yurok Tribe, Regional Water Board, and the US Environmental Protection Agency Environmental Monitoring and Assessment Program.

2.5.2 Temperature

Regional Water Board staff conducted a literature review to evaluate stream temperature requirements for the various life stages of steelhead trout (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*), and Chinook salmon (*Oncorhynchus tschawytscha)* as a means for interpreting the narrative temperature objective in the Basin Plan (Regional Water Board 2007). As a result of this literature review, Regional Water Board staff selected chronic and acute temperature thresholds for evaluating Klamath River basin temperatures. These temperature thresholds are used for assessing the suitability of current Klamath River basin temperatures for fully supporting salmonids. These thresholds are *not* numeric water quality targets used for calculating the Klamath River temperature TMDL. The numeric temperature targets are discussed in Section 2.3.1 and the specific temperature targets are presented in Chapter 5.

Chronic temperature thresholds were selected from the USEPA document *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* (2003), and are presented in Table 2.7. The Region 10 guidance is the product of a three-year interagency effort, and has been reviewed by both independent science review panels and the public. Acute lethal temperature thresholds were selected based upon best professional judgment of the literature, and are presented in Table 2.8. These freshwater temperature thresholds are applicable during the time of year when the life stage of each species is present in the Klamath River basin. Where life history, timing, and/or species needs overlap, the lowest of each temperature metric applies. A discussion of the distribution and periodicity of salmonids in the Klamath River basin is available in Appendix 4, *Fish and Fishery Resources of the Klamath River Basin* (Carter and Kirk 2008). Additional information on the effect of temperature on salmonids and a brief discussion of temperature metrics are available in Appendix 3 (Carter 2008).

Table 2.7: MWMT Chronic Effects Temperature Thresholds

Life Stage	MWMT (°C)
Adult Migration	20
Adult Migration plus Non-Core Juvenile Rearing [1]	18
Core Juvenile Rearing [2]	16
Spawning, Egg Incubation, and Fry Emergence	13

Source: USEPA 2003

[1] The Adult Migration plus Non-Core Juvenile Rearing designation is recommended by USEPA (2003) for the "protection of migrating adult and juvenile salmonids and moderate to low density salmon and trout juvenile rearing during the period of summer maximum temperatures," usually occurring in the mid to lower part of the basin. The phrase "moderate to low density" is not specifically defined.

[2] The Core Juvenile Rearing designation is recommended by USEPA (2003) for the "protection of moderate to high density summertime salmon and trout juvenile rearing" locations, usually occurring in the mid to upper reaches of the basin. The phrase "moderate to high density" is not specifically defined.

Table 2.8: Lethal Temperature Thresholds

Lethal Threshold[1] (°C)			
Life Stage	**Steelhead**	**Chinook**	**Coho**
Adult Migration and Holding	24	25	25
Juvenile Growth and Rearing	24	25	25
Spawning, Egg Incubation, and Fry Emergence	20	20	20

Source: Carter 2008

[1] The lethal thresholds selected in this table are generally for chronic exposure (greater than seven days). Although salmonids may survive brief periods at these temperatures, they are good benchmarks from the literature for lethal conditions. See Appendix 3 (Carter 2008) for further discussion.

2.5.2.1 Mainstem Klamath River

Temperature data from the Klamath River mainstem indicate that seasonal maximum temperatures are not supportive of beneficial uses. Figure 2.11 shows that MWMT values at all sites from the Oregon-California state line to the estuary are well above the suitable temperature range for full support of salmonids as described by USEPA (2003). These data clearly demonstrate that the river has no capacity to assimilate increased heat loads during the hottest critical periods without adversely affecting the beneficial uses COLD, SPWN, RARE, and MIGR.

The results of water quality modeling completed for this TMDL process indicate that human activities have significantly altered the temperature regime of the mainstem Klamath River. The application of the water quality models is described in Chapter 3. These results indicate that the combined effects of human activities in the basin commonly result in temperature alterations in excess of 5 ^{o}F, and these alterations can be as much as 18 ^{o}F. Figure 2.12 presents simulated natural and current Klamath River temperatures, and the calculated difference, at the site of maximum temperature alteration in California.

The temperature modeling indicates human impacts adversely affect both the rearing of juvenile salmonids and the reproductive success of adult salmonids. Under current

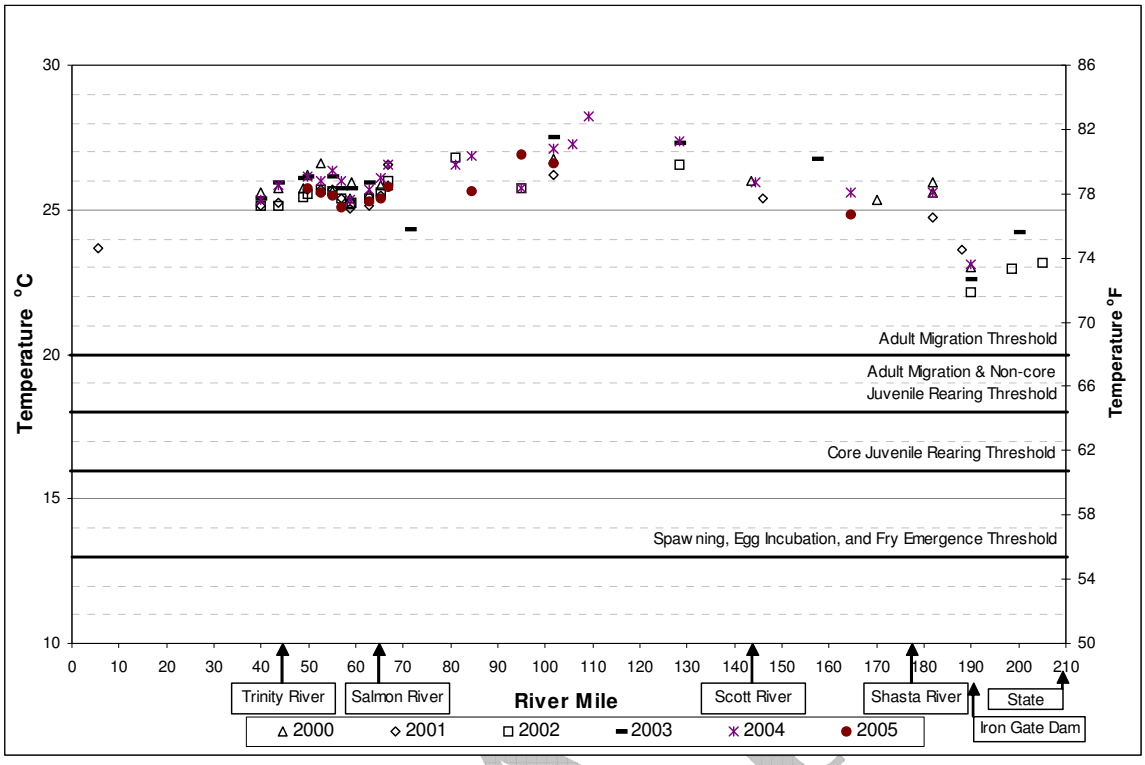


Figure 2.11 : Measured Klamath River MWMTs, 2000-2005.
Note: MWMTs typically occur in late July.

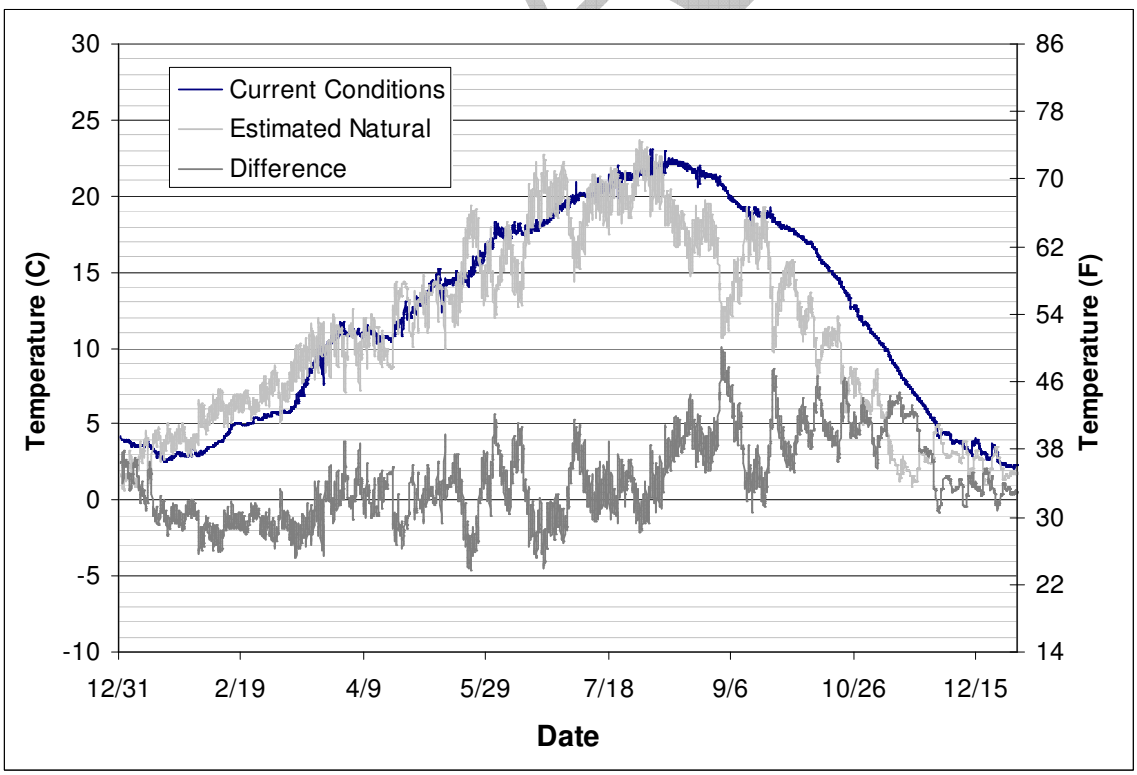


Figure 2.12: Current and Estimated Natural Temperatures Downstream of Iron Gate Dam, 2000
Note: Model results presented at 1-hour time step.

conditions, the increase in temperatures during the winter and spring months is delayed in comparison to estimated natural temperatures. Similarly, the decrease in temperatures during the fall months is also delayed in comparison to estimated natural temperatures.

The growth of juvenile salmonids is partially dependent on temperature (USEPA 2003). The optimal temperature range for juvenile salmonids is 10-15 ^{o}C, with a lower limit of 4 ^{o}C (USEPA 2003). The ability of salmonids to survive the ocean phase of their life cycle is partially dependent on their size upon entering the ocean. Thus, the delay in springtime warming reduces the growth rates of salmonids rearing in the Klamath River, and may ultimately reduce the survival rate of salmonids in the ocean.

USEPA (2001) reviewed multiple literature sources and concluded that optimal protection of salmonids from fertilization through initial fry development requires that temperatures be maintained below 9-10°C, and that daily maximum temperatures should not exceed 13.5-14.5^{o}C. Under current conditions, these temperatures are not reached until late October or November. However, the Chinook spawning season begins in mid-September and peaks in late October (see Appendix 4 [Carter and Kirk 2008] for more details).

Bartholow et al. (2005) concluded that in comparison to the expected temperatures resulting from a natural flow regime, the Klamath River dams create temperature conditions more favorable to migrating juveniles in the spring and less favorable to adults migrating and spawning in the fall. The authors further speculated that the changes in seasonal temperature patterns may have affected the timing of the Chinook salmon run since the dams were constructed.

In summary, the temperature alterations presented in Figure 2.12 result in adverse effects to salmonids. The comparison of estimated natural and current temperatures for the year 2000 at the location downstream of Iron Gate Dam clearly shows that the water quality objective for temperature is regularly exceeded. This conclusion is based on the observation that current temperatures are regularly more than 5°F above the estimated natural temperatures, and the fact that there is no capacity to assimilate increased heat loads during the hottest critical periods without adversely affecting the beneficial uses.

2.5.2.2 Tributaries to the Klamath River

Temperature data from the mouths of Klamath tributaries indicate that the seasonal maximum temperatures of the majority of the tributaries are not supportive of beneficial uses. The MWMT values at most of these sites are well above the suitable temperature range for salmonids (Figure 2.13).

Of the twenty-two tributaries monitored in 2004 (the year with the most tributaries monitored), eighteen had MWMT values in excess of the adult migration and non-core juvenile rearing thresholds for salmonids (USEPA 2003). These data clearly demonstrate that these tributaries have no capacity to assimilate increased heat loads during the hottest critical periods without adversely affecting beneficial uses.

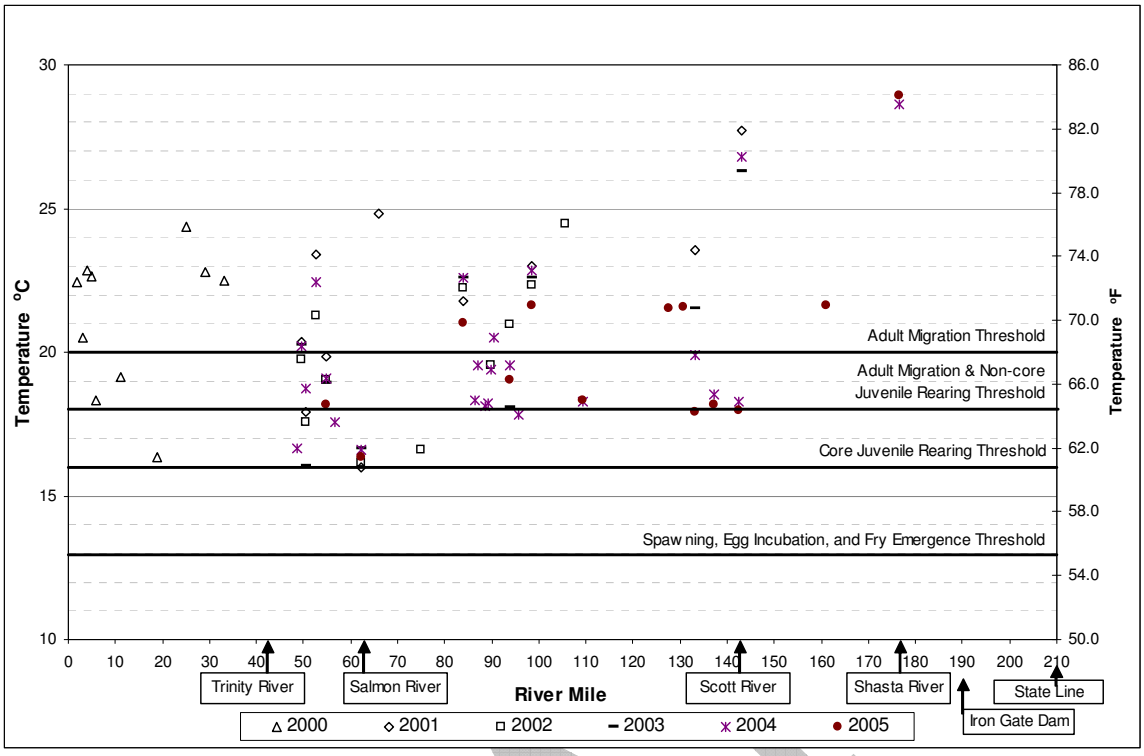


Figure 2.13: Klamath River Tributary Mouth MWMTs Stream Temperatures 2000-2005
Note: MWMTs typically occur in late July.

The Shasta, Scott, and Salmon Rivers, three of the largest Klamath River tributaries, have been listed on the 303(d) list for temperature impairment separately. TMDL analyses developed for these tributaries have confirmed the temperature impairments, as well as the human contribution to elevated temperatures in these basins.

Although the temperatures are high relative to the temperature requirements of salmonids (USEPA 2003), the high temperatures do not exceed the water quality objective for temperature unless they are elevated due to human activities, such as riparian vegetation removal and altered channel morphology. However, it is well documented that the erosion associated with the 1997 flood in the Klamath River basin resulted in widespread stream channel alteration, loss of riparian vegetation, and shade reductions (further discussed in Section 2.5.8) and that a significant amount of the erosion was caused or exacerbated by human activities (De La Fuente and Elder 1998). Similarly, it is well known that historic mining, road building, and silvicultural practices have resulted in riparian disturbances and consequent reductions of stream shade in many tributaries (Elder et al. 2002; KNF 1999; KNF 2002). Therefore, Regional Water Board staff conclude that enough information exists to confirm impairment and justify TMDL development and implementation.

2.5.2.3 Reservoirs

The available Iron Gate and Copco Reservoir temperature and DO profile data indicate that during summer stratified conditions temperatures are only suitable for cold water

species, including salmonids, rearing at depths where the DO concentrations are near lethal levels. Redband/rainbow trout are currently present in both Copco and Iron Gate Reservoir (PacifiCorp 2004b, p.4-53 - 4-55, 4-58). An example of typical summer conditions is illustrated in the vertical profiles of DO concentration and temperature that are presented in Figure 2.14 for Iron Gate Reservoir.

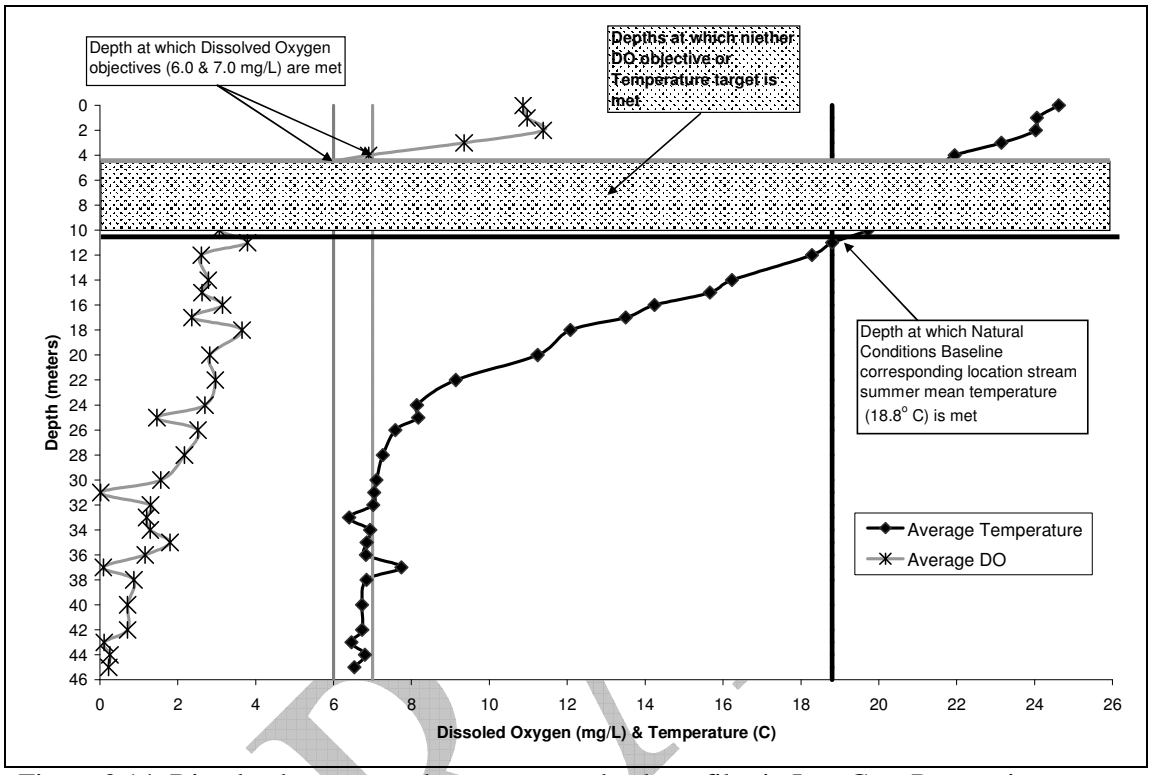


Figure 2.14: Dissolved oxygen and temperature depth profiles in Iron Gate Reservoir – average for July and August 2000 - 2005

The same pattern exists for Copco and for other years. The reservoirs become thermally stratified in the summer months. The stratification of the reservoirs prevents mixing of the low temperature/low DO waters with the high temperature/high DO waters, thus there is no depth in the reservoirs at which the most sensitive beneficial uses are supported. Given that the stratification and the absence of suitable habitat is due to the presence of the reservoirs, Regional Water Board staff have concluded that the reservoirs contribute to exceedances of the temperature and DO water quality objectives.

2.5.3 Nutrients and Indicators of Nutrient-Related Impairment

Except in extreme cases, nutrients alone do not impair beneficial uses. Rather, they cause indirect impacts through their biostimulatory effect on algal growth, low DO, and extreme pH conditions among others that can impair uses. The water quality objectives with distinct numeric limits include DO and pH. The California Nutrient Numeric Endpoints (CA NNE) framework (Tetra Tech 2006) indentifies indicators for biostimulatory effects that can impair beneficial uses, including benthic algal biomass, planktonic chlorophyll-a concentrations, and diurnal DO and pH fluctuations. Other

indicators included here are toxic blue-green algae (*Microcystis*) concentrations, and un-ionized ammonia.

2.5.3.1 Nutrient Concentrations

The primary driver for the nutrient conceptual model is the increased loading of nutrients to the Klamath River ecosystem. High levels of nutrient loading and elevated water column concentrations do not alone result in biostimulatory conditions, but excess nutrients are an essential precondition to this finding. Therefore the first step in evaluating impairment due to biostimulatory conditions is to determine whether existing nutrient loading and water column concentrations exceed natural baseline conditions. If it is determined that nutrient levels above natural baseline concentrations are present in the system, then the CA NNE secondary endpoints are evaluated to determine whether they have exceeded the Beneficial Use Risk Category Level III boundary for impaired waters. It is when both natural baseline nutrient levels and CA NNE Level III indicator boundaries have been exceeded that a finding of impairment due to biostimulatory conditions can be supported.

Several sources within the Klamath and Lost River watersheds contribute nutrient loads. Some of the key sources include irrigated agriculture return flows, internal nutrient cycling from nutrient enriched sediments, nutrients released as a result of wetland conversion, sediments from external sources derived from land disturbance activities, and to much lesser extent point sources. The analysis of Klamath River nutrients involves a comparison of estimated natural baseline water column concentrations of several nutrient species to existing conditions concentrations. Natural baseline conditions are estimated based on TMDL model simulations (described in Chapter 3). These estimates are not interpreted literally but only as approximations of conditions that may have existed under natural conditions. The natural baseline modeling scenario provides an estimate of nutrient loads and concentrations generated from a landscape with minimal anthropogenic disturbance. The existing conditions values come from the mean concentration of composite grab samples taken during the summer (June 1 to September 30) at twelve stations by various organizations from 1996 to 2007. Each station has at least three samples for each summer season over five years. Several stations have a much greater sampling density. The assumption for this analysis is that the annual and daily variability converges to an average over the course of a large number of samples that represent typical conditions during the summer growing season.

The purpose of the comparison is to evaluate whether nutrients have been increased by human related activities above the levels that could cause a nuisance, or adversely affect the water to support specified beneficial uses. This approach does not allow for a complete mass balance comparison for the river since winter flows and concentrations have not been monitored. Rather, the information serves to provide a relative comparison of the mean summer concentrations of total nitrogen and total phosphorus under current and natural baseline conditions to which aquatic life respond (Figures 2.15 and 2.16). The left side of Figures 2.15 and 2.16 present existing conditions from stateline to the estuary, while the right side of the figure presents concentrations under natural conditions baseline. At most stations for both total phosphorous and total nitrogen the existing

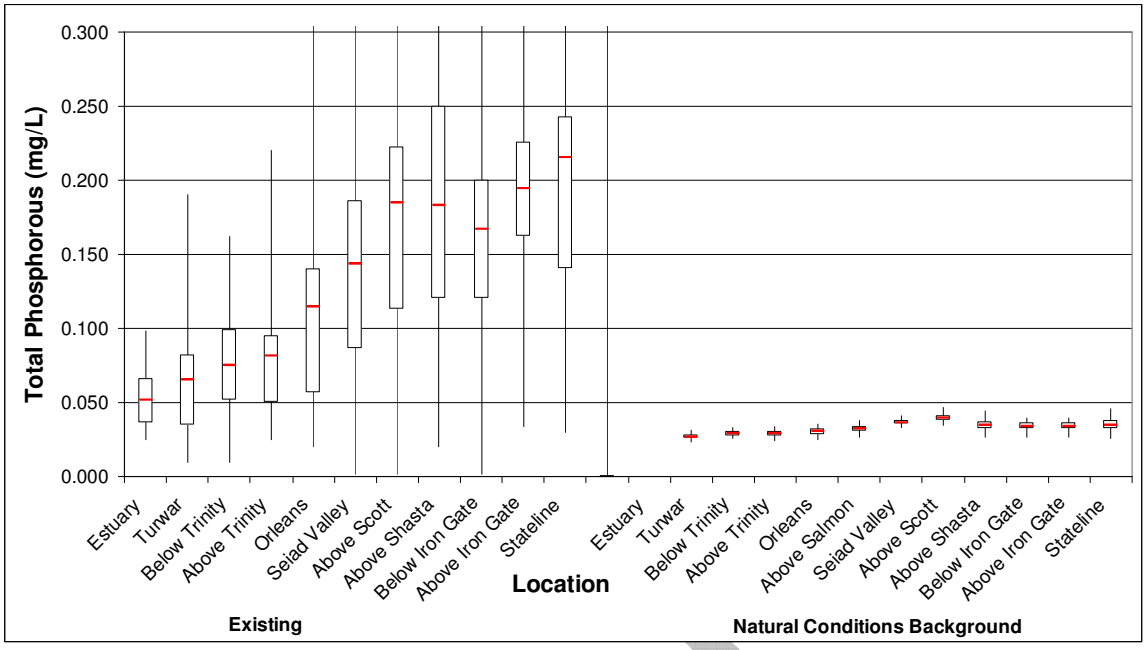


Figure 2.15: Comparison of total phosphorous concentrations for existing conditions (consolidated monitoring data 1996-2007) with estimated (TMDL model) natural conditions baseline at Klamath River monitoring stations in California.

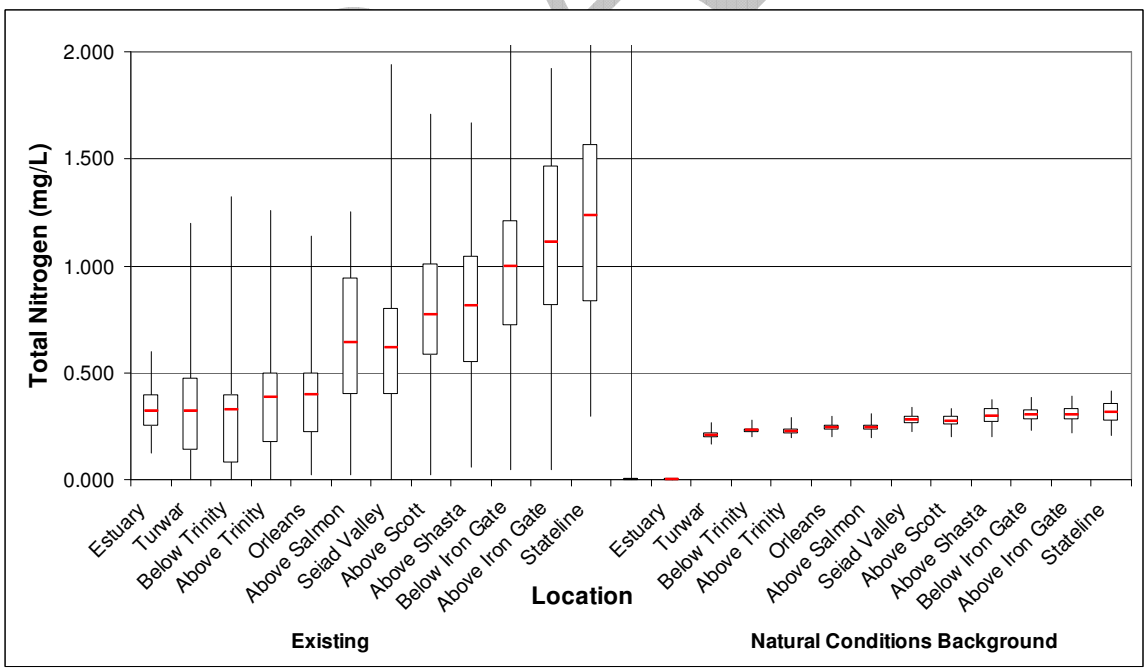


Figure 2.16: Comparison of total nitrogen concentrations for existing conditions (consolidated monitoring data 1996-2007) with estimated (TMDL model) natural conditions baseline at Klamath River monitoring stations in California.

conditions concentrations exceed the natural background conditions. Frequently the existing conditions concentration is more than double the natural background conditions concentration. These results suggest that human activities have increased nutrient loads to the Klamath River.

2.5.3.2 Benthic Algal Biomass

Figure 2.17 presents the results of composited benthic algae biomass monitoring samples collected during summer months in 2003, 2004, 2006, and 2007. There are a total of fifty samples for nine stations. The spatial and temporal sampling density is not ideal, but does indicate that during the summer months Klamath River benthic algae biomass in California exceed the CA NNE and TMDL numeric target of 150 mg chl-a/m^2 at several stations.

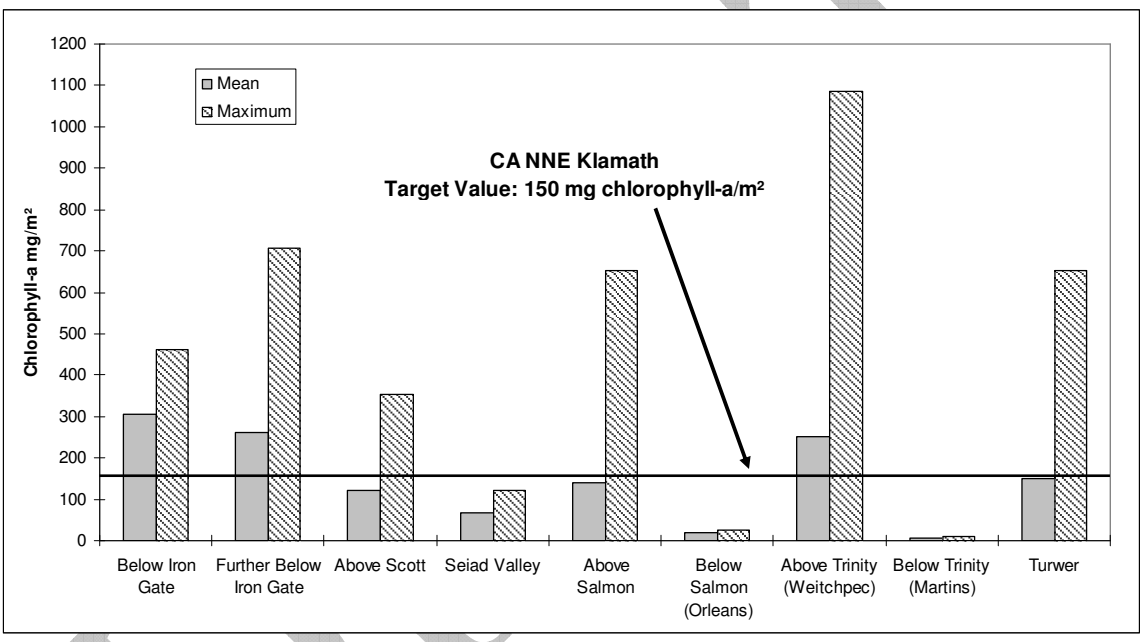


Figure 2.17: Consolidated benthic algal biomass monitoring results (summer mean and maximum) for 2003-2007 with CA NNE/TMDL numeric target.

As demonstrated in the following sections, these benthic algae conditions have a direct impact on water quality via algal photosynthesis and respiration. In addition, the benthic algal biomass densities also provide habitat for polychaetes that serve as a host and source for the fish parasite *C. shasta.* In summary, existing benthic algal biomass conditions strongly suggests impairment.

2.5.3.3 Diurnal DO and pH

For several stations along the Klamath River the diurnal photosynthesis and respiration cycle is strongly influenced by dense colonies of benthic algal biomass which result in extreme diurnal cycles for DO and pH. The water quality conditions of frequent and chronic low DO and high pH illustrated in Figures 2.18 through 2.20 create chronic stressful conditions for fish populations.

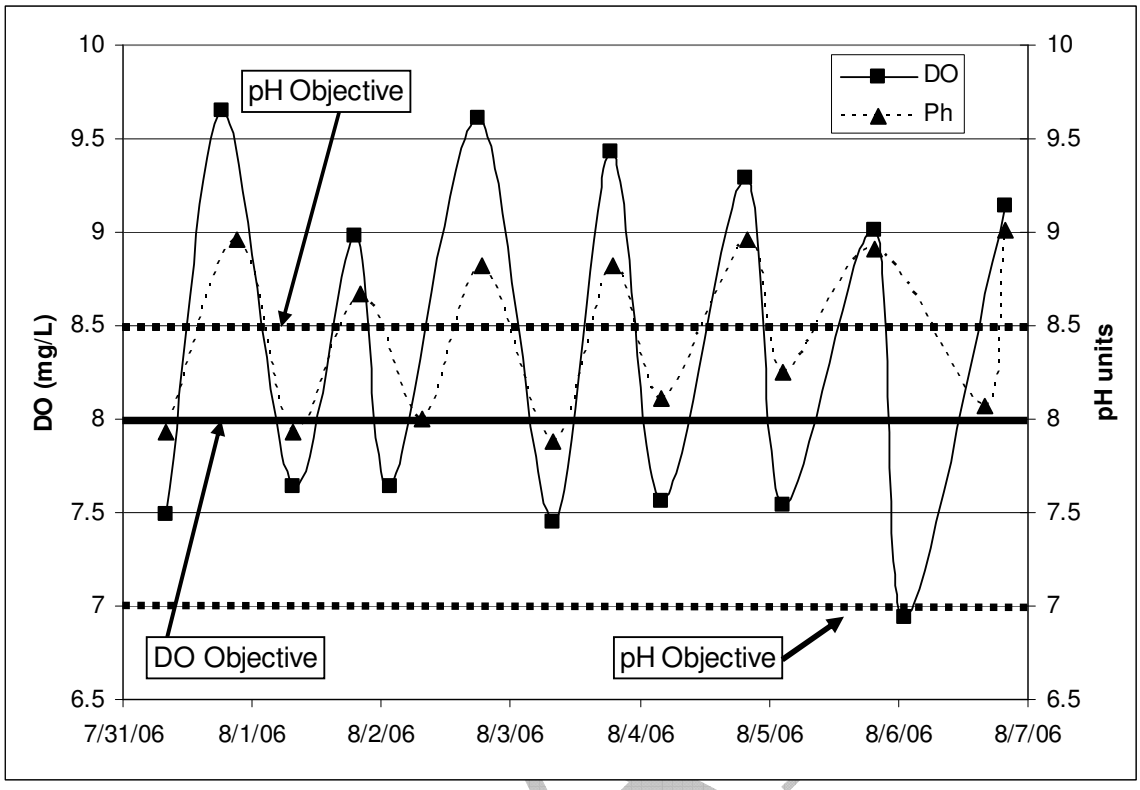


Figure 2.18: Example diurnal DO and pH cycle below Iron Gate Dam, summer 2006

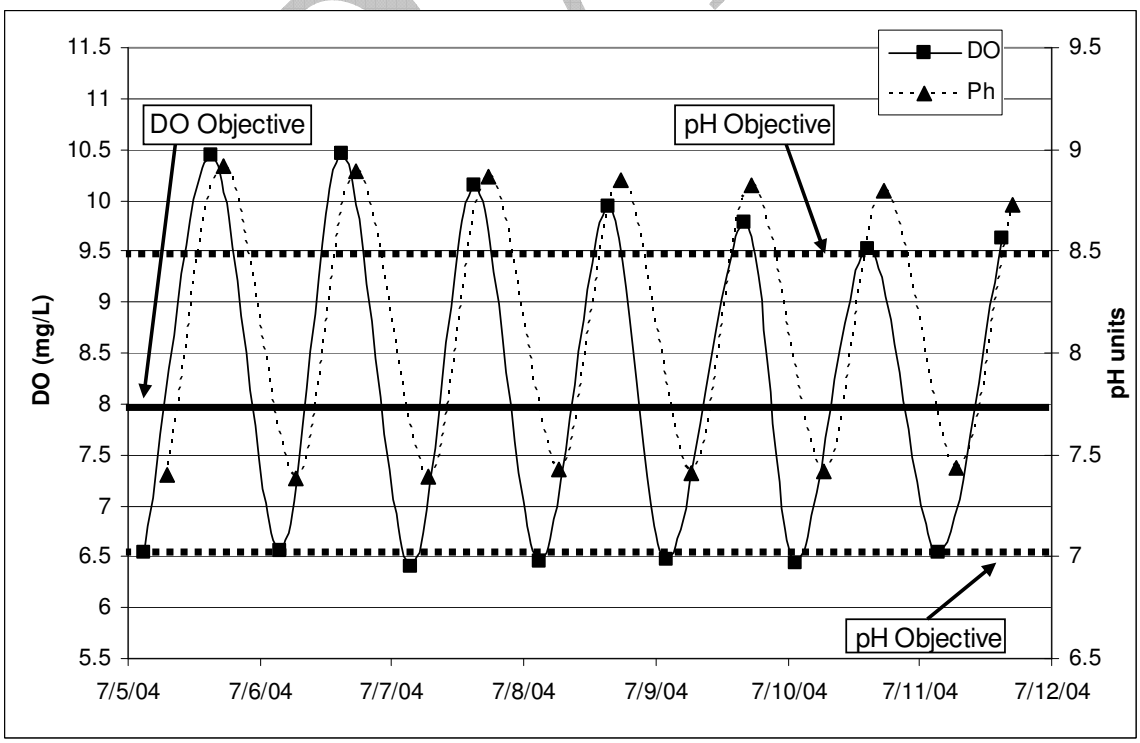


Figure 2.19: Example diurnal DO and pH cycle above the Shasta River, summer 2004

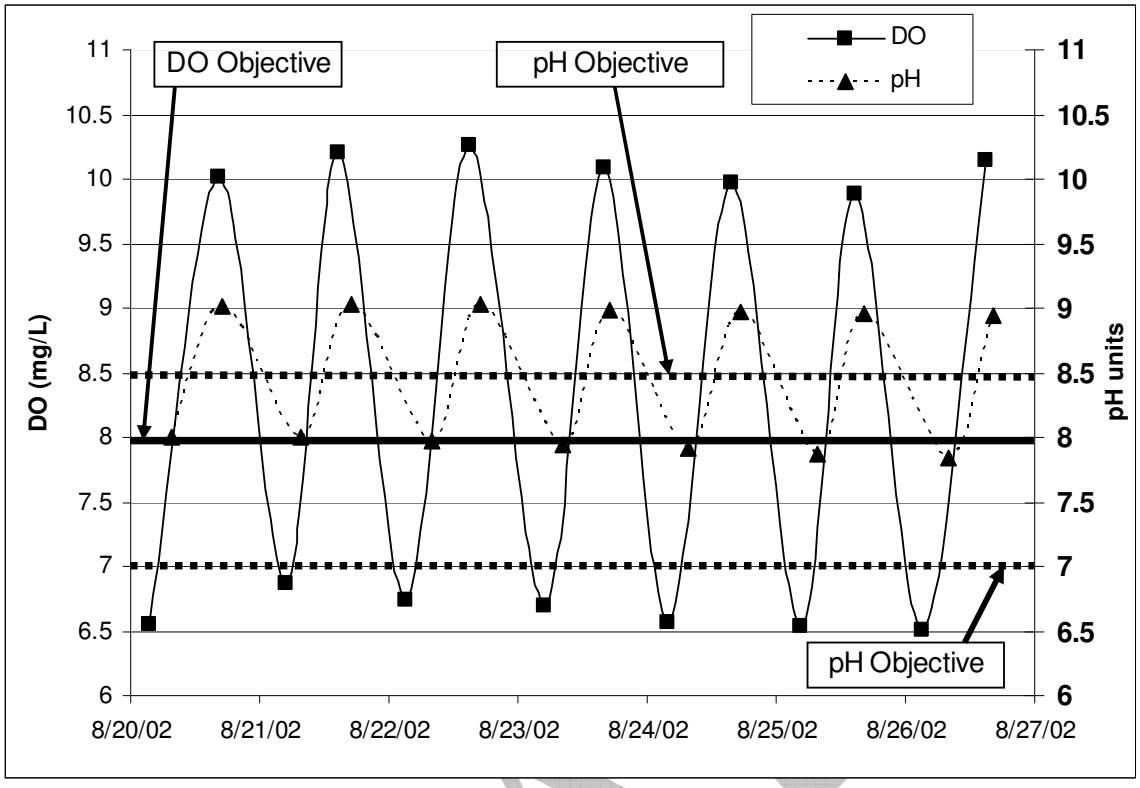


Figure 2.20: Example diurnal DO and pH cycle at Seiad Valley, summer 2002

The three plots present monitoring data from single stations, however the observed pattern is consistent with other time periods and other stations along the Klamath River. Both the existing DO objective (>8 mg/L) and pH objective (not greater than 8.5 and not less than 7.0) for the Klamath River downstream of Iron Gate Dam are exceeded on a regular basis. The extreme magnitude and regular frequency of these excursions indicate impairment from biostimulatory substances (i.e., nutrients).

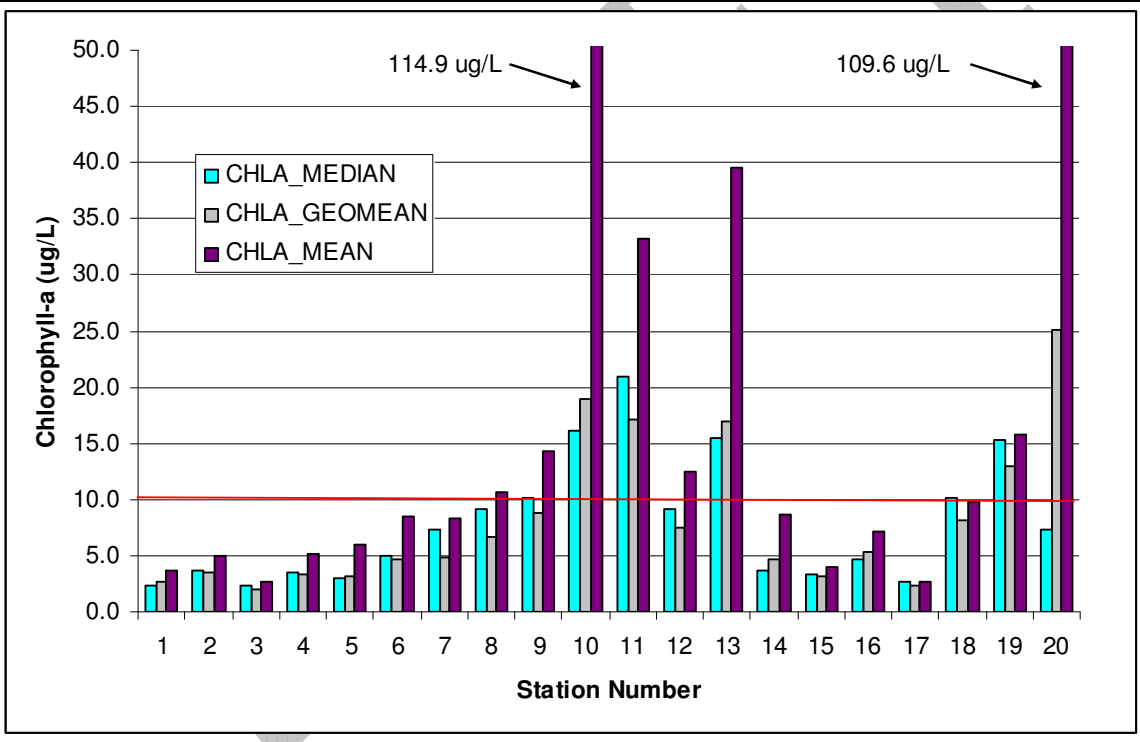
2.5.3.4 Chlorophyll-a – Reservoirs

Figure 2.21 compares various measures of central tendency (mean, geometric mean, and median) of the chlorophyll-a data from samples collected during the summer period (May – September) of 2005, 2006, and 2007 by the Yurok Environmental Program, Karuk Tribe of California Natural Resources Department, and PacifiCorp at twenty stations along the Klamath River. It is important to note that the data presented are from samples collected by different entities using similar but not identical protocols and the number and timing of samples vary from station to station. Presentation of the mean, geometric mean, and median values of a data set, provides a useful way to assess the spread of the data. A close similarity between median and mean values is an indication that the data set is normally distributed. The geometric mean[14] is a useful measure of central tendencies when the data is log normally distributed. All three measures of central tendencies for each station are illustrated in Figure 2.21 allowing a station by station

[14] To calculate a geometric mean of the distribution values (i.e., chlorophyll-a concentrations) the following steps are taken: 1) log transform the data; 2) calculate the mean of the logged values; and 3) then antilog (raise to 10th power) the mean.

comparison of the three measures. Figure 2.22 presents the same data in box and whisker diagrams. The shoulders of the box and whisker diagram represent the 75th and 25th percentile of the distribution of measurements; the median (50th percentile) is the solid line across the box.

Each of the central tendency measures of chlorophyll-a for the Klamath River reservoir stations in California (Copco and Iron Gate) exceed the numeric target of 10 µg/L. There are also high concentrations of chlorophyll-a at Link Mouth, and at Keno Dam and above JC Boyle Reservoir. The high concentrations at these three stations are due in large part to residual algal biomass from Upper Klamath Lake. At most stations the median and the geometric mean are relatively similar, and the mean is higher than both the median and geometric mean. At the California reservoir stations (stations 10-14) however, the mean is significantly higher than either the median or the geometric mean. The very high means can be attributed to the nuisance algae bloom events during the late summer months.



Station List:

1 - Lower Estuary (n=11)
2 - Turwar (n=19)
3 - Below Weitchpec (n=17)
4 - Weitchpec (n=19)
5 - Orleans (n=19)
6 - Seiad Valley (n=26)
7 - Walker Bridge (n=13)
8 - I-5 (n=16)
9 - Below Iron Gate Dam (n=61)
10 - Iron Gate Res. Lower (n=49)
11- Iron Gate Res. Upper (12)
12 - Copco Res. outflow (n=37)
13 - Copco Res. Lower (n=49)
14 - Copco Res. Upper (n=11)
15 - Above Shovel Creek (n=40)
16 - Below JC Boyle Dam (n=9)
17 - JC Boyle Res.(n=3)
18 - Above JC Boyle Res.(n=17
19 - Keno Dam (n=20)
20 - Link Mouth (n=7)

Figure 2.21: Comparison of central tendencies of summer (May – September) chlorophyll-a measurements for 2005, 2006, and 2007 at twenty monitoring stations along the Klamath River. Source: Asarian and Kann 2009

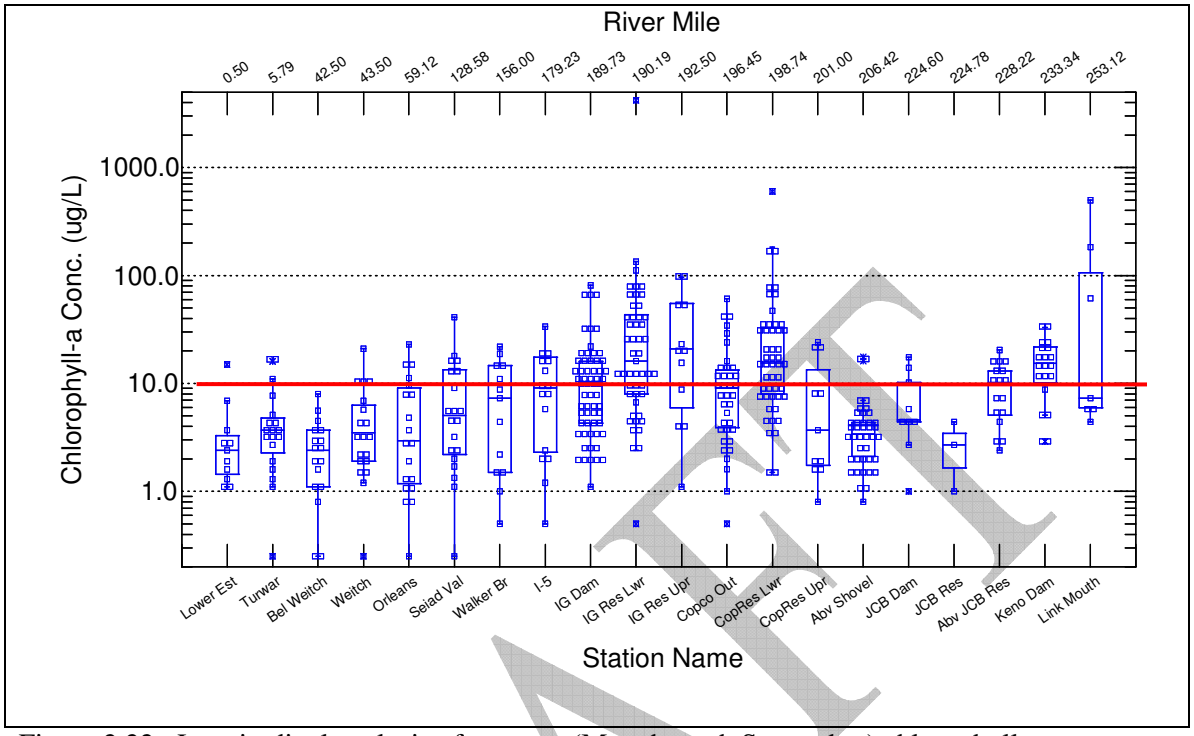


Figure 2.22: Longitudinal analysis of summer (May through September) chlorophyll-a concentrations from 2005 – 2007 along the Klamath River.
Source: Asarian and Kann 2009

Nuisance algal blooms within Iron Gate and Copco Reservoirs are well documented in the regular blue-green algae monitoring program reports by the Karuk Tribe of California Natural Resources Department and PacifiCorp. As illustrated in Figure 2.23 the summer mean concentrations of chlorophyll-a at all of the reporting stations for the reservoirs are at or above the summer mean numeric target of 10 µg/L. The summer mean concentrations at three of the four stations are more than double the target.

The high concentrations of chlorophyll-a in the reservoirs also has water quality impacts downstream. Elevated levels of suspended algae in the Iron Gate Reservoir outlet waters are then available as a food source for polychaetes in the river reaches below the dam. In addition, fine particulate organic matter (FPOM) discharged from the outlet of Iron Gate Reservoir is deposited in the river bottom sediments below the reservoir enhancing habitat conditions for polychaetes which, it is believed, contribute to higher levels of *C. shasta* parasite spores, and therefore contribute to higher rates of infection (Bartholomew et al. 2007; Bartholomew and Bjork 2007). The reservoirs also impact the river below Iron Gate by serving as a source of blue-green algae that continues to grow in backwater and slower sections within the river reaches below the dams (Kann and Asarian 2005).

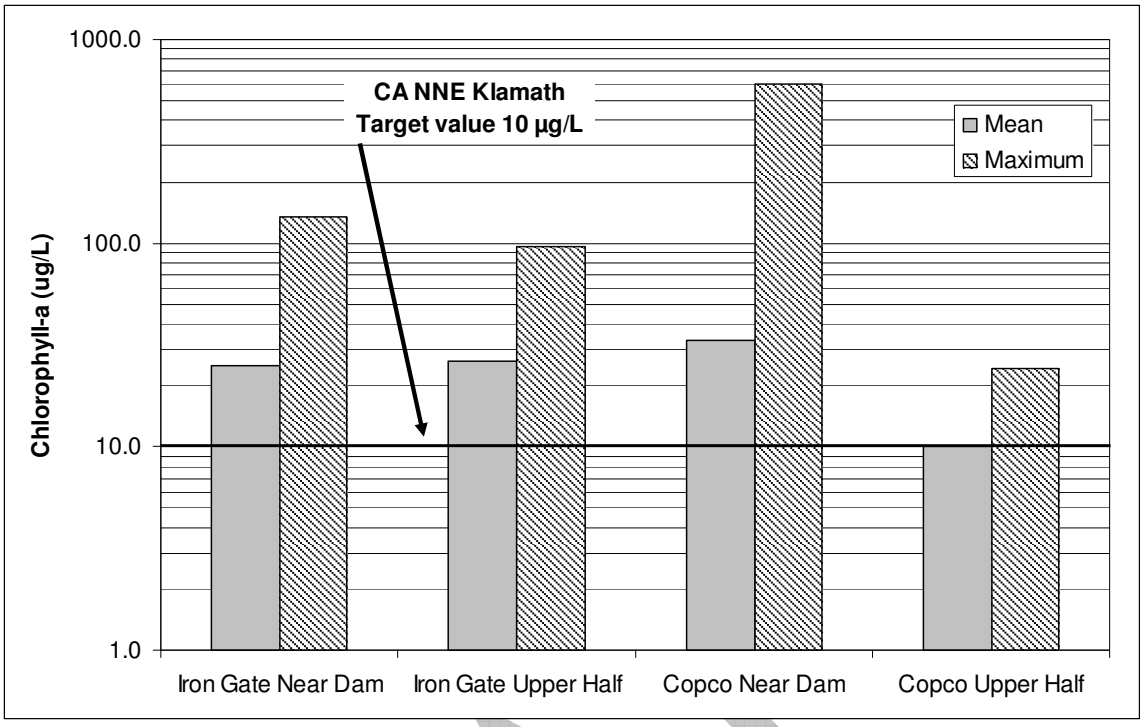


Figure 2.23: Summer mean concentrations of chlorophyll-a (2000 – 2007) at four stations within the Iron Gate and Copco Reservoirs.

2.5.4 Blue-Green Algae and Microcystin Toxin

An important aspect of the nuisance algae conditions within Copco and Iron Gate Reservoirs is the periodic dominance of toxic blue-green algal species during the summer season. The consistent presence of high concentrations of *Microcystis aeruginosa* and microcystin during the late summer period in all reaches of the Klamath River within California has resulted in the impairment of beneficial uses including Native American Culture (CUL), Subsistence Fishing (FISH), Water Contact Recreation (REC-1), Non-Contact Water Recreation (REC-2), Municipal & Domestic Supply (MUN), Shellfish Harvesting (SHELL), Aquaculture (AQUA), Agricultural Supply (AGR), and Commercial and Sport Fishing (COMM). Ongoing research may also demonstrate a direct effect on the health of aquatic organisms from exposure to high levels of microcystin which would lead to the addition of other beneficial uses to this list (de Figueiredo et al. 2004).

The *Public Review Draft Staff Report for the 2008 Integrated Report for the Clean Water Act Section 305(b) Surface Water Quality Assessment and the 303(d) List of Impaired Waters* (Regional Water Board 2008) recommends to the Regional Water Board that the mainstem Klamath River downstream of Iron Gate Dam to the confluence of the Trinity River be listed as impaired for microcystin. At the time of the release of this Peer Review Draft of the Klamath River TMDL Staff Report this recommendation has not yet been considered by the Regional Water Board. On several occasions cell densities and microcystin concentrations have exceeded Regional Water Board impairment criteria threshold by a factor of more than one-hundred times the allowable

concentration. There are many forms of blue-green algae, both toxic and non-toxic. This problem statement focuses primarily on *Microcystis aeruginosa* since it has become the dominant species of concern on the Klamath River below the stateline.

Every year since 2004, Microcystis aeruginosa counts and microcystin concentrations on the Klamath River have exceeded the Blue Green Algae Work Group action levels for harmful algal blooms. Table 2.9 summarizes the blue-green algal monitoring data for the years 2006, 2007, and 2008 with respect to the Blue Green Algae Work Group action levels. Data presented in the table is summarized by reach: Reach 1) Oregon to Iron Gate Dam, Reach 2) Iron Gate Dam to Scott River, Reach 3) Scott River to Trinity River, and Reach 4) Trinity River to Estuary. The blue-green algae listing criteria are most frequently exceeded in Reach 1, which is primarily composed of sample sites within Copco and Iron Gate Reservoirs. Late summer conditions are typically characterized by dense blue-green algae blooms that form thick viscous scums in parts of the reservoirs. The bloom conditions at times span much of the open water areas within the reservoirs. The reservoirs have been posted with public health advisory signs as a result of these summer blooms in 2006, 2007, and 2008.

Table 2.9: Summary of blue-green algae and microcystin monitoring data for 2006, 2007, and 2008

Reach Name	Reach #	Year	# of monitoring samples that exceed thresholds and targets		
			MSAE Cells ≥ 40,000 ml/L	microcystin ≥ 8 ug/L	Tissue ≥ 26 ng/g
Oregon to Iron Gate Dam	1	2006	27	29	*
Iron Gate Dam to Scott River	2	2006	1	1	*
Scott River to Trinity River	3	2006	2	0	*
Trinity River to Estuary	4	2006	0	0	*
Oregon to Iron Gate Dam	1	2007	47	35	41
Iron Gate Dam to Scott River	2	2007	2	0	1
Scott River to Trinity River	3	2007	4	0	4
Trinity River to Estuary	4	2007	2	0	*
Oregon to Iron Gate Dam **	1	2008	**	14	0 ***
Iron Gate Dam to Scott River	2	2008	4	2	*
Scott River to Trinity River	3	2008	9	4	*
Trinity River to Estuary	4	2008	1	1	*

* Data not collected during this period

** Not all data from monitoring programs available at time of report publication.

*** Tissue samples taken prior to bloom to determine baseline conditions, samples were not taken during bloom.

Data sources: Yurok Environmental Monitoring Program Blue-Green Algae Annual Reports: 2006, 2007, and 2008; Karuk Tribe of California Natural Resources Department Blue Green Algae Monitoring Annual Reports: 2006, 2007, and 2008; and PacifiCorp Blue-Green Algae Monitoring Program annual Reports: 2006, 2007, and 2008.

Table 2.9 also indicates that the blue-green algal blooms are occurring downstream of the Iron Gate Dam in reaches 2, 3, and 4. The Klamath River mainstem was posted with

public health advisory signs during the summer of 2008. Sampling for blue-green algae and microcystin toxin was added to the Klamath mainstem monitoring program in 2006 after the regular water quality sampling protocols had been developed. Therefore, most samples on the Klamath River mainstem were taken from the river at mid-point. *Microcystis aeruginosa* requires quiescent waters to reproduce. Few samples have been taken in near shore backwater areas where scums have been frequently reported and photographed. The revised September 2008 Blue Green Algae Work Group report recommends that monitoring for public health should include samples of worst-case conditions in areas in which people and animals are most likely to contact water (State Water Board 2008).

2.5.5 Dissolved Oxygen

The DO indicator is somewhat different than the diurnal DO and pH indicator discussed in Section 2.5.3.3. The diurnal indicator discussed is used to evaluate biostimulatory conditions via a linkage with benthic algal biomass. The DO indicator evaluated in this section is the existing and proposed Basin Plan water quality objective.

The US Fish and Wildlife Service (USFWS), in cooperation with the Karuk and Yurok Tribes, monitored DO conditions with datasondes at several stations along the Klamath River from 2001 to 2006. For the purposes of this assessment measured DO concentrations from the three most recent years (2004 – 2006) are evaluated in comparison to the existing and proposed DO objective. USFWS conducted an in-depth quality control review of the DO data (Armstrong and Ward 2008). The corrected data-sonde results have been summarized by station by evaluating the percent of total measurements during the summer season that fall below the current Basin Plan DO Objective of 8.0 mg/L. The datasondes recorded water quality conditions at 30-minute increments, for a total of forty-eight daily measurements.

Greater than ten percent of the DO measurements are less than 8.0 mg/L at six of the nine stations along the Klamath River (Table 2.10 and Figure 2.24). At four stations (below Iron Gate, above Shasta River, above Scott River, and at Seiad Valley) more than 40% of the measurements are less than the current Bain Plan objective.

Table 2.10: Percent of DO measurements below Basin Plan Water Quality Objective of 8.0 mg/L for 2004 – 2006 at nine stations along the Klamath River

% Measurements below 8 mg/L	2004		2005		2006	
	n	%	n	%	n	%
At Iron Gate	2706	64	4498	45	5391	61
Above Shasta River	5478	50	5533	49	-	-
Above Scott River	2966	58	4457	47	-	-
At Seiad Valley	3381	57	4713	45	5526	40
At Orleans	4057	37	4533	23	5349	15
Above Trinity	-	-	5535	5	5739	3
At Weitchpec	4142	48	5400	7	5332	6
Below Weitchpec	5500	16	3529	11	5293	4
At/above Turwar	5066	30	5543	6	-	-

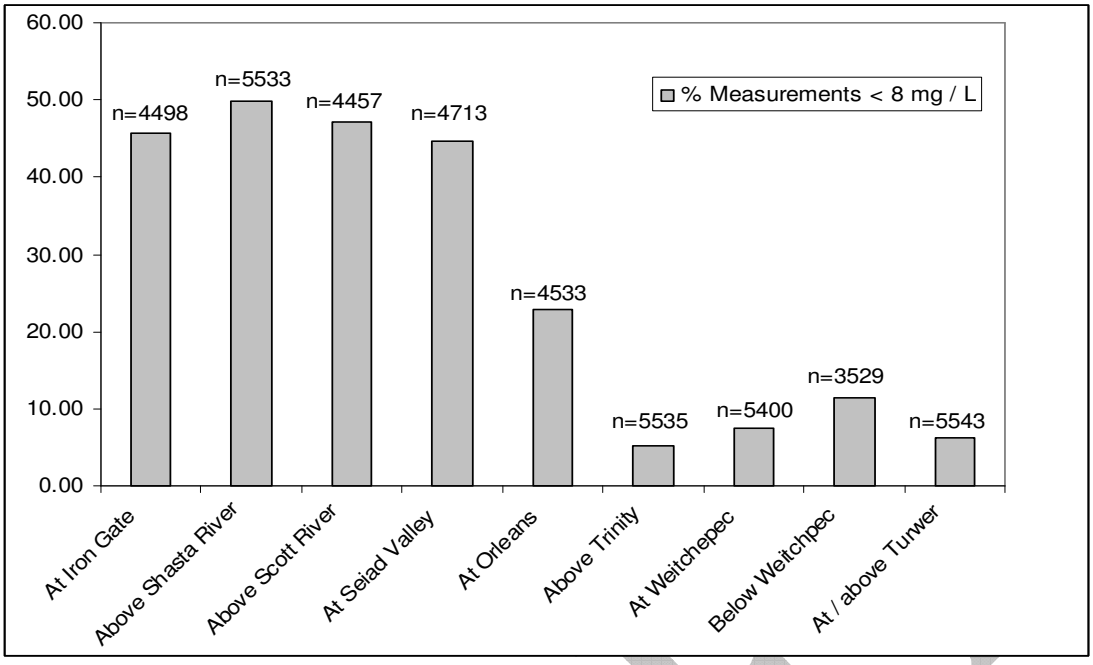


Figure 2.24: Percent of DO measurements below Basin Plan Water Quality Objective of 8.0 mg/L for 2005 at nine stations along the Klamath River

The analysis presented below addresses the revised DO objective being proposed. The revised objective requires that in those waterbodies identified as COLD but unable to meet the salmonid life cycle requirements due to natural conditions, a minimum 85% saturation limit, as calculated based on natural water temperatures must be maintained.

In order to compare the USFWS measured DO data to the proposed DO objective assumptions related to temperature and barometric pressure were made. Percent DO saturation was calculated based on measured water temperatures and using a seasonal average barometric pressure. These assumptions make for a very conservative estimate of the percent of measurements below the proposed objective of 85% DO saturation at natural water temperatures. Natural water temperatures for the years 2004-2006 are not known as the TMDL model has not been applied to these years. The results of the analysis are presented in Table 2.11 and Figure 2.25. In 2004, six of the nine stations had more than 10% of the DO measurements below 85% DO saturation.

Table 2.11: Percent of calculated percent DO saturation estimates below the proposed Basin Plan Water Quality Objective of 85% saturation for 2004 – 2006 at nine stations along the Klamath River

% Measurements below 85% saturation at median of pressure range	**2004**		**2005**		**2006**	
	n	**%**	**n**	**%**	**n**	**%**
At Iron Gate	2706	10	4498	6	5391	18
Above Shasta River	5478	25	5533	24	-	-
Above Scott River	2966	35	4457	20	-	-
At Seiad Valley	3381	14	4713	11	5526	0
At Orleans	4057	6	4533	0	5349	0
Above Trinity	-	-	5535	0	5739	0
At Weitchpec	4142	19	5400	0	5332	0
Below Weitchpec	5500	0.1	3529	0	5293	0
At/above Turwar	5066	12	5543	0	-	-

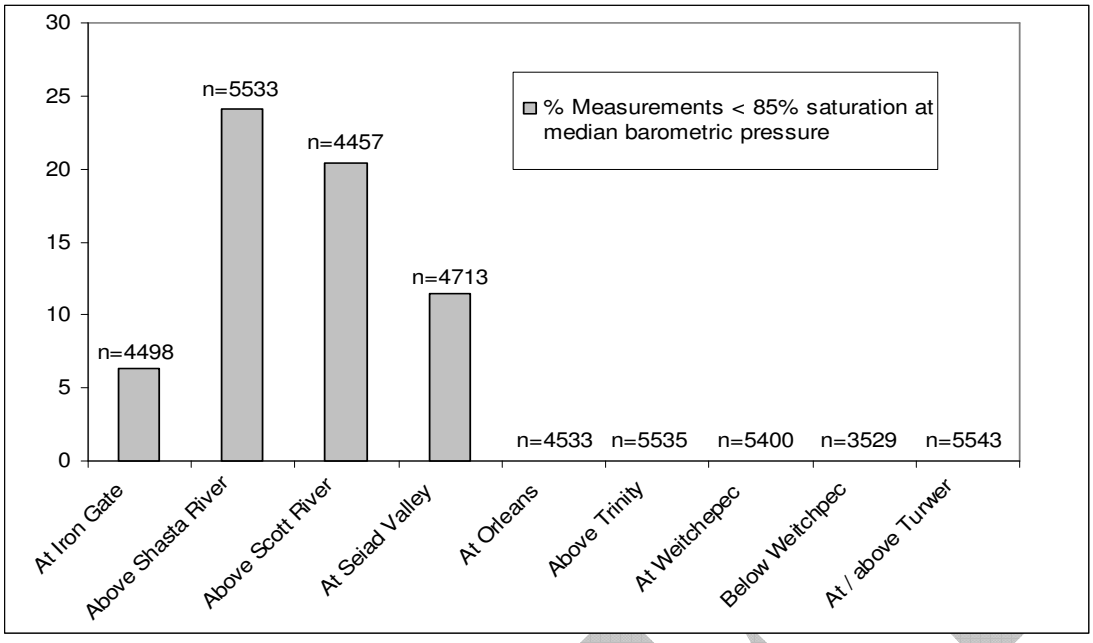


Figure 2.25: Calculated percent DO saturation at nine stations on the Klamath River for 2005

2.5.6 pH

This assessment includes an evaluation of pH conditions along the Klamath River independent of the diurnal variation driven by photosynthesis that was addressed in Section 2.5.3.3. The data for this analysis also comes from the USFWS, Karuk and Yurok Tribes datasonde measurements. The same years (2004 – 2006) used in the DO analysis were also selected for the pH assessment. The Basin Plan water quality objective for pH is a maximum of 8.5 and a minimum of 7.0.

For 2005 (Figure 2.26) at six of the nine Klamath River stations the Basin Plan objective of 8.5 is exceeded in more than 15% of the samples taken.

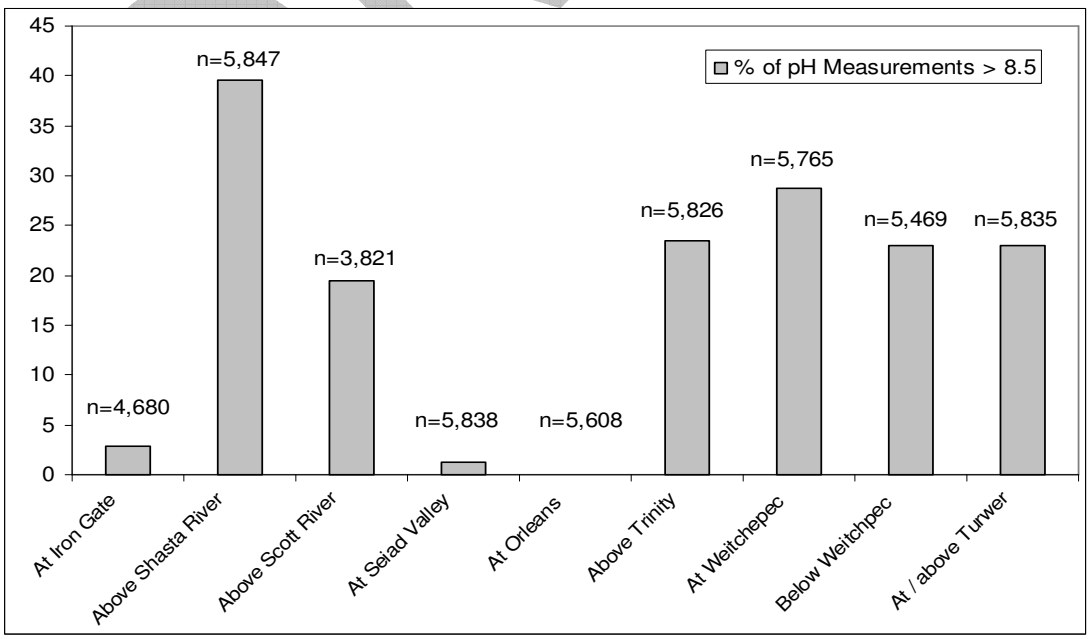


Figure 2.26: Percent of 2005 pH measurements in the Klamath River that exceed 8.5

Five of the stations have more than 20% noncompliant measurements. The highest rate of noncompliant measurements is 48% recorded at Orleans in 2006 (Table 2.12). In the three year sample all nine stations exceeded a noncompliant measurement rate of greater than 10 percent at least once. The rate of noncompliance for the minimum pH of 7.0 is less than 0.05% at all stations. Therefore a sampling station summary table and plot have not been prepared for minimum pH.

Table 2.12: Percent of pH measurements above 8.5 for 2004 – 2006 at nine stations along the Klamath River.

Percent of Measurements above 8.5	2004		2005		2006	
	n	%	n	%	n	%
At Iron Gate	5192	32	4680	3	5486	30
Above Shasta River	5762	37	5847	40	-	-
Above Scott River	3834	28	3821	19	-	-
At Seiad Valley	3808	1	5838	1	5576	32
At Orleans	4844	0	5608	0	5442	48
Above Trinity	-	-	5826	23	5746	18
At Weitchpec	4449	33	5765	29	5823	27
Below Weitchpec	5823	1	5469	23	5125	42
At/above Turwar	4712	16	5835	23	-	-

2.5.7 Ammonia Toxicity

Regional Water Board staff evaluated all the data within our compiled Klamath River datasets in which all 3 parameters (pH, NH3, and temperature) were collected at the same time. Based upon the evaluation, there were no documented times in which acute or chronic aquatic life criteria for ammonia toxicity was exceeded.

To take this one step further, staff evaluated all the available pH and temperature data to determine what the concentration of ammonia would need to be in order for toxicity (acute or chronic) to be present. The results of that effort showed that acute toxicity probably does not occur on the Klamath River in California. However, the results showed that there are probably times when the chronic criteria are exceeded, but only for short durations of perhaps a few hours in a day on a few days in a year. EPA guidance suggests that chronic criteria for the protection of aquatic life should be addressed over an averaging period of 4-days. Regional Water Board staff concludes that based on the available data, acute ammonia toxicity has not occurred in the times/years when data is available, and excursions of the chronic ammonia criterion probably only occur for short durations on a few days in a year, and, if so, do not constitute an impairment of beneficial uses.

2.5.8 Sediment

The New Years Day flood of 1997 provided an example of some of the ways in which increased sediment loads affect stream temperatures in the Klamath River basin. A report by Klamath National Forest personnel (De La Fuente and Elder 1998) documenting the flood impacts within the Klamath national Forest reported 536 miles (19%) of channels that were significantly altered (i.e. with significant scouring,

excessive sediment deposition, or riparian vegetation removal) by the flooding and associated sediment pulses of the 1997 flood. The report stated that "there appeared to be a considerable reduction in size, volume, and depth of pools in Elk, Indian, Beaver, Grider, Tompkins, South Fork Salmon, and Walker Creeks, and there is a larger proportion of fine sediment in the substrate. Alluvial reaches were made shallower and wider due to the sedimentation". The report found that approximately 30% to 60% of riparian vegetation was lost in the alluvial reaches of the most affected tributaries. These effects of increased sediment loads were observed in Elk, Indian, Ukonom, Independence, Grider, Oneil, Portuguese, Beaver, Horse, and Walker Creeks, as well as numerous other streams throughout the Klamath basin after the flood of 1997 (Figure 2.27 (De La Fuente and Elder 1998; Kier Associates 1999).

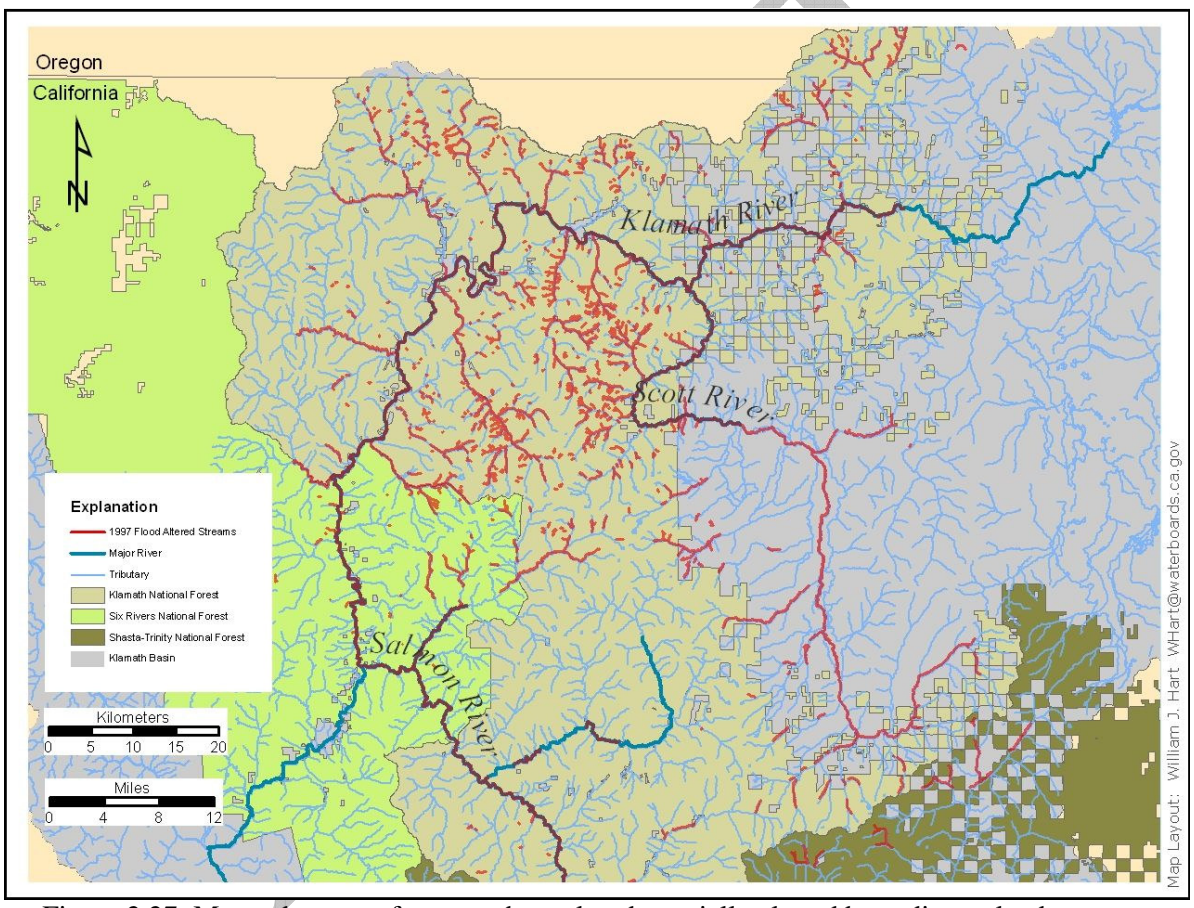


Figure 2.27: Mapped extent of stream channels substantially altered by sediment loads associated with the 1997 flood. Source: Klamath National Forest.

De la Fuente and Elder presented a comparison of Elk Creek temperature data before and after the flood. The data showed that in the summer after the flood, the peak temperature was the highest of seven years of record, and was 3.8°F higher than the average from 1990-1995. Likewise, the diurnal variation increased to 12.5°F, 4.9°F higher than the 1990-1995 average.

The *Public Review Draft Staff Report for the 2008 Integrated Report for the Clean Water Act Section 305(b) Surface Water Quality Assessment and the 303(d) List of Impaired Waters* (Regional Water Board 2008) recommends to the Regional Water Board that the Klamath River watershed downstream of Iron Gate Dam to the Trinity River be listed as impaired for sedimentation/siltation. This recommendation has not yet been considered by the Regional Water Board. The portion of the Klamath River watershed from the Trinity River to the mouth of the Klamath is currently on the section 303(d) list for sedimentation/siltation impairment.

2.6 Evidence of Beneficial Use Impairment

Section 2.5 demonstrates that temperature, DO, biostimulatory substances, and related water quality objectives are not met at many locations at some times of the year in the Klamath River in California. Exceedance of these water quality objectives contributes to the impairment of a number of existing beneficial uses in the Klamath River. Evidence of impairment of the COLD, RARE, MIGR, SPWN, CUL, FISH, REC-1, REC-2, and MUN beneficial uses is presented in this section. This evidence of beneficial use impairment compels the need to develop TMDLs to address the temperature, DO, and nutrient water quality problems in the Klamath River.

2.6.1 Evidence of Impairment to Cold Freshwater Habitat (COLD), Rare, Threatened, or Endangered Species (RARE), Migration of Aquatic Organisms (MIGR), and Spawning, Reproduction, and/or Early Development (SPWN)

The COLD, RARE, MIGR, and SPWN beneficial uses are currently not fully supported in the Klamath River in California, as demonstrated by the decline of salmonid populations, adult and juvenile fish kills caused by disease outbreaks, migration barriers for adult and juvenile salmonids, and degradation of spawning habitat.

2.6.1.1 Salmonid Population Decline

Although historically there were large runs of salmonids in the Klamath River basin, current data indicate that populations have declined sharply since the early 1900's. Utilizing information from Snyder (1931), the NRC estimated that the annual total catch in the Klamath River during the period from 1916-1927 was probably 120,000 to 250,000 fish, and thus the number of potential spawners and total population numbers was considerably higher (NRC 2004, p.267, 268). In 2007, fall and spring Chinook population estimates were 132,167 and 12,628 respectively (CDFG 2008). No current estimate of steelhead and coho populations has been made, however, it is presumed that populations have declined dramatically from historic numbers (Brown and Moyle 1991, p.8; Brown et al. 1994; Busby et al. 1994 as cited by NRC 2004, p.274; CDFG 2002, p.1; NRC 2004, p.273). More detailed information on the decline of salmonid populations in the Klamath River basin can be found in Appendix 4 (Carter and Kirk 2008), and brief summaries are presented below.

Fall Chinook Salmon

Fall Chinook numbers in the Klamath River basin have dramatically declined during the past century (Hardy and Addley 2006, p.7). The Klamath River fall Chinook run once

totaled as many as 500,000 fish annually (Moyle 2002, p.258). Fall Chinook numbers in the Shasta River basin alone, historically numbered 20,000-80,000 fish per year (Regional Water Board 2006, p.1-25). Basin-wide fall Chinook population estimates for the period from 1978-2007 ranged from a high of 239,559 fish in 1987 to fewer than 35,000 fish in 1991 (CDFG 2008).

Spring Chinook Salmon

A population of more than 100,000 spring-run Chinook was once present in the basin, although this estimate is probably low because spring-run fish were the main run of Chinook in the Klamath mainstem in the 1800's (Moyle 2002, p.259). Historic run size estimates in each of the Sprague River, Williamson River, Shasta River, and Scott River alone were at least 5,000 fish (CDFG 1990 as cited by Moyle 2002, p.259). Population estimates for spring Chinook during the period from 1980-2006 ranged from a high of 69,004 fish in 1988 to fewer than 1,945 in 1983 (CDFG 2006).

Steelhead Trout

Hardy and Addley (2006, p.6) report that historical run sizes for steelhead trout in the Klamath River basin were estimated at "400,000 fish in 1960 (USFWS 1960 as cited by Leidy and Leidy 1984), 250,000 in 1967 (Coots 1967), 241,000 in 1972 (Coots 1972) and 135,000 in 1977 (Boydston 1977)." More recent run sizes are summarized below.

Spring/Summer Steelhead Trout

Annual counts of spring/summer steelhead in holding areas throughout the Klamath River basin ranged from 500 to 3,000 fish (Roeloffs 1983, as cited by Hopelain 1998, p.1). In the 1990's it was estimated that there were 1000-1500 spring/summer steelhead adults divided among eight populations in the basin (Barnhart 1994; Moyle et al. 1995; Moyle 2002 as cited by NRC 2004, p.274). NMFS considers spring/summer steelhead stocks depressed and in danger of extinction (Busby et al. 1994 as cited by NRC 2004, p.274).

Fall Steelhead Trout

The fall steelhead represent the largest of the three steelhead runs, and were estimated to include 55,000-75,000 spawning adults and 150,000-225,000 half-pounders during the period from 1980-1982 (D.P. Lee, CDFG, pers. comm. as cited by Hopelain 1998, p.1).

Winter Steelhead Trout

Run size estimates for Klamath River winter steelhead were 170,000 in the 1960s, 129,000 in the 1970s, and 100,000 in the 1980s (Busby et al. 1994 as cited by NRC 2004, p.273). Current population estimates for winter steelhead have not been conducted, although Hopelain (1998, p.1) estimated a run-size of about 5,000 to 25,000 during 1980-1982. It is presumed that winter steelhead abundance is still declining although estimates, both past and present, are not very reliable (NRC 2004, p.273).

Coho Salmon

It is clear from the information available that coho salmon populations statewide have undergone a dramatic decline from historic levels (Brown and Moyle 1991, p.8; Brown et

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al. 1994; CDFG 2002, p.1). Maximum estimates for coho spawners in California during the 1940's range from 200,000-500,000 fish (Sagar and Glova 1988 as cited by Moyle 2002, p.250). Brown et al. (1994) state that California coho populations are probably less than 6% of what they were in the 1940s, and there has been at least a 70% decline since the 1960s. In 1994, Brown et al. estimated the coho salmon population in California to be 30,000 fish, with natural spawners comprising 43% of the total population or 13,240 fish.

The Southern Oregon/Northern California Coast Evolutionary Significant Unit (SONCC ESU), which encompasses Klamath River stocks, has been listed as threatened by the State of California and the Federal government. Coho salmon occupy only 61% of the SONCC ESU streams previously identified as historical coho salmon streams (CDFG 2002, p.2).

Historical spawning escapement estimates for the Klamath River basin approximate 15,400-20,000 coho, with 8,000 of these fish originating in the Trinity River (USFWS 1979, App. as cited by Brown et al. 1994). In 1965, CDFG estimated 15,400 coho spawners per year in the basin (CDFG 1965, p.369). In 1994, Brown et al. estimated a total abundance of 18,125 coho in the Klamath River, including 1,860 native and naturalized fish. Current population estimates for coho in the Klamath River basin have not been conducted, although adult coho return numbers to the Iron Gate Hatchery, Trinity River Hatchery, and Shasta River Fish Counting Facility during the last 42 years averaged 5949 fish (Hampton 2004, p.1; Hampton 2005a, p.1; Hampton 2005b; KRIS 2006; Marshall 2005; and Rushton 2005).

2.6.1.2 Juvenile and Adult Fish Kills

Poor water quality conditions in the Klamath River have resulted in both adult and juvenile fish kills reflecting an impairment of the COLD and RARE beneficial uses. Figure 2.28 identifies the mainstem Klamath River reaches in California where adult and juvenile fish kills have been documented.

It is believed that juvenile fish kills are very common in the Klamath River from Iron Gate Dam to the mouth of the river but often go undetected. Direct observation of juvenile fish kills is not common due to the small size of the juvenile fish within the large river system and the generally small number of outmigrant traps that operate in the river (Klamath Fish Health Assessment Team [KFHAT] 2005, p.5, 6).

Juvenile fish kills in the Klamath River in California have been documented for the years 1994, 1997, 1998, 2000, 2001, and 2004 (Table 2.13). Estimates of the number of dead fish range from 269-300,000 juvenile salmonids and non-salmonids. Disease was the ultimate cause of death in all juvenile fish kills documented. The effects of disease were exacerbated by poor water quality conditions, including low DO, high water temperature, high ammonia concentrations, and low flow. Temperatures documented during these fish kills were as high as 25 ^{o}C, well above the lethal threshold for juvenile salmonids. Additionally, DO levels as low as 3.1 mg/L were recorded during these fish kills, which is well below the current Basin Plan objective of 8 mg/L.

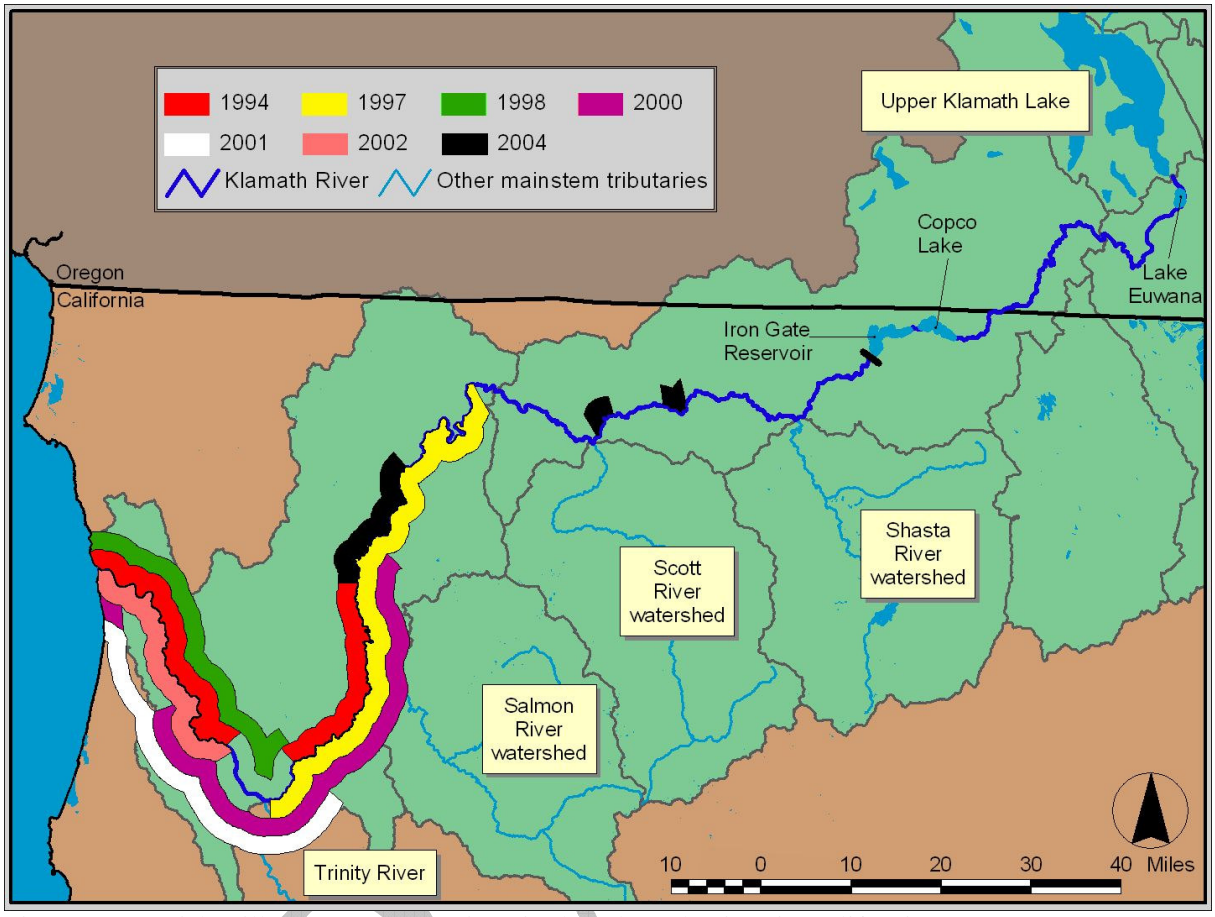

Figure 2.28: Fish Kill Years and Locations in the Klamath River in California

Table 2.13: Juvenile Fish Kill Locations and Causes in the Klamath River in California

Year	River Location	Fish	Cause of Death	Exacerbating Factors				Citations
				D.O.	Temp	NH_3	Flow	
1994	middle/ lower	~300 Chinook	Non stated		X			Foott (2005) USFWS (1997)
1997	Middle	non-salmonids salmonids	Disease	X	X	X	X	Hannum (1997) Hendrickson (1997) USFWS (1997)
1998	Various	~148,000 Chinook	Disease	X	X		X	Williamson and Foott (1998)
2000	middle/ lower	10,000-300,000 Chinook & steelhead	Disease	X	X			CDFG (2000, p.1, 10, 11), Deas (2000), Foott (2000), USFWS (2003a)
2001		269 Chinook[1]	Disease					Foott et al. (2002)
2004	upper/ middle	<250,000 Chinook	Disease		X			Engbring (2004) KFHAT (2005) Klamt and Carter (2004)

[1] It is likely that the peak of the disease epizootic and associated mortalities of juvenile Chinook likely occurred prior to when KFHAT conducted their reconnaissance surveys, and thus the actual number of dead fish was much higher (KFHAT 2005).

Documentation of adult fish kills in the Klamath River in California is available for 1997 and 2002 (Table 2.14). The 1997 fish kill was determined to be caused by Columnaris and other diseases and was exacerbated by maximum water temperatures around 26°C, low DO levels of 3.1 mg/L, low flows, and high ammonia concentrations (Hannum 1997; Hendrickson 1997).

In mid to late September 2002 at least 34,000 fish died in the lower 36 miles of the Klamath River, although actual losses may have been more than double this number (CDFG 2004, p.III). Approximately 98.4% (33,527) of the fish killed were anadromous salmonids, representing 19.2% of the total 169,297 Klamath-Trinity run for 2002 (USFWS 2003b p.ii).

Table 2.14: Adult Fish Kill Locations and Causes in the Klamath River in California

Year	River Location	Fish	Cause of Death	Exacerbating Factors					Citations
				D.O.	Temp	NH_3	Flow	Sediment	
1997	middle	>50/day non-salmonids	Disease	X	X	X	X		Hannum (1997) Hendrickson (1997) USFWS (1997)
2002	lower	>34,000 (including >33,500 salmonids)	Disease		X		X	X	USFWS (2003a) USFWS (2003b) CDFG (2004)

Multiple compounding factors likely contributed to the 2002 fish kill, including an early large run of fall Chinook, low river discharge which did not provide suitable attraction flows to trigger upstream migration, and warm water temperatures which were optimal for disease proliferation (CDFG 2004, p.III, 33, 124; USFWS 2003a, p.ii). Additionally, fish passage through the lower Klamath River may have been impeded by the shallow depth of the water flowing over some riffles, which were created by sediment deposition during high discharge events in the winters of 1997 and 1998 (CDFG 2004, p.III; USFWS 2003a, p.37). The majority of the dead fish examined were infected with the fish diseases *Ichthyophthiriasis* (Ich) and Columnaris, which was identified as the principal cause of death (CDFG 2004, p.III; USFWS 2003a, p.ii). Maximum daily water temperatures recorded at Turwar (RM 7) during September ranged from 18-23°C (CDFG 2004, p.70). Seven-day running averages of the weekly maximum temperature (MWMT) during this period ranged from 19-22.5°C (CDFG 2004, p.70), which exceeds the USEPA (2003) MWMT threshold values of 16°C (adult migration/core juvenile rearing), 18°C (adult migration/non-core juvenile rearing), and 20°C (adult migration). Although these high water temperatures are not unusual for the Klamath River, they are ideal for disease proliferation and thus contributed to a disease epizootic (the equivalent of an epidemic in humans) (CDFG 2004, p.III, 124; USFWS 2003a, p.ii).

2.6.1.3 Adult and Juvenile Salmonid Migration Barriers and Spawning and Rearing Habitat Degradation

Unless otherwise specified, the following information is from CDFG 2004 (p.III, 83), Hardy and Addley 2006 (p.10, 15, 20), and USFWS 2003a (p.ii, 36).

Poor water quality conditions are contributing to the impairment of migration (MIGR) of aquatic organisms, particularly salmonids. Section 2.4.4.1 summarized findings by Strange (2007) that adult fall Chinook salmon migration is dependent on stream temperature. As shown in Section 2.5.2 Klamath River mainstem and tributary water temperatures during the period of fall Chinook migration are often over the temperatures noted by Strange (2007) that inhibit upstream migration. Thus elevated water temperatures contribute to the impairment of MIGR.

Alterations in flow in the Klamath River basin have contributed to the degradation of salmonid spawning and rearing habitat (SPWN). Principal factors affecting anadromous fish production in the Klamath River from Iron Gate Dam to Weitchpec include impaired flow in some tributaries (particularly the Shasta and Scott Rivers), impaired flows in the mainstem, and alterations to the timing and magnitude of mainstem flows. Alterations in flow due to the presence of dams have resulted in armoring of the streambed, which combined with a lack of gravel recruitment from upstream sources, has resulted in degraded spawning habitat (Hardy and Addley 2006, p.15). One of the primary limiting factors for anadromous fish production in the Klamath River from Weitchpec to the mouth is the cumulative effect of impaired flow and alterations in the seasonal hydrograph. These impacts have contributed to the degradation of available spawning gravel from sedimentation (Hardy and Addley 2006, p.20).

Cumulative impacts resulting in sediment delivery to many tributaries of the Klamath River in California, in conjunction with alterations in the hydrograph of the mainstem, which has reduced high flows that historically flushed sediment through the system, have contributed to the formation and persistence of large delta fans at many tributary confluences, impeding adult and juvenile migration (MIGR). In low flow years, this accumulation of sediment can inhibit or block access to these tributaries, thereby restricting access to habitat and thermal refugia for migrating adult and juvenile salmonids. Salmonids that are unable to enter the tributaries are forced to seek space in the limited areas of thermal refugia in the mainstem Klamath River. Overcrowding of salmonids in mainstem thermal refugia areas, combined with the high water temperatures can exacerbate disease proliferation.

As mentioned in the previous section, there is evidence that conditions inhibiting adult migration may have contributed to the 2002 adult fish kill in the Klamath River. USFWS reported that in 2002 Klamath River flows were too low to trigger upstream migration causing adults to congregate in the lower river. After the fish kill was underway the U.S. Bureau of Reclamation increased flows, and salmonids responded by migrating out of the lower river. CDFG hypothesized that fish passage may have been impeded by shallow water depth over certain riffles, resulting from low flows and lack of cues for upstream migration.

> CDFG…reported that in 1997 and 1998 high discharge events occurred in northern California that could have altered the channel of the Klamath River. They suggested that the input of high sediment loads during high discharge events could have resulted in the filling of

> pools and increased the elevation of riffles in the lower Klamath River. Furthermore, they speculated that discharges that may have been sufficient for fish passage in low discharge years prior to 1997 were inadequate for passage in September 2002 (CDFG 2003b, as cited by USFWS 2003a, p.37).

Additionally,

> USFWS biologists working on the lower Klamath River [in September of 2002] observed low-flow conditions, making it more difficult to traverse shallow riffles in a jet boat than in previous years (Shaw 2002, personal communication). They observed that water depth at Pecwan and Ah Pah riffles appeared shallow enough to be an impediment to adult fish passage. Yurok biologists also observed that fish passage over some riffles was confined to multiple small channels, in which their jet boat with a six-inch draft, would occasionally touch bottom (Belchik 2003, personal communication). A former NMFS fisheries biologist (Gilroy 2003, personal communication) with experience working on the Klamath river suggested when flows are low, fish passage over certain riffles is confined to smaller channels, representing the main thalweg and much of the riffle is too shallow to pass fish. The DFG Fisheries Biologist, who has participated in angler surveys on the Klamath River since 1985, described water levels during September 2002 in the fish-kill area as the lowest she has observed in over 20 years of experience (Borok 2003, personal communication). These anecdotal observations raised concern that shallow water depth over certain riffles might have impaired the ability of salmon and steelhead to migrate upstream (CDFG 2004, p. 87).

Thus, alterations in flow and changes in channel conditions resulting from sedimentation in the mainstem Klamath River in California have contributed to the impairment of MIGR, and SPWN.

2.6.2 Impairment of Native American Culture (CUL) and Subsistence Fishing (FISH) Beneficial Uses

The Water Quality Control Plan for the North Coast Region (Basin Plan) includes two Native American Cultural beneficial uses; Native American Culture (CUL) and Subsistence Fishing (FISH). The CUL beneficial use covers "uses of water that support the cultural and/or traditional rights of indigenous people such as subsistence fishing and shellfish gathering, basket weaving and jewelry material collection, navigation to traditional ceremonial locations, and ceremonial uses"; FISH encompasses "uses of water that support subsistence fishing" (Regional Water Board 2007). CUL is designated as an "Existing" use in the Ukonom, Happy Camp, Seiad Valley, Klamath Glen, and Orleans Hydrologic Subareas of the Klamath River. Due to a lack of available information at the time of the last update of the Basin Plan, no waterbodies in the North Coast have been designated as "Existing" or "Potential" use for FISH. Based on the available

information, however, Regional Water Board staff consider FISH an existing use within the same Hydrologic Subareas of the Klamath River as those designated CUL.

The CUL beneficial use in the Klamath River in California is currently impaired due to the decline of salmonid populations and degraded water quality resulting in changes to or the elimination of ceremonies and ceremonial practices and risk of exposure to degraded water quality conditions during ceremonial bathing and traditional daily activities. The FISH beneficial use is currently impaired in the Klamath River basin in California due to the decline of salmonid populations and other Tribal Trust fish populations resulting in decreased use, abundance, and value of subsistence fishing locations, altered diet and associated physical and mental health issues, and increased poverty. Additionally, the presence of the toxin microcystin in fish and mussels in the Klamath River has the potential to impair both the CUL and FISH benefical uses. It is important to note that other beneficial uses, such as COLD and MUN, are linked to the support of the CUL and FISH beneficial uses throughout the year.

2.6.2.1 Decline in Salmonid and Other Fish Populations

The decline of salmon populations, as well as the decline of other Tribal Trust fish species of the Klamath River basin in California including sturgeon, eulachon (candlefish), lamprey (eel) and some species of suckers, has impaired the CUL and FISH beneficial uses. The elimination of the spring Chinook run above the Salmon River has resulted in the elimination of cultural ceremonies associated with the migration of this species through the length of the Klamath River. Declines in fish populations, especially salmonids, has also resulted in decreased use, abundance, and value of subsistence fishing locations, an altered daily diet that has been linked to health issues for Tribal Members, and increased poverty.

An elaborate ceremony called the First Salmon Ceremony, marks the passing of the first spring Chinook salmon up the Klamath River. This migrating salmon was allowed to pass all the way up the Klamath River to its spawning ground. It was believed that the first spring Chinook migrating upstream would leave its scales at each spawning location for the rest of the salmon run to follow (Roberts 1932 as cited by Sloan 2003, p. 25). This first migrating salmon of the year was considered taboo, and if eaten would cause convulsions and death. Thus, the First Salmon Ceremony allowed this fish to pass safely upstream, thereby lifting the taboo, and allowing the Native People to fish for salmon in the river (Waterman and Kroeber 1938 as cited by Sloan 2003, p.25). The dramatic decline in the spring Chinook run has made it impossible for the Klamath River Tribes to conduct the First Salmon Ceremony. "And how do you perform the Spring Salmon Ceremony, how do you perform the First Salmon Ceremony, when the physical act of going out and harvesting that first fish won't happen?"(Leaf Hillman 2004 as cited by Norgaard 2005, p.35).

The Karuk Tribe historically depended on the abundant populations of fish found in the mainstem Klamath River for subsistence. However, as fish populations have declined the Karuk have shifted their reliance to other food source (Reed 2007a). Ron Reed (2005), traditional dipnet fisherman and cultural biologist for the Karuk Tribe, states that there is

only one remaining Tribal fishery location that provides any level of subsistence fishing to the Karuk Tribe, Ishi Pishi Falls. According to Reed (2005), in 2002, about 1,500 fish were caught at Ishi Pishi falls, in 2003 approximately 1,000 fish were caught, and in 2004 only 100 fish were harvested at this location. The limited harvest of fish at Ishi Pishi Falls has meant that even ceremonial salmon consumption is limited (Ron Reed Pers. Comm. as cited by Norgaard 2005, p.4). According to Norgaard (2006), in addition to declining salmonid numbers, the fishery at Ishi Pishi Falls is negatively affected by low flows. When flows are too low the ability to perform dip net fishing is limited and fewer fish are caught (Norgaard 2006).

The importance of fishing to Tribal Members is reflected by the fact that fishing locations are a form of real property (Pierce 2002, p.7-2; Sloan 2003, p.17). They can be owned by individuals, families, or a group of individuals, and can be borrowed, leased, inherited, and bought and sold (Sloan 2003, p.17, 18). The quality, use, and value of these fishing locations has been reduced as factors including increased siltation and decreased salmonid abundance have occurred in the Klamath River and its tributaries (Sloan 2003, p.18, 28).

Historically, the Karuk Tribe had a platform fishery associated with each of their 100 Tribal village sites (Reed 2006). These fisheries were located near the tops of riffles, where eddies were created along the margins of the Klamath River. These areas of low velocity were where the salmon would hold and/or utilize this microhabitat as a migration corridor. According to Reed (2006) these 100 platform fishery locations are no longer as productive as they once were, or are gone. Tribal elders convey that the riffles near these fishing areas have been filled in and flattened out by sediment, contributing to the decline in overall fish populations (Reed 2006), as well as contributing to the loss of a culturally significant way of life.

The decline of salmonids and other Tribal Trust fish populations in the Klamath River basin has altered the diet of each of the Tribes along the river and its tributaries. Historically, traditional consumption of fish by the Karuk Tribe was estimated at 450 pounds per person per year, while in 2003 the Karuk People consumed less than 5 pounds of salmon per person, and in 2004 less than ½ pound per person was consumed (Norgaard 2005, p.13). In 2005 over 80% of Karuk households surveyed reported that they were unable to harvest adequate amounts of lamprey (eel), salmon or sturgeon to fulfill their family needs (Norgaard 2005, p.4). Furthermore, 40% of Karuk households reported that there are fish species that their family historically caught, which are no longer harvested (Norgaard 2005, p.7).

The decrease in abundance and availability of traditional foods, including salmon, trout, eel, shellfish, sturgeon and riparian plants, is responsible for many diet related illnesses among Native Americans including diabetes, obesity, heart disease, tuberculosis, hypertension, kidney troubles and strokes (Joe and Young 1993 as cited by Norgaard 2005, p.9, 39). These conditions result from the lack of nutrient content in foods consumed in place of the traditional foods such as salmon, as well as from the decrease in exercise associated with fishing and gathering food (Norgaard 2005, p.40). The

estimated diabetes rate for the Karuk Tribe is 21%, nearly four times the U.S. average, and the estimated rate of heart disease for the Karuk Tribe is 39.6%, three times the U.S. average (Norgaard 2005, p.40).

In addition to altered diet and increased health issues, declines in fish populations have resulted in a documented increase in poverty rates for some Klamath River Tribes.

> The destruction of the Klamath river fishery has led to both poverty and hunger. Prior to contact with Europeans and the destruction of the fisheries, the Karuk, Hupa and Yurok tribes were the wealthiest people in what is now known as California. Today they are amongst the poorest. This dramatic reversal is directly linked to the destruction of the fisheries resource base.
>
> The devastation of the resource base, especially the fisheries, is also directly linked to the disproportionate unemployment and low socio-economic status of Karuk people today. Before the impacts of dams, mining and over fishing the Karuk people subsisted off salmon year round for tens of thousands of years. Now poverty and hunger rates for the Karuk Tribe are amongst the highest in the State and Nation. The poverty rate of the Karuk Tribe is between 80 and 85% (Norgaard 2005 Exec Summary).

2.6.2.2 Degraded Water Quality

Degraded water quality in the Klamath River basin in California, including the seasonal presence of blue-green algae and algal toxins in the Klamath River and reservoirs (see Section 2.5.4), has impaired the CUL and FISH beneficial use. Known and/or perceived health risks associated with degraded water quality have resulted in the alteration of cultural ceremonies to exclude or limit ingestion of river water. Additionally, known or perceived risk of exposure to degraded water quality conditions during ceremonial bathing and traditional cultural activities such as bathing, gathering and preparing basket materials, and collecting and using plants has resulted in an impairment of CUL.

The presence of blue-green algae and algal toxins in the Klamath River and reservoirs has impaired the cultural practice of subsistence fishing. The Karuk Tribe has only one fishing location available to them and it is flow dependent. Thus, when fish are in the river and the flow is suitable for fishing, Tribal Members must fish even if blue-green algae and algal toxins are present in the river. Susan Corum, Water Resources Coordinator for the Karuk Tribe, states: "It is really not a choice to fish. It is part of their culture which they need to maintain (Corum 2007)."

Microcystin has been identified in the waters of Klamath River, as well as in the liver of salmonids and in mussels from the river. Laboratory analyses detected a trace of microcystin in the liver of an adult steelhead, and 0.54 µg/kg in the liver of a half-pounder steelhead landed in the Klamath River at Weitchpec on October 3, 2005. Although these levels are not above the 250 µg/kg threshold which is advised by Van

Buynder et al. (2001) to protect human health, the Yurok Tribe has expressed concern that the mid- to late summer blooms of *Microcystis* in the Klamath River generally coincides with increased salmonid upstream migrations and subsequent usage of salmonid meat for recreational, cultural, and sport purposes. Mussels in the Klamath River have also had detectable levels of microcystin found in them. In 2007, a mussel was found in the Klamath River containing >1500 µg/kg microcystin, over the threshold to protect human health advised by Van Buynder et al. (2001). The presence of microcystin in salmonids and mussels of the Klamath River has resulted in an impairment of the cultural practice of subsistence fishing.

The Klamath River Tribes practice their culture through their "World Renewal" ceremonial cycle, such as the "First Salmon Ceremony" and Jump Dance, the Boat Dance, the War Dance, and the White Deerskin Dance (Reed 2007b). Other Tribal ceremonies and rituals include the Brush Dance and the Flower Dance, as wells as other rituals that require a spiritual cleansing process such as for fishing and hunting, funerals, and good luck (Reed 2007b). All of these ceremonies and rituals require Tribal members to be in close proximity to the Klamath River and they are integrally linked to the river and its health (Sloan 2003 p.18).

According to Karuk Cultural Biologist Ron Reed (2006, 2007b), the "World Renewal" ceremonial cycle is held on the Klamath River at Amerikirum (approximately 2 miles below Somes Bar), Clear Creek (Inam), Somes Bar (Katimin), and Orleans (Panamnik) starting in April and continuing through September of each year. The Medicine Man, who leads the ceremony at Clear Creek, walks 14 miles through the ridges and hills along the Klamath River and is joined halfway through his journey by children and adults of the Tribe who follow him the rest of the way for good luck. Upon reaching the Klamath River at the end of this walk, it was historically tradition to drink water from the river to complete the ceremony. This is no longer done due to health concerns about drinking water directly from the river, though children are still known to jump in and drink the water (Reed 2006).

Ceremonial bathing in the river is an important part of most ceremonies (Curtis 1924 as cited by Sloan 2003, p.28). For example, bathing in the Klamath River and its tributaries is a requirement for participants in the Brush Ceremony (Sloan 2003, P.16). "During the Fish Dam Ceremonies at *Kepel*, young girls were selected by the Medicine Man to participate in the ceremonies. Once selected, they were sent to the river to bathe and then were dressed in full regalia which they would wear during the ceremonies. Then they were sent home to their families, and were required to fast and bathe in the river every day" (Van Stranlen 1942 as cited by Sloan 2003, p. 28). During the World Renewal Ceremonies, the Medicine Man and other participants bathe in the Klamath River for up to 10 days (Reed 2006).

Bathing is also associated with funeral services, subsistence practices, recreational swimming, courtship, and for individual hygiene (Reed 2007a). Bathing associated with funeral rituals occurs year round and includes preparation for burial, and purification after burial (Curtis 1924 as cited by Sloan 2003, p.28). The Karuk Tribe historically

bathed freely in the Klamath River, however in more recent years degraded water quality conditions during the summer have forced them to take precautionary steps while bathing in the river (Reed 2007a). The Yurok Tribe has reported that detached algae have been present in the Klamath River in amounts high enough to prevent access and negatively affect the spirituality associated with bathing areas (McKernan 2006).

Willow roots, wild grape, Cottonwood, and Oregon Grape are collected by Tribal Members in the riparian zone of the Klamath River and used to make baskets (Reed 2007a). Traditional collection of these basketry materials often involved wading in the water (Sloan 2007a), and further contact occurs when the material is washed and cleaned in the water (Reed 2007a). Additionally, willow roots are peeled by mouth following cleaning with river water (Reed 2006). In addition, plants are collected for food, medicine, materials, and other cultural functions (Reed 2007a). Gathering plants or plant materials involves wading and contact with the Klamath River (Sloan 2007a; Reed 2007a). Ingestion of water can occur because plants are often cleaned in the river water and water is consumed with medicinal plants (Sloan 2007a). Given degraded water quality conditions, ingestion of water may pose a potential health risk.

Table 2.15 provides a summary of the activities that are encompassed by the CUL and FISH beneficial uses. Table 2.15 also denotes when those activities occur during the year, and the footnotes identify the amount of physical contact with the water associated with each of these activities. This table is not comprehensive, but conveys the magnitude and diversity of activities that are covered under these uses. Based on the information presented, Regional Water Board staff find that the CUL and FISH beneficial uses of the Klamath River in California are not being fully supported.

2.6.3 Impairment of Water Contact Recreation (REC-1), Non-Contact Water Recreation (REC-2), and Municipal and Domestic Supply (MUN)

Toxigenic blue-green algae blooms and their associated toxins measured in Copco and Iron Gate Reservoirs and in select reaches of the Klamath River downstream from the reservoirs are periodically impairing the Water Contact Recreation (REC-1) and Non-Contact Water Recreation (REC-2) beneficial uses. Additionally, the toxins have the potential to impair Municipal and Domestic Supply (MUN) beneficial use in the Klamath River.

2.6.3.1 Recreational Impacts

The available data on blue-green algae and toxin concentrations in the Klamath River and reservoirs are presented in Section 2.5.4. Water contact recreation (REC-1) during swimming, diving, and other direct water contact presents a high risk of exposure to inhalation or ingestion of cyanotoxins in waters contaminated with *Microcystis aeruginosa* (or other toxigenic species). Blooms of *Microcystis* and the presence of its cyanotoxin, microcystin, have prompted health advisories in local newspapers as well as the posting of on-site warnings for the public to use caution during water contact recreational activities in Iron Gate and Copco Reservoirs and some reaches of the river since 2005.

Table 2.15: Karuk, Yurok, and Quartz Valley Tribes Cultural Beneficial Uses (CUL and FISH) of the Klamath River and Tributaries[4]

Resource	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CUL												
Plants[1,3]	■	■	■	■	■	■	■	■	■	■	■	■
Fish[1]	■	■	■	■	■	■	■	■	■	■	■	■
Fishing[1,2]	■	■	■	■	■	■	■	■	■	■	■	■
Water-drinking, steaming, cooking[1,3]	■	■	■	■	■	■	■	■	■	■	■	■
Rocks[1]	■	■	■	■	■	■	■	■	■	■	■	■
Bathing[2]	■	■	■	■	■	■	■	■	■	■	■	■
Boating[1,2]	■	■	■	■	■	■	■	■	■	■	■	■
Wildlife[1]	■	■	■	■	■	■	■	■	■	■	■	■
Hunting & Trapping[1]	■	■	■	■	■	■	■	■	■	■	■	■
River & Trail Access[1]	■	■	■	■	■	■	■	■	■	■	■	■
Training[2]	■	■	■	■	■	■	■	■	■	■	■	■
Swimming[2]				■	■	■	■	■	■	■		
Prayer & Meditation[1]	■	■	■	■	■	■	■	■	■	■	■	
Fish Dam[1,2]							■	■	■			
Washing[1]	■	■	■	■	■	■	■	■	■	■	■	■
Meditation[1]	■	■	■	■	■	■	■	■	■	■	■	■
Wood Gathering[1]	■	■	■	■	■	■	■	■	■	■	■	■
Tanning Hides[1]	■	■	■	■	■	■	■	■	■	■	■	■
Roots[1,3]	■	■	■	■	■	■	■	■	■	■	■	■
Sticks, Shoots & Bark[1]	■	■	■	■	■	■	■	■	■	■	■	■
Weaving[1]	■	■	■	■	■	■	■	■	■	■	■	■
Shells[1]	■	■	■	■	■	■	■	■	■	■	■	■
World Renewal Ceremonial Cycle[2,3]				■	■	■	■	■	■			
FISH												
Plants[1,3]	■	■	■	■	■	■	■	■	■	■	■	■
Fishing[1,2]	■	■	■	■	■	■	■	■	■	■	■	■
Eeling[1,2]	■	■	■	■	■							
Shellfish[1,2]						■	■	■				
Water-drinking, steaming, cooking[1,3]	■	■	■	■	■	■	■	■	■	■	■	■
Rocks[1]	■	■	■	■	■	■	■	■	■	■	■	■
Bathing[2]	■	■	■	■	■	■	■	■	■	■	■	■
Boating[1,2]	■	■	■	■	■	■	■	■	■	■	■	■
Wildlife[1]	■	■	■	■	■	■	■	■	■	■	■	■
River & Trail Access[1]	■	■	■	■	■	■	■	■	■	■	■	■

Sources: Bowman 2006; Norgaard 2006; Reed 2007a, Reed 2007b; Sloan 2007a, Sloan 2007b

■ Indicates time of use.

1-Wading, 2-Full submersion, 3-Ingestion of water

4-Tributaries utilized by the Tribes of the Klamath River for cultural purposes include many of those from the Scott River down to the mouth of the Klamath river. Additionally, the Quartz Valley Tribe utilized all tributaries which flow into the Scott and Shasta Rivers. Tributaries considered as having cultural beneficial uses include any tributary that provides spawning or rearing, or provides a migration pathway for Tribal Trust species.

Note: This table is not an exhaustive list of all activities covered under the CUL and FISH beneficial uses.

The presence of elevated *Microcystis* and microcystin concentrations Iron Gate and Copco Reservoirs during August 2005 prompted the State Water Board cooperating with the Regional Water Board, USEPA, and Karuk Tribe to issue a joint press release (State Water Board 2005). The press release warned of the potential adverse health effects to persons recreating in waterbodies of the Klamath River system contaminated with noticeably excessive algal concentrations. The Siskiyou County Health Department also issued a health advisory warning people about elevated toxin levels in Copco Reservoir. Additionally, warning signs were posted at key recreational access facilities around Iron Gate and Copco Reservoirs by the Regional Water Board.

During mid-August 2006, large blooms of *Microcystis aeruginosa* and high concentrations of microcystin led the State Water Board, Karuk Tribe, Regional Water Board, and USEPA to issue another press release, again warning recreational water users and other area residents to use caution when near the reservoirs, or avoid water contact recreation altogether in locations with noticeable blue-green algal blooms in Copco and Iron Gate Reservoirs (State Water Board 2006). The Siskiyou County Health Department also issued a public health advisory for Iron Gate and Copco Reservoirs in 2005 (Siskiyou County Public Health Department 2006). In early September 2006 the Regional Water Board posted warning signs at prominent recreational access points in both reservoirs reiterating the cautionary advisories contained in the earlier press release. In addition to these postings at the reservoirs, the Yurok Tribe posted health advisory signs along the mainstem Klamath River within the reservation borders (Fetcho 2006).

Microcystis scums were present in Iron Gate and Copco Reservoir from mid- to late-June 2007 at concentrations that prompted the Regional Water Board to post precautionary health advisory signs at boat launches, campgrounds, swimming areas, and other high traffic, recreational use access points along the shorelines of the reservoirs. Shortly after the posting of the two reservoirs the USEPA as lead agency, with a number of state agencies, and the Yurok and Karuk Tribes issued a joint press release on July 5, 2007 advising the public to use caution when recreating at the two reservoirs (USEPA 2007). In August 2007, Microcystis cell counts in the mainstem Klamath River exceeded the California BGA Group's guidelines for posting health advisories. Consequently, Regional Water Board staff posted precautionary health advisory signs at 24 locations along the mainstem Klamath River from the sport fishing access point at Iron Gate Hatchery to the Aikens Creek Campground.

2.6.3.2. Health Impacts

Blooms of *Microcystis aeruginosa*, and subsequent releases of its cyanotoxin, microcystin, during the summer and early fall in the mainstem Klamath River have the potential to impair the municipal and domestic supply (MUN) beneficial use. The State Water Board's Department of Water Rights Information Management System (WRIMS 2006) shows numerous existing water rights that utilize in-river water withdrawals for sources of domestic drinking water and other uses. Nearly all of the water rights are located downstream from Iron Gate dam. The location, engineering, and timing of water withdrawals, as well as the magnitude and velocity of streamflow are factors that affect the possibility of entraining blue-green algae and their toxins in water supplies. There have

been no documented human health impacts due to drinking or recreating in Klamath River water during *Microcystis* blooms. However, the presence of the toxin during periods when water withdrawls are occurring and when people are recreating, presents the possibility that human health impacts could occur.

In August of 2007, a dog became very ill a few hours after swimming in Copco Reservoir and drinking the water during a *Microcystis* bloom (Blue Green Algae Work Group 2007; Tobler 2007). The sick dog was taken to the vet and tests showed elevated levels of several enzyme indicative of liver disease. Microcystin is a liver toxin, and is capable of producing this type of an enzymatic response.

2.6.3.3. Aesthetic Impacts

Visible scums formed by the presence of *Microcystis aeruginosa* and other blue-green algae in Copco and Iron Gate Reservoirs present an aesthetic nuisance, potentially impacting the aesthetic enjoyment (REC-2) of these reservoirs. A study conducted by CH2M Hill for PacifCorp, compiled interviews and survey responses of recreational water users about their experiences at locations along the Klamath River, including Copco and Iron Gate Reservoirs (PacifiCorp 2004a). Interviewee's responses showed that water condition during the summer to early fall seasons has affected the quality and enjoyment of their experiences. The survey did not link responses to a specific time period; however, nearly all of the concerns expressed by respondents pertained to the summer and early fall recreational seasons of 2001 and 2002.

Approximately 70% (n = 89), of the responses to the interview questions stated water quality either detracted a lot or a little from their aesthetic enjoyment of the Klamath River within the geographical boundaries of the survey. By far, the most common complaint related to large amounts of "algae" and odors related to "algae." The survey data show that of the 70% of water uses reporting unfavorable recreational experiences with "algae," approximately 42% (n = 37) of those negative responses directly involved Iron Gate and Copco Reservoirs. Though not stated, presumably the "algae" in question were blue-green algal species that tend to accumulate along shorelines, forming scums and surface films during blooms.

2.6.4 Impairment of Commercial and Sport Fishing (COMM)

The Commercial and Sport Fishing (COMM) beneficial use is currently impaired in the Klamath River in California, as demonstrated by restrictions and closures on the sport and commercial fishing industries in the basin and beyond. Salmonid population decline has resulted in severe reductions in available Chinook salmon for both the in-river and ocean troll commercial fishing communities, and sport fishing community. Additionally, federal regulations have eliminated the right to harvest coho salmon stocks due to their dwindling numbers. Evidence documenting declining numbers of salmonids returning to spawn in the Klamath River basin is discussed in detail in Appendix 4 (Carter and Kirk 2008). The apparent disappearance of eulachon (*Thaleicthys pacificus*) spawning activity in the Klamath River (Belchik and Larson 1998) has resulted in the cessation of a historically important, commercially valuable non-salmonid fishery that was primarily utilized by Yurok Tribal members.

2.6.4.1 In-River Sport Fishing Impairment

Decreased salmon populations in the Klamath River have resulted in the alteration of fishing regulations further restricting the number of in-river fish harvested recreationally and the length of the recreational salmon in-river fishing season. For the 2006 season, the California Fish and Game Commission (Commission) decreased the number of days that recreational salmon fishing could occur by 11 days in the Klamath River below the Highway 96 bridge at Weitchpec (CFGC 2006). This was done in an attempt to ensure that the quota for in-river recreational harvest would not be met before Labor Day, allowing fishing during the holiday weekend (CFGC 2006).

The documentation of microcystin toxin concentrations in fish tissue of yellow perch from Copco Reservoir above human health thresholds represents an impairment of in-river sport fishing. Table 2.16 presents data from 2005 and 2007 when salmonids were collected in the Klamath River and Yellow Perch were collected in the reservoirs to test for the presence of microcystin. As the table reflects, microcystin was detected in the liver of a salmonid collected at Iron Gate Hatchery at a level >250 µg/kg, which is over the threshold recommended by Van Buynder et al. (2001) to protect human health. Additionally, four of the yellow perch fish tissue samples and one of the liver samples collected in Copco Reservoir was >250 ug/kg. Yellow perch are commonly harvested from Copco and Iron Gate Reservoirs for consumption.

Table 2.16: Detection of Microcystin in Fish Tissue and Liver Samples from the Klamath River and Reservoirs

Location Fish Collected	Year	# of fish tissue samples where Microcystin Detected	# of fish tissue samples with Microcystin total >250 µg/kg	# of fish liver samples where Microcystin Detected	# of fish liver samples with Microcystin total >250 µg/kg
Klamath River	2005	0 of 2*	0	2 of 4*	0
Iron Gate Hatchery	2005	0 of 2*	0	0 of 2*	0
	2007	0 of 1*	0	1 of 1*	1
Iron Gate Reservoir	2007	15 of 19**	0	2 of 3*	0
Copco Reservoir	2007	18 of 19**	4	3 of 3*	1

*salmonid
** yellow perch

2.6.4.2 Ocean Sport Fishing Impairment

During the period from 1960 through 1965 there was no closed season for ocean salmon sport fishing north of Tomales Point (CDFG 1967). The catch limit during this period remained constant at 3 salmon per day. In 1960 and 1961 the minimum size limit for salmon was 22 inches, and in 1962 one fish of any size was allowed with the remainder to be over 22 inches. From 1963 through 1965 the minimum size limit was one salmon over 20 inches and two over 22 inches.

In contrast, the currently depressed state of the fall Chinook run in the Klamath Management Zone (KMZ), and the listing of coho as threatened on both the federal (1997 listing) and California (2005 listing) Endangered Species lists, has resulted in increased

restrictions on the ocean sport fishery. The 2007 ocean sport fishing season in the Klamath Management Zone (KMZ), extending from Humbug Mountain, OR to Point Arena, CA, was open from May 5 to September 4th (PFMC 2007). However, the Klamath Control Zone, extending 6 miles north and south of the Klamath River and 12 miles off-shore, was closed in August. The catching of coho was prohibited and the Chinook catch was limited to two fish per day (PFMC 2007). Chinook were required to be a minimum of 24 inches in total length to be legal to keep (PFMC 2007). These greater restrictions have contributed to the impairment of the sport fishery in the Klamath River basin.

2.6.4.3 In-River Commercial Fishery Impairment

Between 1912 and 1934 approximately 957,000 pounds of Chinook salmon, representing close to 55,000 fish, were harvested and preserved during a single fishing season in the Klamath River (Snyder 1931, p. 7, 8, 88, and 89). Daily salmonid catches by the Tribal commercial fishery commonly ranged from 7,000 to 10,000 fish per day, with a one-day high that was reportedly approximately17,000 fish. Catch totals were mostly Chinook, but coho salmon, steelhead trout, lamprey, and green sturgeon were also caught and preserved (Snyder 1931, p. 7, 8, 88, and 89). Due to precipitous declines in salmonid populations attributed to over harvesting by the in-river commercial salmon fishery, the fishery was declared illegal and closed by court order in 1934. It was subsequently reopened by another court order in 1977; however, the Bureau of Indian Affairs closed the Tribal in-river commercial fishery the following year under a "conservation moratorium." It remained closed until 1987, when it was again reopened (Pierce 1998; Yurok Perspectives 2001, p. 7.1-7.13).

In 1993 the Department of Interior modified catch limits for the Klamath River basin Tribes, allotting 50% of the available Klamath River basin salmon harvest to the Hoopa and Yurok Tribes, or an amount sufficient to support a moderate standard of living, which ever is less. Given the depressed condition of the Klamath River basin salmon stocks in 1993, the Department of Interior concluded that 50% of the salmon harvest during that year would be allocated to the Tribes because there weren't enough fish to allow them to catch enough to support a moderate standard of living (50 CFR Part 661, NOAA 1993). Of the 50% allocated to the Tribes, 80% and 20% of that allocation, referred to as Tribal shares, are allotted to the Yurok and Hoopa Tribes, respectively. Currently, the Yurok and Hoopa Tribes are the only Tribes with Federally-recognized commercial fishing rights in the Klamath River (Pierce 1998; Yurok Perspectives 2001, p. 7.1-7.13)

From 1990 through 1998 the in-river Tribal fishery was closed to commercial gillnetting due to depressed salmon runs. In recent years, harvest rates for the Tribal gillnet fishery have varied and are currently so low that it is hard to support an in-river commercial fishery. For the 2006 salmon season the PFMC, working with the Klamath Fisheries Management Council, determined that the allowable Tribal share of the Klamath-Trinity River basin salmon harvest is 10,000 fish (PFMC 2006a). This would allocate 8,000 salmon to the Yurok Tribe and 2,000 salmon to the Hoopa Tribe from the in-river salmon fishery. The salmon allocated to the Yurok Tribe for 2006 are thought to be well below

harvest levels capable of supporting a commercial fishery (Eureka Times-Standard 2006) and it is presumed the same also would be true for the Hoopa Tribe's allocation.

2.6.4.4 Ocean Commercial Fishery Impairment

Salmon sold to fish buyers and processors within the Klamath Management Zone (KMZ) have dwindled significantly since 1976 through 1980 when an average of 143,900 Chinook and 72,100 coho salmon were delivered per season to the port of Crescent City alone (PFMC 2003, 2006b). From 1993 through the present, concerns about the plummeting coho salmon populations have led to the closure of the entire California ocean commercial troll for coho. In order to more rigorously protect all salmonid stocks within the KMZ, regulations on the ocean commercial fishery (consisting mostly of Chinook salmon) has been progressively more restrictive.

The economic impacts to the fishermen and on-shore industries that support the ocean commercial salmon industry have been, and continue to be significant. The maximum dollar values for the ex-vessel price (the price received by fishermen for fish landed at the dock) adjusted to 2005 dollar values are presented in Table 2.17 for the four major ports in the KMZ. The seasons when regulatory closures prohibited commercial ocean salmon fishing are not shown in the table, and correspond to no income for fishermen.

Table 2.17: Estimates of Maximum Dollars for the ex-Vessel price of the Commercial Ocean Salmon Fishery for the Four Major Ports within the KMZ from 1976-1990 and 1991-2001.

Port	Year(s)[1] / Maximum Dollars	Year(s)[1] / Maximum Dollars
Brookings, OR	1976-1980 / 7,355,000	1991-1995 / 126,000
Crescent City, CA	1976-1980 / 5,931,000	1991-1995 / 9,000
Eureka, CA	1976-1980 / 8,884,650	1991 / 43,640
Fort Bragg, CA	1986-1990 / 14,902,000	2001 / 663,000

Source: PFMC 2006b

[1]Multiple year's values represent the average income per year

As a result of the Klamath River fish kill in 2002, the 2006 ocean commercial troll non-Tribal salmon fishery was severely curtailed along much of the west coast by the PFMC. The potential offspring of the 2002 Chinook stocks, the four year age class, are that cohort of fish that were predicted to have subsequently returned to the Klamath River as spawners in 2006. In particular, within the KMZ, extending from Humbug Mountain north of Brookings, OR to Horse Mountain just south of Shelter Cove, CA, the 2006 season was closed (NOAA 2006). South of Horse Mountain to Point Arena the season was open only from September 1 through September 15, or when a Chinook salmon quota of 4,000 fish was reached. The extreme seasonal and take restrictions were deemed necessary by the PFMC to assure an adequate numbers of spawners returned to the Klamath River.

During 2007 the PFMC (2008) considered Chinook salmon stocks within the KMZ somewhat healthier than 2006 but only opened the ocean commercial Chinook season from September 10 - September 30, imposing a fleet quota of 6,000 fish. Chinook stocks south of the KMZ to Point Arena were deemed depressed to the point that the PFMC only

allowed fishing during the periods from April 9-April 27 (fleet quota of 2,000 fish) and August 29-September 30 (no quota set). The ocean coho salmon fishery remained closed along the California coast for the entire fishing season.

2.7 Problem Statement Synthesis

Based on the analysis presented in this chapter, there is little doubt that the Klamath River is an impaired waterbody. The Klamath River TMDL problem statement has identified numerous water quality related factors that must be addressed in the TMDL allocations and the implementation plan. The following is a summary of the water quality conditions and impacts that are addressed in the TMDL.

- Nutrient concentrations in much of the Klamath River watershed are well above natural background levels and contribute to excess periphyton and suspended algae growth, which in turn contributes to poor DO and pH conditions, and also contributes to increased abundance and exposure of fish to parasites (i.e., *C. shasta*).
- Conditions of low DO and high pH are persistent in much of the Klamath River and contribute to multiple impacts on cold water fisheries including: migration barriers, decreased growth and fecundity, decreased reproductive success, increased juvenile fish mortality, increased adult mortality, and lower overall fish populations.
- High levels of nutrients and the presence of impoundments have contributed to the development of nuisance levels of blue-green algae that have created potential health hazards for people exposed to reservoir and downstream river waters. This health hazard has negatively impacted both recreational and ceremonial use of the reservoirs and the river.
- Temperature conditions that exceed natural levels exist throughout the Klamath River basin and contribute to: chronic stress and sometimes acute lethal conditions for cold water fisheries, proliferation of fish diseases such as Columnaris, presence of migration barriers, lower reproductive success, increased juvenile and adult mortality, and lower overall fish populations.
- Excess sediment delivery to the Klamath River and tributary streams has contributed to habitat impairment, increased levels of nutrients, and contributed to the development of water column temperatures that exceed Basin Plan water quality objectives.
- Reduced flows contribute to increased water column temperatures, the accumulation of organic matter, and low DO conditions which have contributed to impacts on aquatic life.
- Water quality objectives for temperature, DO, pH, biostimulatory substances, and toxicity are regularly exceeded in the Klamath River basin in California.

DRAFT

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CHAPTER 3. ANALYTIC APPROACH

3.1 Introduction

This chapter describes the analytic approach for developing the Klamath River TMDLs for California. The analysis incorporated empirical data analysis of the best quality assured water quality data available, review of available reports, and application of water quality models. The water quality models applied were the primary analytic tools used to establish the relationships between pollutant loadings and instream water quality response. In turn, the models were used to quantify the loading capacity of the Klamath River, establish appropriate numeric targets, and calculate load and waste load allocations necessary to achieve the loading capacity and meet water quality standards. Section 3.2 describes these water quality models applied to the Klamath River, and describes the model calibration and corroboration process. Section 3.3 describes the application of these models for Klamath River TMDL development. Results of the modeling analyses are presented in Chapter 4 – Pollutant Source Analysis, and in Chapter 5 – Klamath River TMDLs – Allocations and Numeric Targets.

3.2 Modeling Approach

3.2.1 Primary Models Applied

To support TMDL development for the Klamath River system, the need for an integrated receiving water hydrodynamic and water quality modeling system was identified. A model for the Klamath River had already been developed by PacifiCorp to support studies for the Federal Energy Regulatory Commission Hydropower relicensing process (Watercourse Engineering, Inc. 2004) when this project commenced. The version of the model available in 2004 is hereafter referred to as the PacifiCorp Model. Regional Water Board, ODEQ, and EPA determined that this existing PacifiCorp Model would provide the optimal basis, after making some enhancements, for TMDL model development. The PacifiCorp Model uses hydrodynamic and water quality models with a proven track record in the environmental arena and has already been reviewed by most stakeholders in the watershed. Additionally, it can be directly compared to ODEQ, Regional Water Board and Tribal water quality criteria.

The original PacifiCorp Model consisted of Resource Management Associates (RMA) RMA-2 and RMA-11 models and the U.S. Army Corps of Engineers' CE-QUAL-W2 model. The RMA-2 and RMA-11 models were applied for Link River (which is the stretch of the Klamath River from Upper Klamath Lake to Keno Dam), Keno Dam to J.C. Boyle Reservoir, Bypass/Full Flow Reach, and Iron Gate Dam to Turwar. RMA-2 simulates hydrodynamics while RMA-11 represents water quality processes. The CE-QUAL-W2 model was applied for Lake Ewauna-Keno Dam, J.C. Boyle Reservoir, Copco Reservoir, and Iron Gate Reservoir. CE-QUAL-W2 is a two-dimensional, longitudinal/vertical (laterally averaged), hydrodynamic and water quality model (Cole and Wells 2003).

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Since the estuarine portion of the Klamath River (Turwar to the Pacific Ocean) was not included in the original PacifiCorp Model, one of the first updates made was to include an estuarine model. From a review of available data for the estuary, it was apparent that hydrodynamics and water quality within the estuary are highly variable spatially and throughout the year and are greatly influenced by time of year, river flow, tidal cycle, and location of the estuary mouth (which changes due to sand bar movement). Additionally, transect temperature and salinity data in the lower estuary showed significant lateral variability, as did DO to a lesser extent. Therefore, EPA's Environmental Fluid Dynamics Code (EFDC), which is a full 3-D hydrodynamic and water quality model, was selected to model the complex estuarine environment.

EFDC is capable of predicting hydrodynamics, nutrient cycles, DO, temperature, and other parameters and processes pertinent to the TMDL development effort for the estuarine section. It is capable of representing the highly variable flow and water quality conditions within years and between years for the estuary. As with RMA-2, RMA-11, and CE-QUAL-W2, EFDC has a proven record in the environmental arena and model results can be directly compared to ODEQ, Regional Water Board and Tribal water quality criteria. A major advantage of EFDC is that it is EPA-endorsed and supported and available freely in the public domain.

The combination of the PacifiCorp Model (RMA and CE-QUAL-W2), with enhancements discussed below, and the EFDC model for the estuary resulted in the Klamath River model used for TMDL development. Table 3.1 identifies the modeling elements applied to each river segment. These segments are depicted graphically in Figures 3.1 and 3.2. Linkages between the different modeling segments were made by transferring time-variable flow and water quality from one model to the next (e.g., output from the Link River model became input for the Lake Ewauna-Keno Dam model).

Table 3.1: Models applied to each Klamath River and estuary segment

Modeling Segment #	Modeling Segment	Segment Type	Model(s)	Dimensions
1	Link River	River	RMA-2/RMA-11	1-D
2	Lake Ewauna-Keno Dam	Reservoir	CE-QUAL-W2	2-D
3	Keno Dam to J.C. Boyle Reservoir	River	RMA-2/RMA-11	1-D
4	J.C. Boyle Reservoir	Reservoir	CE-QUAL-W2	2-D
5	Bypass/Full Flow Reach	River	RMA-2/RMA-11	1-D
6	Copco Reservoir	Reservoir	CE-QUAL-W2	2-D
7	Iron Gate Reservoir	Reservoir	CE-QUAL-W2	2-D
8	Iron Gate Dam to Turwar	River	RMA-2/RMA-11	1-D
9	Turwar to Pacific Ocean	Estuary	EFDC	3-D

Although the original *PacifiCorp Model* is capable of addressing the identified water quality issues, a number of adaptations to the model were identified to expedite and strengthen the model for the rigors of TMDL development for the Klamath River. Enhancements were made in the following areas: BOD/organic matter (OM) unification,

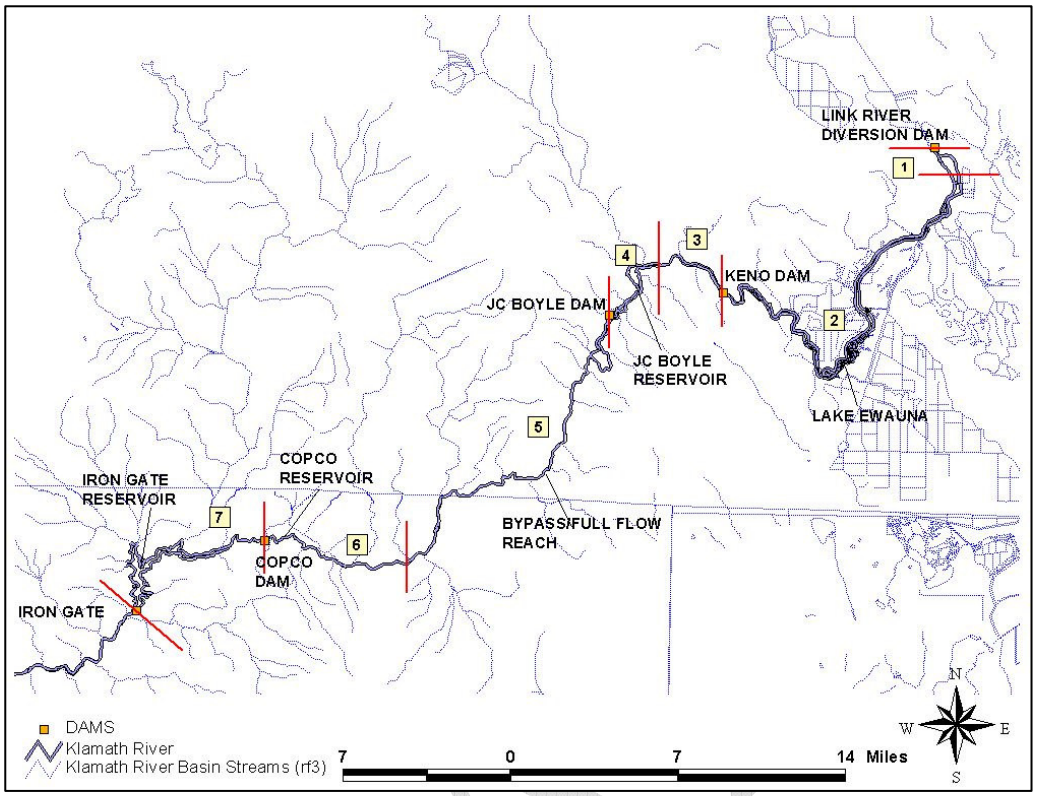

Figure 3.1: Model segments in Oregon and Northern California

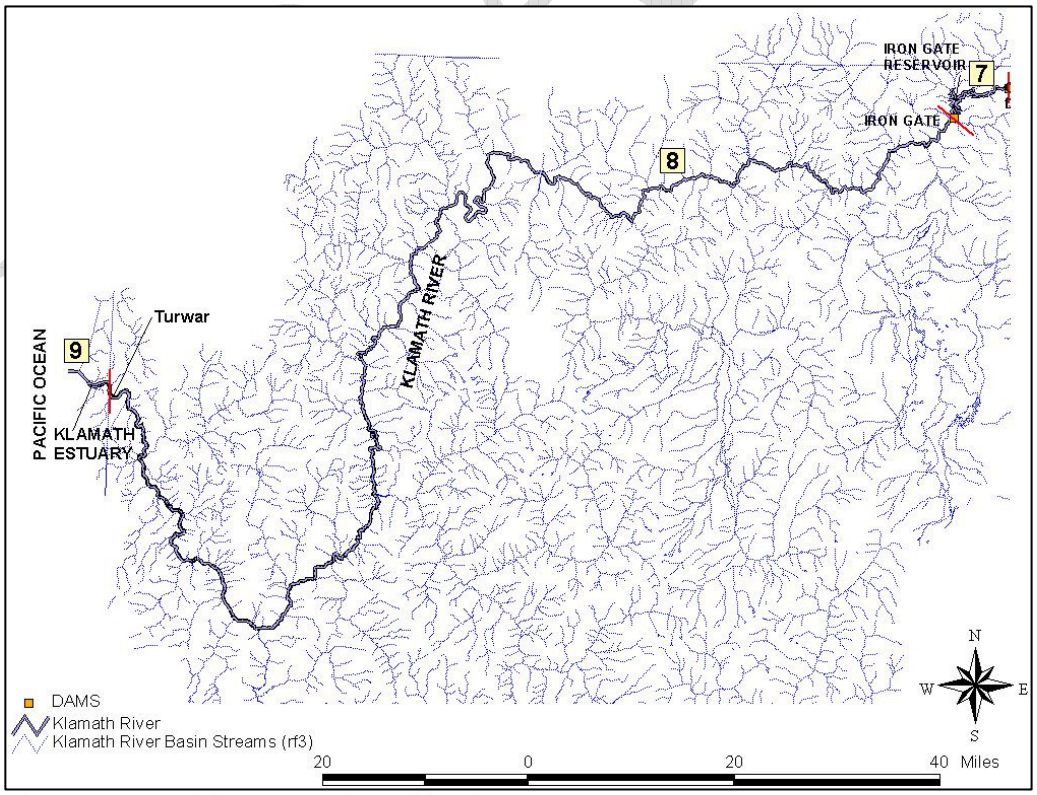

Figure 3.2: Model segments in California

algae representation in Lake Ewauna, Monod-type continuous SOD and OM decay, pH simulation in RMA, OM-dependent light extinction simulation in RMA, reaeration formulations, and dynamic OM partitioning. It should be noted that PacifiCorp has also updated their original model based on comments from reviewers (PacifiCorp 2005) and after reviewing enhancements made for TMDL model development.

In combination, the RMA/CEQUAL-W2/EFDC models as applied for Klamath River TMDL development, are referred to as the Klamath River TMDL models.

3.2.1.1 Model Configuration and Testing

The Klamath River TMDL model was configured by designating state variables, preparing the computational grid, and preparing boundary conditions. Once configuration was complete, the model was tested through a rigorous calibration and corroboration process. A summary of these steps is described below, however, a more detailed discussion is included in Appendix 5, *Model Configuration and Results – Klamath River Model for TMDL Development* (Tetra Tech 2008a). The Model Configuration and Results report (Tetra Tech 2008a) includes accompanying reports that are not included in Appendix 5. Appendix 5, as well as the accompanying reports is available for review during the peer review period at: <http://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/klamath_river/pdf/Peer_Review_Draft.zip>.

State variables were designated to most accurately predict TMDL impairments, with particular attention paid to temperature, DO, pH, and ammonia toxicity, as well as related physical, chemical, and biological processes. State variables varied for each model type in the Klamath River model (RMA, CE-QUAL-W2, and EFDC). The following state variables were configured for the riverine segments of the Klamath River model (for the RMA portions of the model):

1) Arbitrary Constituent (configured as a tracer to evaluate the mass balance)
2) DO
3) Organic matter (OM)
4) Orthophosphorus (PO_4)
5) Ammonium (NH_4)
6) Nitrite (NO_2)
7) Nitrate (NO_3)
8) Suspended algae
9) Temperature
10) Periphyton
11) Total inorganic carbon (TIC)
12) Alkalinity (Alk)

The reservoir segments of the Klamath River, where the CE-QUAL-W2 model was applied, were configured using the following active state variables:

1) Labile dissolved organic matter (LDOM)
2) Refractory dissolved organic matter (RDOM)
3) Labile particulate organic matter (LPOM)
4) Refractory particulate organic matter (RPOM)
5) Inorganic Suspended Solids (ISS)
6) PO_4
7) NH_4
8) NO_2/NO_3
9) DO
10) Suspended algae
11) Alk
12) TIC
13) Temperature
14) Tracer
15) TDS
16) Age (to track detention time at different locations)
17) Coliform bacteria

The estuarine portion of the Klamath River, which was modeled using EFDC, was configured with the following constituents as state variables:

1) Suspended algae
2) Periphyton
3) Labile particulate organic carbon (LPOC)
4) Labile dissolved organic carbon (LDOC)
5) Labile particulate organic phosphorous (LPOP)
6) Labile dissolved organic phosphorous (LDOP)
7) PO_4
8) Labile particulate organic nitrogen (LPON)
9) Labile dissolved organic nitrogen (LDON)
10) NH_4
11) NO_2/NO_3
12) DO
13) Temperature
14) Salinity

Note that pH is not included as a state variable in the lists above. It is computed from alkalinity and total inorganic carbon for the riverine and reservoir segments. Alkalinity and total inorganic carbon are transported by the model and are thus included as state variables.

Preparation of the computational grid consisted of segmenting the entire Klamath River into smaller computational segments for application of the various models. In general, bathymetry is the most critical component in developing the grid for the system. Within each of the model segments described above (excluding the Klamath Estuary), the

primary waterbody (either a Klamath River section or a reservoir) was subdivided into higher resolution elements for greater detail in modeling. The TMDL modeling framework components were segmented similarly to the *PacifiCorp Model*. Only the main-stem Klamath River and its reservoirs were simulated with the Klamath River model. All tributaries to the river were represented as boundary conditions (i.e., they were not explicitly modeled). The tidal portion of the Klamath River from Turwar to the Pacific Ocean, which was not included in the *PacifiCorp Model*, was modeled using EFDC. A boundary-fit curvilinear grid was developed to accurately represent the shape of the estuary. In the modeling domain, each cell is represented by 4 vertical layers.

To run the model, external forcing factors known as boundary conditions were specified for each model segment in the system. These forcing factors are a critical component in the modeling process and have direct implications on the quality of the model's predictions. External forcing factors include a wide range of dynamic information:

- Upstream Inflow Boundary Conditions: Upstream external inflows, temperature, and constituent boundary conditions
- Tributary (or Lateral) Inflow Boundary Conditions: Tributary inflows, temperature, and constituent boundary conditions
- Withdrawal Boundary Conditions
- Surface Boundary Conditions: Atmospheric conditions (including wind, air temperature, solar radiation)

Once the Klamath River model was configured, the model was tested through a calibration and corroboration process at multiple locations. Calibration refers to the adjustment or fine-tuning of modeling parameters to produce an adequate fit of the simulated output to the field observations. The sequence of calibration for the Klamath River model involved calibrating flow and water surface elevation first and then calibrating water quality using available monitoring data. Since the original *PacifiCorp Model* was already calibrated for hydrodynamics, the focus of efforts was on hydrodynamic calibration of the EFDC portion of the model (estuary) and the water quality calibration of the entire model. The corroboration process involved testing calibrated model parameters for a separate time period to ensure their appropriateness.

The upper Klamath River model (Model Segments 1 through 8) was calibrated using data from the year 2000. This year was selected for calibration because relatively good boundary condition data and in-stream data were available in the upper portion of the system. Data were available, but not to the same extent, for the lower portion of the system (particularly downstream of Iron Gate Dam). Selection of this year was deemed appropriate because water quality conditions in the upper portion of the system drive the response downstream. Although this was an average hydrologic year in terms of flow, simulating the entire year inherently tests the model's ability to represent a range of hydrologic regimes and associated water quality impacts. The model was also corroborated using data from the year 2002, which was a relatively low hydrologic year in terms of flow, for Model Segments 1 through 5. Again, considerably more data were

available for the upper portion of the system in 2002 than for other years. The model was not run downstream (Segments 6 through 9) for 2002 primarily due to limited resources (i.e., cost) and limited boundary data. Boundary condition data are limited in terms of representing the full temporal, spatial, and parameter variability. Thus, it is very likely that evaluation of additional calibration would be more tied to data limitations/ uncertainty than model performance. The estuarine portion (Model Segment 9) was calibrated using data from the year 2004, because bathymetric data and data for key water quality parameters were available. Water quality data were collected as part of an intensive monitoring effort. Insufficient data were available to calibrate for the year 2000 or 2002 in the estuarine portion of the Klamath River. Calibration and corroboration results are presented in Appendix 5.

3.2.1.2 Assumptions, Limitations, and Uncertainty

Like any dynamic water quality model, the Klamath River TMDL models were developed based on assumptions, and therefore have inherent limitations and uncertainty. The Model Configuration and Results – Klamath River Model for TMDL Development (Tetra Tech 2008a) report (included as Appendix 5 of this report) details model assumptions, limitations, and uncertainty.

3.2.2 Nutrient Numeric Endpoint Analysis

An additional line of evidence for establishing TMDLs in the Klamath River system was provided by an application of the California Nutrient Numeric Endpoint (NNE) approach (Tetra Tech 2006) to the Klamath River (Tetra Tech 2008b [*Nutrient Numeric Endpoint Analysis for the Klamath River, CA* included as Appendix 1 of this report]). The NNE approach (Tetra Tech 2006) is a risk-based methodology in which targets are developed from multiple lines of evidence for response variables such as algal density that are associated with impairment of narrative standards relative to nutrient enrichment. These response targets can then be converted to site-specific nutrient targets through use of modeling tools. Nutrient targets established in this way are supplemental to those established to meet specific numeric criteria, such as water quality criteria for dissolved oxygen.

Tetra Tech (2006) also documents a set of relatively simple, but effective, spreadsheet scoping tools for application in lake/reservoir or riverine systems to assist in evaluating the translation between response indicators and nutrient concentrations or loads.

The California NNE approach recognizes that there is no clear scientific consensus on precise levels of nutrient concentrations or response variables that result in impairment of a designated use. To address this problem, waterbodies are classified in three categories, termed Beneficial Use Risk Categories (BURCs). BURC I waterbodies are not expected to exhibit impairment due to nutrients, while BURC III waterbodies have a high probability of impairment due to nutrients. BURC II waterbodies are in an intermediate range, where additional information and analysis may be needed to determine if a use is supported, threatened, or impaired. Tetra Tech (2006) lists consensus targets for response indicators defining the boundaries between BURC I/II and BURC II/III. The

BURC II/III boundary provides an initial scoping point to establish minimum requirements for a TMDL.

As part of the Klamath River NNE analysis multiple lines of evidence including the use of the scoping tools were used to develop numeric targets for maximum reach-averaged density of benthic chlorophyll-a in the Klamath River below Iron Gate Dam, and planktonic chlorophyll-a and blue-green algae (*Microcystis aeruginosa* and microcystin) numeric targets for Copco and Iron Gate Reservoirs (Tetra Tech 2008b; Appendix 1 of this report). Application of the NNE spreadsheet scoping tool for reservoirs successfully predicts observed average concentrations of TN, TP, and chlorophyll a in Copco and Iron Gate reservoirs, as well as the observed blue-green algal dominance.

Another important tenet of the California NNE approach (Tetra Tech 2006) is that targets should not be set lower than the value expected under natural conditions. The natural conditions baseline scenario (T1BS) predicts TN concentrations in the Klamath River below Iron Gate that are somewhat above the targets estimated by the NNE benthic biomass scoping tool; however, the model results are tempered by the fact that the frequency of scouring events that limit periphyton biomass development would also increase in a dams-out scenario. The NNE benthic biomass scoping tool suggests that maximum periphyton chlorophyll a densities in the river under natural conditions would likely be very close to the 150 mg/m^2 target.

3.3 Model Application to TMDL Determination

After testing the Klamath River TMDL models through hydrodynamic and water quality calibration and corroboration, a series of scenarios was implemented to support TMDL determination. The scenarios followed a logical progression that enabled numeric and natural conditions criteria for relevant parameters to be fully evaluated and used as the driver for allocation. They can be grouped into the following broad categories: current (i.e. existing) conditions, natural baseline conditions, and Oregon and California compliance conditions. This section describes these scenarios and associated assumptions.

3.3.1 Current Conditions (S1)

The calibrated and corroborated Klamath River model provided the basis for the current conditions scenario (S1). The model was run for the year 2000 and results were generated from Upper Klamath Lake to the Pacific Ocean.

3.3.2 Natural Baseline Conditions (T1BS)

In order to fully evaluate applicable water quality standards, it was necessary to simulate natural baseline conditions throughout the Klamath River. The natural baseline conditions scenario (T1BS) simulated the Klamath River from Upper Klamath Lake to

the Pacific Ocean in the absence of all dams, except for Link Dam[1]. The Klamath River model for this scenario used a different configuration than that for the current conditions. The entire length of the river from Upper Klamath Lake to just upstream of the estuary was simulated using the riverine RMA model. No CE-QUAL-W2 modeling segments were included.

The Upper Klamath Lake boundary condition for the model was based on the existing Upper Klamath Lake TMDL (ODEQ 2002). Specifically, median concentrations for water quality constituents and existing temperature were applied at the outlet and based on 1995 Upper Klamath Lake model output. Flow from Upper Klamath Lake was set at existing conditions, in order to maintain consistency with the existing conditions scenario. The flow balance for the current conditions model (when dams are present) and the reservoir operations limit the ability to represent natural flows. It should be noted that results for two model runs: one that used current conditions flows from Upper Klamath Lake and one that used estimated flows from a natural regime (USBR 2005), were compared and not found to be substantially different. A comparison of the temperatures resulting from the current condition flows and natural regime flows is presented in Figure 4.5.

Permitted point sources were removed from the model (i.e., both flow and water quality contributions were removed). The Lost River Diversion Channel (LRDC) and Klamath Straits Drain (KSD) were represented using current conditions flow, however, their water quality and temperature were set to be the same as Upper Klamath Lake. Current flow was again used to maintain consistency with the current conditions scenario. For tributaries to the Klamath River in California, natural and TMDL conditions were represented (described below), depending on the tributary.

In summary, the key components of the natural conditions baseline scenario are:

- Representation of the river with no dams (except Link Dam);
- The Upper Klamath Lake (UKL) boundary condition based on existing UKL TMDL compliant conditions;
- Absence of all point sources;
- LRDC and KSD represented using current conditions flow, but water quality set equal to UKL TMDL compliant conditions; and
- California tributaries flow and water quality conditions set at estimated natural and existing TMDL compliant conditions.

As with current conditions scenario, the model was run for the year 2000.

3.3.3 TMDL Compliance

To achieve compliance with water quality criteria in Oregon and California and

[1] The presence of Link Dam was maintained in the natural baseline condition scenario as it creates hydrodynamic conditions comparable to a natural basalt reef that was present at the same location.

determine appropriate load and wasteload allocations, multiple sets of scenarios were simulated. The first set of scenarios focused on temperature compliance in Oregon since temperature directly affects the remaining parameters evaluated and since impaired segments in Oregon are located upstream of those in California. After achieving temperature compliance in Oregon, temperature compliance in California was evaluated. Compliant conditions in Oregon were used as an upstream boundary for evaluating conditions in California. Compliance with dissolved oxygen criteria in both Oregon and California was evaluated in a similar manner. All scenarios were run for the year 2000.

3.3.3.1 Temperature Compliance in Oregon (TOT1 and TOT2)
A series of iterative simulations were implemented to analyze temperature compliance in Oregon. The objective was to determine temperature allocations for all the permitted point sources and discrete nonpoint sources in Oregon. Permitted point sources include the Klamath Falls STP, South Suburban STP, Columbia Forest Products, and Collins Forest Products (2 discharge locations). Discrete nonpoint sources include LRDC and the KSD.

Due to the nature of the temperature criteria, compliance determination was only possible by running multiple simulations. The series of scenarios was grouped into permitted point source impacts (TOT1) and discrete nonpoint source impacts (TOT2). LRDC and KSD model configuration for TOT1 and TOT2 was based on the natural baseline conditions scenario, however flow and temperature were also included for all permitted point sources.

3.3.3.2 Temperature Compliance in California (TCT1 and TCT2)
Once compliance with temperature criteria was achieved in Oregon, a series of simulations were implemented to analyze temperature compliance in California. The objective of these runs was to determine if the California temperature criterion could be achieved with the permitted point and discrete nonpoint source allocations resulting from the Oregon compliance runs (TOT2). To better evaluate the impact of tributary contributions in California on temperature in the Klamath River, two separate scenarios were simulated (TCT1 and TCT2). TCT1 represents tributary contributions based on estimated natural flow and temperature conditions. TCT2, the regulatory compliance scenario, depicts flow and temperature conditions compliant with the existing tributary TMDLs (i.e. Shasta, Scott, and Salmon River temperature TMDLs) and the Trinity River Record of Decision (ROD). Ultimately the TCT2 boundary conditions have been applied to represent California temperature compliance conditions, and these boundary conditions serve the basis for tributary load allocations. However, a comparison of the TCT1 and TCT2 results is informative in assessing the effects of Shasta and Scott River flows on Klamath River temperatures.

TCT2 is based on the same conditions upstream of the Shasta River as TCT1, the only difference being the flows and temperatures of the Shasta, Scott, and Trinity. The tributary temperature increases that are due to resource management (i.e. changes in shading, altered channel geometry, flow diversions, and tailwater return flows) are

assumed to occur between June 1 and October 15, except in the Shasta natural conditions scenario, which estimated natural temperatures and flows throughout the year. Consistent with the existing temperature TMDLs, the temperatures depicted for the Shasta, Scott, and Salmon Rivers for the regulatory compliance scenario (TCT2) reflect site-potential riparian shade conditions. The flows depicted for the Scott and Salmon Rivers for TCT2 equal current (year 2000) flows. The flows depicted for the Shasta River for TCT2 however, are 45 cfs greater than current (year 2000) flows, based on the flow goal included in the Shasta River temperature TMDL. Results of these model scenarios are presented in Chapter 4.

The development of the estimated natural tributary temperature and flow boundary conditions for TCT1 is described below.

Shasta River

For TCT1 the Tennessee Valley Authority's River Modeling System model (Hauser and Schohl 2002) was applied to depict natural temperatures of the Shasta River at the mouth. This modeling exercise built on a previous model implementation developed as part of the Shasta River Temperature TMDL. The model application for the Shasta River TMDL scenario represented Shasta River temperatures associated with potential riparian shade on the tributaries and mainstem, absence of thermal load from irrigation tailwater return flows, and estimated natural flows and temperatures from Big Springs Creek, a major spring fed tributary.

The Shasta River natural conditions model scenario added to the Shasta River TMDL scenario by representing full natural flows and associated temperatures for the Shasta River and all tributaries (Deas and Null 2007). The estimates of natural Shasta River flows are based in part on historic flow measurements, and the understanding that much of the summer flow of the Shasta River originates at Big Springs. As such, the estimates are reasonable, and Regional Water Board staff have moderate confidence in them.

Scott River

For TCT1 Regional Water Board staff developed a depiction of potential natural temperatures of the Scott River at its mouth using the Heat Source temperature model (Boyd and Kasper 2003). Unimpaired flows were assumed to be equivalent to natural flows for this analysis. For this analysis, unimpaired flow refers to the flow of a stream without regulation, control, diversion, or artificial additions; natural flow is the same as unimpaired flow, but also incorporates changes in process, such as changes in transpiration due to more dense vegetation in the uplands, or changes in runoff resulting from soil compaction, for instance. This modeling exercise built on previous model scenarios implemented as part of the Scott River TMDL (Regional Water Board 2005). Further model scenarios were implemented to evaluate the combined effects of potential riparian shade (in both the tributaries and mainstem Scott River), and unimpaired flows on temperatures at the mouth of the Scott River. Neither the temperature effect of these tributaries, nor the effects of unimpaired flows on Scott River temperatures had been previously evaluated in this way. The effects of unimpaired discharges were not

evaluated previously because estimates of unimpaired flows were unavailable. The effects of natural Scott River temperatures and flows were evaluated for two time periods in 2000: July 28 – August 1 and August 12 – September 25. These time periods were chosen because they coincide with time periods previously evaluated for 2003 conditions as part of the Scott River TMDL development.

Regional Board used a range of unimpaired flow estimates representing possible natural flows, and meteorological data from 2000, to evaluate the thermal effects of natural Scott River flows on the Klamath River. A range of flows were evaluated due to the uncertainty associated with unimpaired Scott River flow estimates. The flow estimates were developed based on simple water balance assumptions and estimated rates of consumptive water use.

The hydrology of the Scott River is complicated by the high degree of groundwater-surface water interaction in Scott Valley. In most years, the Scott Valley aquifer is replenished by infiltration of precipitation and stream flows from November to May, generally speaking. Once the height of the Scott River drops below the height of the surrounding water table, water drains from the aquifer back to the river. In this way the Scott Valley aquifer acts as a large sponge soaking up water when it is plentiful, and releasing it when it is scarce. This process occurs to such a degree that the Scott Valley aquifer accounts for the majority of the Scott River water leaving Scott Valley in the summer months. For instance, on August 9, 1972, the Scott River was flowing just 5 ft^3/s near the upstream end of Scott Valley (river mile 50), but was flowing at 61 ft^3/s at the downstream end of the valley (river mile 22), despite the surface diversion of 28 ft^3/s and minimal tributary inflows in between (State Water Board 1974). Similarly, on August 27, 2003 Regional Water Board staff measured 11 ft^3/s at river mile 50 and 34 ft^3/s at river mile 19, and estimated surface diversions and tributary inflows as 17 ft^3/s and 2 ft^3/s, respectively (Regional Water Board 2005).

Extraction of Scott Valley groundwater can reduce the amount of groundwater discharging to the Scott River when the drawdown (or pressure wave in a confined setting) associated with extraction intersects the river. If the effects of groundwater extraction don't reach the river before the next season's replenishment begins, the amount of extracted groundwater volume will be replenished and there will be no decrease in surface flows. Similarly, due to their geomorphology, many of the Scott River tributaries historically percolated into alluvial fans at times of low flow. A portion of irrigated surface water in Scott Valley is diverted from those creeks that historically percolated into alluvial fans. The amount of water diverted from these creeks that would have resurfaced in the Scott River in the same season is unknown. A reduction in stream flow percolation would result in a reduction in Scott River flow if percolating water would have reached the river before the next season's replenishment. Otherwise, if replenishment refills the aquifer prior to the time that the diverted stream flow would have otherwise reached the river, the diversion resulting in reduced stream flow would not affect Scott River flow.

Given these complexities and uncertainties associated with Scott River hydrology, using water use data to estimate unimpaired Scott River flows is difficult. As a starting point, Regional Water Board staff used the full unimpaired Scott River flows estimated by US Bureau of Reclamation for 2000 (Hicks 2006). The USBR method for estimating Scott River full unimpaired flows is summarized here. The entire estimated seasonal evapotranspiration of applied water (ETAW) for Scott Valley (71,010 acre-ft) was assumed equal to the seasonal flow impairment (ETAW is the loss of applied irrigation water to evaporation and transpiration). The ETAW value was then distributed through the irrigation season, by month, using estimates of monthly percentage impairment from USBR's Irrigation Training and Research Center, resulting in estimates of monthly unimpaired flow. Regional Water Board staff then distributed the monthly unimpaired flow estimates as groundwater inputs throughout Scott Valley in proportion to rates of groundwater accretion measured by the State Water Board (1974).

The USBR analysis assumes that any water irrigated in a particular month would have otherwise flowed out of Scott Valley down the Scott River in the same month. This assumption implies no travel time between the points of diversion or extraction. While this approach is grounded in water use estimates, it also relies on a simple model of a complicated hydrologic system that likely results in overestimated flows. For instance, approximately 50% of water irrigated in Scott Valley is pumped groundwater. However, given the complex nature of the Scott Valley hydrology described above, it is unlikely that the entire amount of water lost due to evapotranspiration of extracted groundwater would have otherwise discharged to the Scott River in the same month, or even same season, in the absence of water use. Any extracted water that would not have reached the river should not be routed to the river in the same month or season.

Based on this assessment of USBR's analysis, Regional Water Board staff developed two simple alternative depictions of unimpaired 2000 Scott River flows. The first alternative depiction was developed by simply reducing the groundwater accretion calculated for the USBR estimate by 50%, and the second alternative depiction was developed by reducing the groundwater accretion calculated for the USBR estimate by 75%. The rates of groundwater accretion were reduced in these depictions because surface water inflows to Scott Valley account for a small fraction of the total outflow leaving Scott Valley in the summer months. This resulted in natural flow depictions based on 100%, 50%, and 25% of ETAW added to the measured flow of the Scott River. The estimated flows at the USGS Scott River flow gauge (located just downstream of Scott Valley) for these three natural flow scenarios are presented in Table 3.2. Table 3.2 also includes monthly average measured flows from August and September of 2000, as well as the mean of the August and September monthly average flows for the 1942-1976 time period, for comparison purposes. The 1942-1976 time period is significant because it represents a period prior to the extensive use of groundwater for irrigation in the Scott Valley (SRWC 2004).

The three estimates of natural Scott River flows span a broad range, but provide reasonable estimates of the upper and lower bounds, as well as an intermediate estimate.

Comparison of the data presented in Table 3.2 indicates that the 25% ETAW scenario results in flows that are only slightly higher than the mean of the average August flow from 1942-1976, and slightly lower than the mean of the average September flow from 1942-1976. Given that the flows from 1942-1976 time period reflect a time of extensive water use, the true unimpaired flows must be higher than those estimated in the 25% ETAW scenario.

Table 3.2: Estimated and measured flows at USGS' "Scott River near Fort Jones" gauge.

Source	Monthly average flow estimate, August (cfs)	Monthly average flow estimate, September (cfs)
USBR estimated unimpaired flow	253	193
Modeled flows, 100% ETAW	277	188
Modeled flows, 50% ETAW	154	100
Modeled flows, 25% ETAW	94	59
Mean of monthly average, 1942-1976	77	62
Monthly average, 2000	19	24

This analysis is further complicated, however, by the fact that Van Kirk and Naman (2008) estimate that July 1 – October 22 Scott River flows have declined approximately 13% due to changes in the regional-scale climate, on average, since the 1942-1976 time period, based on an analysis of nearby streams. Van Kirk and Naman also estimated a 20% decrease in stream flow that isn't explained by changes in climate.

A second component of the natural Scott River temperature and flow analysis was the estimation of natural Scott River tributary temperatures. Regional Water Board staff simulated two natural tributary scenarios. The first scenario assumed a reduction of 1°C in all tributaries from Kidder Creek (river mile 32) to the mouth of the Scott River. The second scenario assumed a 2°C reduction of mean temperatures in the Scott River tributaries from Kidder Creek to the mouth of the Scott River. The assumptions were based on the results of an analysis of potential temperature reductions of Klamath tributaries conducted by Regional Water Board staff for minor tributaries of the Klamath River.

The estimates of natural Scott River flows and temperatures are used to assess the effects of Scott River flows and temperatures on stream temperatures at the mouth of the Scott River and on the Klamath River. These estimates are based on a moderate amount of verifiable information, coupled with reasonable assumptions about the hydrology of Scott Valley. Given the sensitivity of temperature and flow estimates to groundwater – surface water interaction, and the poor understanding of those processes in the Scott Valley, there is uncertainty associated with those estimates.

Salmon River

The results of the Salmon River temperature TMDL analysis indicate that temperature improvements in the Salmon River watershed will result in de minimus changes at the mouth of the Salmon River. Therefore, no alteration of the current Salmon River hydrograph or temperature boundary conditions are required to represent the Salmon

River TMDL compliance conditions. Because these data come from measured flows, Regional Water board staff have high confidence in these estimates.

Trinity River

There is no temperature listing for the Trinity River and no temperature TMDL analysis has been conducted on the Trinity. However, the Trinity River Record of Decision (ROD) prescribes flows for a range of water year types. Evidence suggests that increased flows will increase thermal mass in the river, reduce travel time, and therefore result in a lower water temperature at the Trinity confluence with the Klamath. The reduction in temperature associated with increased flows was estimated by comparing the 2005 stream temperature and meteorological conditions (the first year of ROD flows) with temperature and meteorological conditions of 2002-2004. Based on this comparison, we estimated stream temperatures would be reduced by 0.5^{o}C under natural conditions. Because the ROD flows for the summer period of 2000 are similar to our estimate of natural flows for the same period, we chose the same temperature reduction for both the scenarios. The estimates of natural Trinity River flows are based on gauged flow data. The estimates of natural Trinity River temperatures are based on observation, and professional judgment. Accordingly, Regional Water Board staff have high confidence in the flow estimates and moderate confidence in the temperature estimates.

3.3.3.3 Dissolved Oxygen Compliance in Oregon (TOD1 and TOD2)

After achieving compliance for temperature, a series of iterative simulations were implemented to analyze dissolved oxygen compliance in Oregon. The objective of the simulations was to determine dissolved oxygen allocations for the permitted point sources and discrete nonpoint sources in Oregon. Due to the nature of the dissolved oxygen criteria and dissolved oxygen's interaction with physical, chemical, and biological processes, this was only possible by running multiple simulations.

The series of scenarios was grouped into permitted point source impacts (TOD1) and discrete nonpoint source impacts (TOD2). The model configuration for TOD1 and TOD2 was based on TOT1 and TOT2. For the two major dischargers, Klamath Falls STP and South Suburban STP, nutrient and dissolved oxygen discharge concentrations were adjusted until dissolved oxygen criteria were met. Concentrations were set the same for both dischargers. Since Columbia Forest Products and Collins Forest Products were found to have a non-detectable impact on dissolved oxygen levels their discharge concentrations were not adjusted. TOD1 boundary conditions for LRDC and KSD were the same as for Upper Klamath Lake in the natural conditions scenario (current flow and TMDL-based water quality). Under TOD2, however, boundary conditions for LRDC and KSD were set initially to current conditions and then iteratively reduced until dissolved oxygen compliance was reached.

3.3.3.4 Dissolved Oxygen Compliance in California (TCD2)

The California dissolved oxygen compliance scenario (TCD2) was based on TOD2. That is, once designations to boundary conditions were made for Oregon in TOD2, they were applied to analysis in California. California tributary boundaries were based on the

natural baseline conditions scenario, while flows and temperatures for the Shasta, Scott, Salmon, and Trinity rivers were based on those used for temperature compliance in California (TCT2).

3.3.4 Dam Impacts (T4BS1)

Finally, in order to evaluate the impact of dams on water quality along the length of the Klamath River, a scenario (T4BS1) was run with dams present and boundary water quality inputs based on the final compliance scenarios for Oregon and California (TOD2 and TCD2). The model was configured using the current conditions model (i.e., a combination of CE-QUAL-W2, RMA, and EFDC models). All dams were present. This scenario enabled comparisons to be made between the current conditions scenario and the final Oregon and California compliance scenarios and promoted calculation of load allocations for the dams and reservoirs.

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CHAPTER 4. POLLUTANT SOURCE ANALYSIS

4.1 Introduction

The purpose of a TMDL pollutant source analysis is to inventory and describe all sources of pollutants that are impacting the water quality standards of the impaired waterbody. In addition, this chapter describes the processes for delivery of the pollutants and quantifies the pollutant sources within the watershed. The water quality parameters (or pollutants) considered in this Klamath River TMDL source analysis include:

- Temperature;
- Organic matter – measured as Carbonaceous Biochemical Oxygen Demand (CBOD)[1];
- Total Phosphorus;
- Total Nitrogen; and
- Dissolved Oxygen.

This analysis draws upon several sources of information and analytic tools to evaluate the various pollutant sources contributing to impairments within the Klamath River. It also draws upon the most current quality assured data available from ongoing monitoring programs conducted by various entities throughout the Klamath Basin. Application of the Klamath River TMDL models (described in Chapter 3) serves as the primary analytic tool for analyzing the water quality impacts of pollutant source loads. In addition, the source analysis incorporates information from published reports, including the approved TMDLs for the Klamath River tributaries listed below.

- Upper Klamath Lake Drainage TMDL and Water Quality Management Plan – Upper Klamath Lakes and Agency Lakes. Oregon Department of Environmental Quality – May 2002;
- Lost River, California Total Maximum Daily Loads: Nitrogen and Biochemical Oxygen Demand to address Dissolved Oxygen and pH Impairments. United States Environmental Protection Agency Region 9. December 2008;
- Staff Report for the Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Loads. State of California North Coast Regional Water Quality Control Board. June 2006;
- Staff Report for the Action Plan for the Scott River Watershed Sediment and Temperature Total Maximum Daily Loads. State of California North Coast Regional Water Quality Control Board. December 2005;
- Salmon River, Siskiyou County, California: Total Maximum Daily Load for Temperature and Implementation Plan. State of California North Coast Regional Water Quality Control Board. June 2005; and

[1] In this TMDL CBOD refers to CBOD- ultimate. The water quality models represent CBOD as organic matter; it is converted to CBOD-ultimate for TMDL calculations.

- Trinity River Total Maximum Daily Load for Sediment. U.S. Environmental Protection Agency Region IX. December 2001.

Pollutant loads for the year 2000 (the model calibration year) are quantified from fourteen geographic areas or entities (called 'source areas') within the Klamath River basin. Each source area has a different combination of source categories / processes at work which contribute to the load from that area. The geographic source areas can be more generally grouped as follows:

- Stateline – waters entering California from Oregon at stateline, which includes the Williamson and Sprague River watersheds, Upper Klamath Lake, the Lost River watershed that drains the Klamath Project area, municipal and industrial point sources to the Klamath River in Oregon, and Klamath River waters passing through Keno and JC Boyle Reservoirs. ODEQ's Klamath River TMDL source analysis evaluates the contributions from these discrete sources on the water quality of the Klamath River in Oregon;
- Copco 1 and 2 and Iron Gate Reservoirs – Copco 1 and 2 Reservoirs are treated as a single source for the purposes of this TMDL;
- Iron Gate Hatchery; and
- Tributaries – Five individual creeks and rivers are included as discrete source areas, while groups of smaller creeks are combined into five additional source areas for this analysis.

The Klamath River has historically been referred to as a "river of renewal." The Klamath River is unusual in that it has its origins in a naturally shallow, eutrophic lake, Upper Klamath Lake, which delivers warm water with high levels of nutrients and organic matter to the Klamath River. Due to an increasing stream gradient and inputs from tributaries with water that is both cooler and generally lower in nutrient content, the Klamath River undergoes a renewal process that leaves it in a more pristine state as the river approaches the Pacific Ocean, creating conditions that historically made it one of the most productive cold-water fisheries on the Pacific coast. Despite this unique attribute, current source loads have overwhelmed the historic renewal capabilities of the Klamath River , leading to its impaired status. The intent of the source analysis is to identify and quantify current pollutant source loads, in order to determine the source loads necessary to allow the river once again be restored through its own unique renewal capabilities.

4.1.1 Pollutant Source Categories

Both point and non-point sources of pollution contribute to the water quality impairments in the Klamath River. Land use pollutant source categories impacting Klamath River water quality are identified in Table 4.1. Though difficult to quantify exactly, and sometimes not reflected specifically by watershed models, these source categories contribute to water quality impairments in most of the Klamath River source areas. Each land use and its potential source contribution is addressed in detail in the implementation plan - Chapter 6. Chapter 6 also addresses other potential source contributions, which

includes sources such as suction dredging, hard rock mining, and individual and small community wastewater collection and treatment systems in the Klamath River basin in California. Often loading from one source category contributes to multiple impairments, as shown in Table 4.1. For example, sediment delivered to the Klamath River from timber harvest related activities and roads can contribute to temperature impairments, but also may contain nutrients that can contribute to DO impairment through biostimulatory effects. Another example of a combined effect is the alteration of riparian functions, such as the degradation of vegetation that provides shade to the waterbody. Not only can this lead to an increase in the temperature load to the water column, it also increases light levels that can increase biostimulatory activity. Finally, alteration of riparian functions can reduce the capacity of the riparian zone to filter sediment and nutrients.

Table 4.1: Klamath River Anthropogenic Pollutant Source Categories Impacting Water Quality Parameters of Concern.

Land Use Source Categories Affecting	Temperature	DO	Nutrients	Organic Matter
Wetland conversion		X	X	X
Grazing	X	X	X	X
Irrigated agriculture	X	X	X	X
Timber harvest	X	X	X	X
Roads	X		X	

4.1.2 Natural Conditions Baseline - Background Loads

The starting point for the Klamath River pollutant source analysis involved quantifying natural conditions baseline water quality conditions of the river. The amount of temperature, nutrient, and organic matter loading from natural background sources varies dramatically from one geographic region to another. The TMDL source analysis and allocations recognize and account for the naturally higher background levels of nutrients and organic matter within the upper Klamath River basin in comparison to other ecoregions in California. This higher natural background loading translates into a smaller loading capacity of the river, and less available assimilative capacity to avoid excess heat load, oxygen consuming and biostimulatory conditions.

As detailed in Chapter 3, the Klamath River TMDL models were applied to characterize natural baseline water quality conditions of the Klamath River. In estimating the natural baseline water quality conditions of the Klamath River the following characteristics about the Klamath River watershed were incorporated.

The underlying geology in much of the Upper Klamath basin is of volcanic origin. Soils derived from this rock type are naturally high in phosphorus (Walker 2001). Through natural erosion and leaching processes these soils contribute a high background phosphorous load to Upper Klamath basin waters. In a nutrient loading study conducted by Rykbost and Charlton (2001), monitoring of several natural artesian springs in the upper Klamath basin were characterized by high levels of nitrogen and phosphorus,

demonstrating the high natural background loading of nutrients. Upper Klamath Lake has long been noted for its eutrophic condition and demonstrated presence of high levels of organic matter (algae), including nitrogen fixing blue-green algae (Kann and Walker 2001). This nutrient and organic-matter rich Upper Klamath Lake water is the headwaters source of the Klamath River.

Within the Klamath Mountains Province of the mid- and lower-Klamath River, the underlying geology is not volcanic, and therefore does not tend to have the high levels of nitrogen and phosphorus characteristic of the Upper Klamath basin. Consequently, the tributaries that drain to the Klamath River within this province have considerably lower nutrient concentrations. As a result, the quality of the Klamath River generally improves as it flows from the Upper Klamath basin to the Pacific Ocean.

Alkalinity is a measure of the ability of water to neutralize acids. In the natural environment, alkalinity comes primarily from the dissolution of carbonate rocks. Carbonate rock sources are rare in much of the Klamath basin due to its volcanic origin. As a result, the Klamath River has a relatively low alkalinity (<100 mg/L). The low alkalinity provides for a weak buffering capacity of Klamath River water. Photosynthetic activity removes carbon dioxide in the water (in the form of carbonic acid) which increases the water pH. Natural alkalinity serves as a buffer to minimize the photosynthetically induced increase in pH. In low alkalinity waters such as the Klamath River, this buffering capacity is frequently exceeded and high pH values are observed during daytime hours when photosynthesis is occurring. The large daily variation of pH observed in the Klamath River is caused by photosynthetic activity in the low alkalinity water.

Further exacerbating the effect of the naturally productive and weakly buffered system is the presence of regionally high ambient summer air temperatures, and the resulting high heat load to the shallow and predominantly un-shaded Upper Klamath Lake. These naturally warm waters are the source of the Klamath River. In addition, the east-west aspect of much of the Klamath River also makes it prone to heating, even within the steep gorges of some reaches of the river.

In summary, the high ambient air temperatures, coupled with the high levels of biological productivity and respiration that is enhanced by the high levels of biostimulatory nutrients, yield large volumes of organic matter, seasonally high water temperatures, daily low dissolved oxygen, and high pH levels. All of these water quality conditions can be extremely stressful to many forms of aquatic life. These natural background heat, nutrient, and organic matter loads to the Klamath River underscore the very limited capacity of the river to assimilate anthropogenic pollutant sources, and the necessity for establishing load allocations that will result in attainment of water quality standards.

4.1.3 Pollutant Source Loads - Overview

The Klamath TMDL models were used to calculate loads for the year 2000, and for purposes of the Klamath TMDL, year 2000 loads represent current loading conditions.

The cumulative pollutant loads to the Klamath River for the year 2000 are identified in the schematic diagrams below (Figures 4.1, 4.2, and 4.3). These figures provide an illustration or graphical representation of the current cumulative loading to the Klamath River for total phosphorus, total nitrogen, and organic matter (CBOD[2]) from the fourteen source areas within California. Cumulative loads used in this analysis include the total annual mass generated from upstream sources that pass through the assessment location. The analysis represents a mass-balance of loads in California that sums all of the mass inputs and outputs to reaches of the river on an annual basis and, includes within-stream and reservoir dynamics (e.g., losses, retention, and fluxes). The width of a segment arrow is proportional to the magnitude of the loading for that reach. These figures demonstrate that, unlike in many other river systems, the Klamath River pollutant loads are larger (~50% of the total load) in the upper half of the basin. The source area loads are also summarized in Table 4.2. Figures 4.1, 4.2, and 4.3 and Table 4.2 provide a comprehensive overview of current loading conditions. Table 4.2 also presents natural conditions baseline loadings for comparison. In addition, Table 4.2 provides source loading estimates for the critical six month period (May – October) when water quality impairments are worse. Finally, Table 4.2 presents the percentage of annual loading associated with each parameter for each source area.

Given the different units typically used to characterize heat load, vector diagrams and a summary table are not presented to summarize the temperature loads to the Klamath River. The temperature effects from different source areas and source categories are presented in Section 4.2.

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[2] CBOD is a quantitative measure of the amount of dissolved oxygen required for the biological oxidation of carbon-containing compounds.

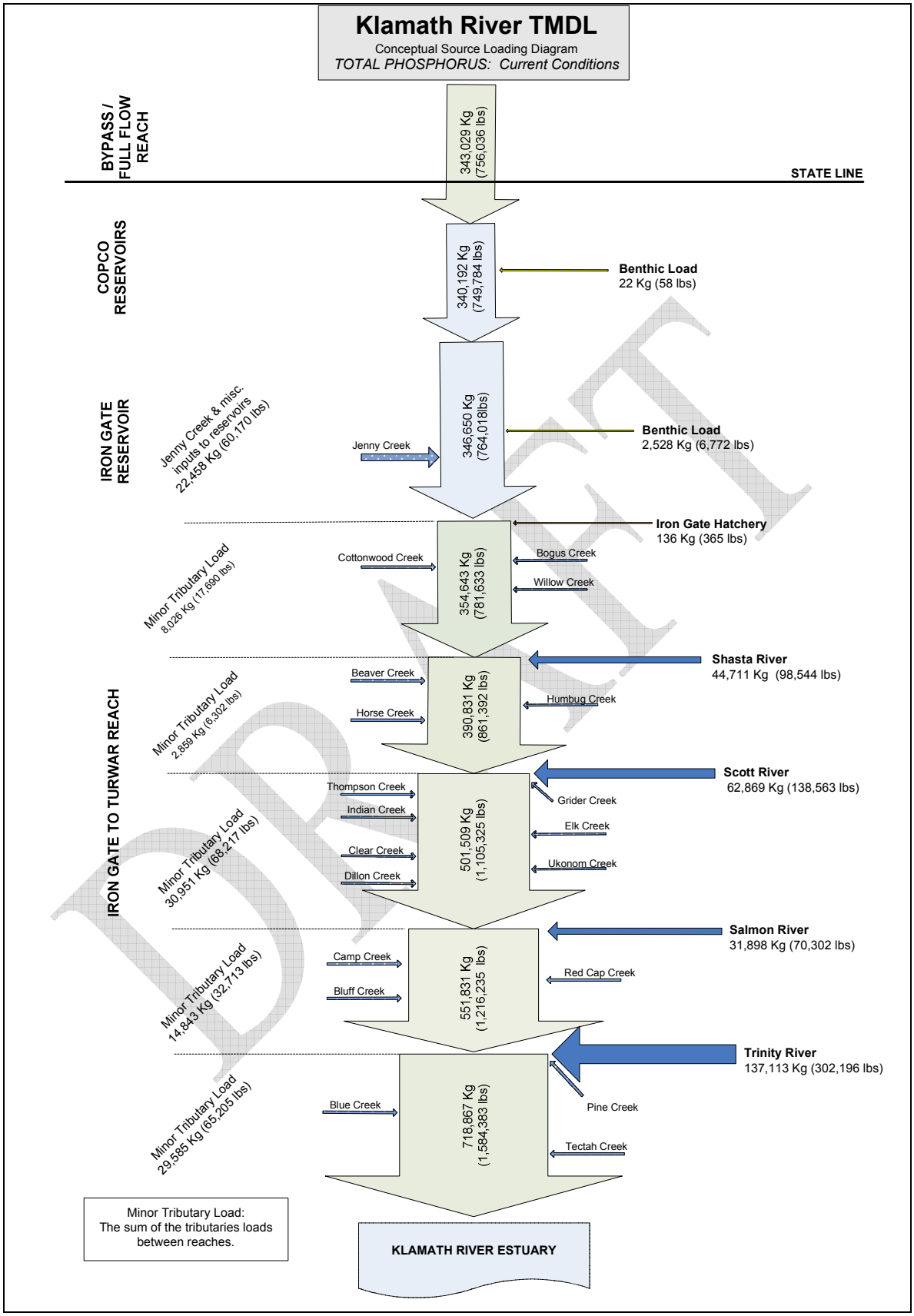

Figure 4.1: Current total phosphorous annual loading diagram

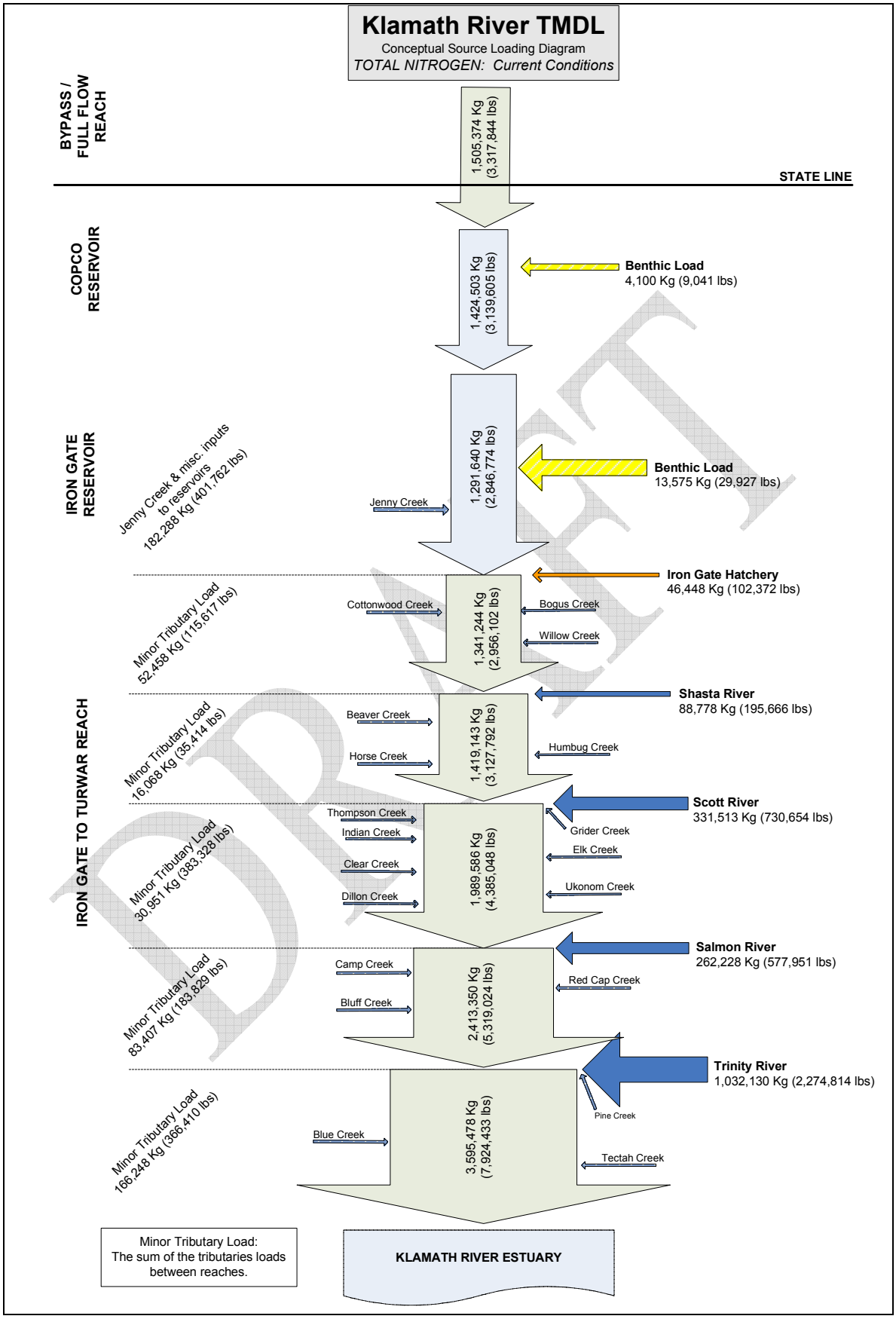

Figure 4.2: Current total nitrogen annual loading diagram

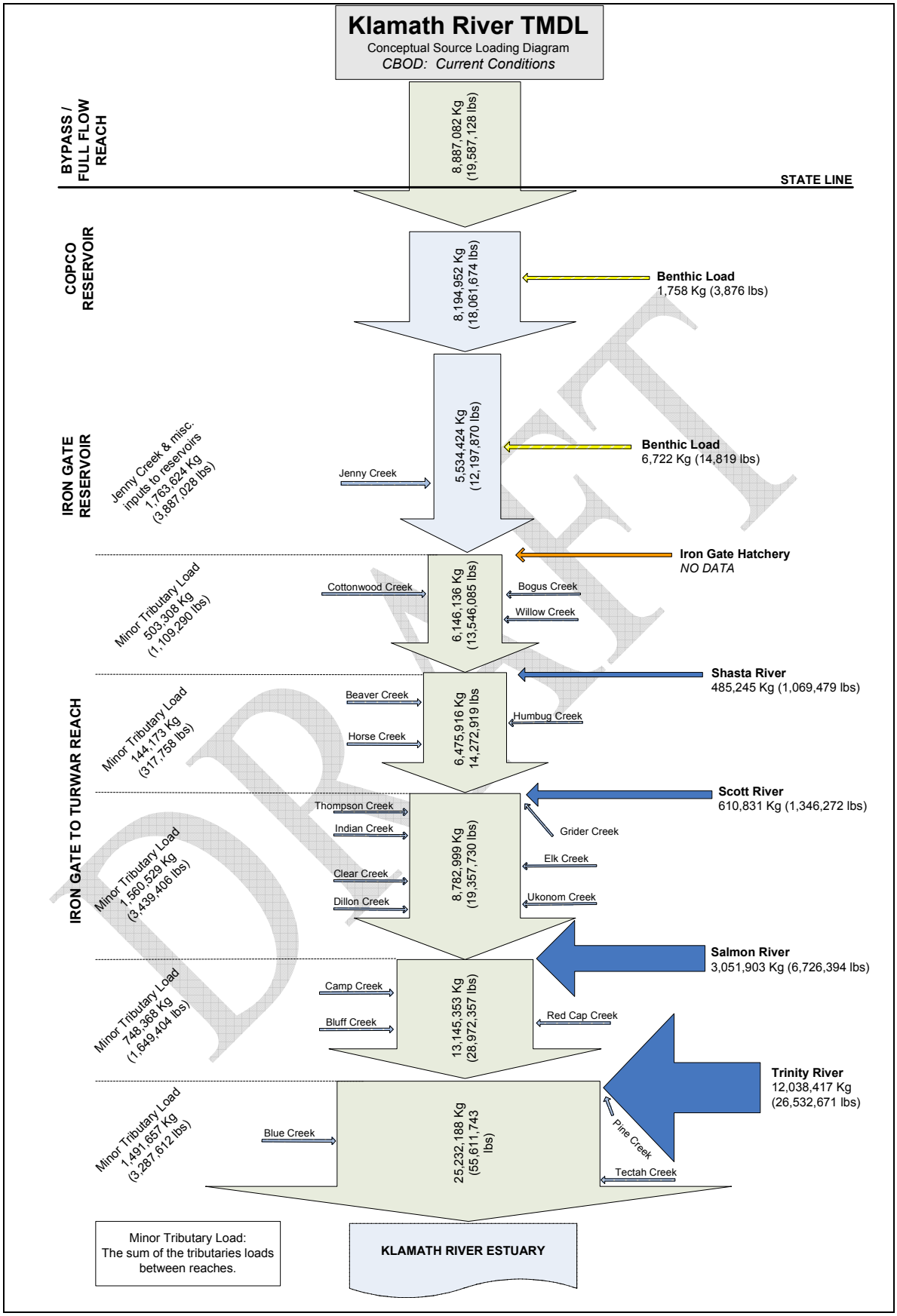

Figure 4.3: Current organic matter (as CBOD) annual loading diagram

Table 4.2: Current and Natural Conditions Baseline Nutrient and Organic Matter Loadings to the Klamath River in California

Klamath River TMDL Source Analysis Summary										
		Annual Source Loads (lbs.)			Critical Period Source Loads (lbs.) May - October (six months)			Current Percent Total Annual Loading		
Source Area		**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**
Klamath River - Stateline	Current	756,036	3,317,844	19,587,128	336,092	1,384,030	6,057,025	46.6%	38.5%	28.4%
	Natural Baseline	125,129	1,371,919	11,536,548	51,719	542,311	4,124,493			
Copco Reservoir Outlet	Current	749,784	3,139,605	18,061,674	337,863	1,187,850	5,114,281			
	Natural Baseline	125,134	1,371,911	11,416,187	50,990	534,171	4,085,650			
Copco Reservoirs – sediment flux	Current	58	9,041	3,876	44	8,286	2,478	0.0%	0.1%	0.0%
	Natural Baseline	0	0	0	0	0	0			
Stateline to Iron Gate inputs	Current	60,170	401,762	3,887,028	15,192	101,436	981,390	3.7%	4.7%	5.6%
	Natural Baseline	60,170	401,762	3,887,028	15,192	101,436	981,390			
Iron Gate Reservoir Outlet	Current	764,018	2,846,774	12,197,870	340,710	921,302	3,390,355			
	Natural Baseline	137,675	1,507,003	12,347,969	56,855	595,266	4,531,091			
Iron Gate Reservoir – sediment flux	Current	6,772	29,927	14,819	3,770	15,640	13,322	0.4%	0.3%	0.0%
	Natural Baseline	0	0	0	0	0	0			
Iron Gate Fish Hatchery	Current	365	1,361	no data	182	680	no data	0.0%	0.0%	no data
	Natural Baseline	0	0	0	0	0	0			
Iron Gate to Shasta Tributaries ▪ Bogus Creek ▪ Willow Creek ▪ Cottonwood Creek	Current	17,690	115,617	1,109,290	4,697	30,701	294,558	1.1%	1.3%	1.6%
	Natural Baseline	17,690	115,617	1,109,290	4,697	30,701	294,558			
Shasta River	Current	98,544	195,666	1,069,479	33,104	64,093	592,149	6.1%	2.3%	0.9%
	Natural Baseline	27,284	80,259	878,229	8,916	26,298	288,023			

Table 4.2 (cont.): Current and Natural Conditions Baseline Nutrient and Organic Matter Loadings to the Klamath River in California

Klamath River TMDL Source Analysis Summary										
		Annual Source Loads (lbs.)			Critical Period Source Loads (lbs.) May - October (six months)			Current Percent Total Annual Loading		
Source Area		**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**
Shasta to Scott Tributaries ▪ Humbug Creek ▪ Beaver Creek ▪ Horse Creek	Current	6,302	35,414	317,758	1,673	9,401	84,348	0.4%	0.4%	0.5%
	Natural Baseline	6,302	35,414	317,758	1,673	9,401	84,348			
Scott River	Current	138,563	730,654	1,346,272	52,957	208,948	1,056,452	8.5%	8.5%	2.0%
	Natural Baseline	138,563	730,654	1,346,272	52,957	208,948	1,056,452			
Scott to Salmon Tributaries ▪ Grider Creek ▪ Thompson Creek ▪ Happy Camp Creek / Indian ▪ Elk Creek ▪ Clear Creek ▪ Ukonom Creek ▪ Dillon Creek	Current	68,217	383,328	3,439,406	12,978	72,930	654,360	4.2%	4.4%	5.0%
	Natural Baseline	68,217	383,328	3,439,406	12,978	72,930	654,360			
Salmon River	Current	70,302	577,951	6,726,394	15,358	192,412	1,946,043	4.3%	6.7%	9.8%
	Natural Baseline	70,302	577,951	6,726,394	15,358	192,412	1,946,043			
Salmon to Trinity Tributaries ▪ Camp Creek ▪ Red Cap Creek ▪ Bluff Creek	Current	32,713	183,829	1,649,404	6,002	33,726	302,610	2.0%	2.1%	2.4%
	Natural Baseline	32,713	183,829	1,649,404	6,002	33,726	302,610			
Trinity River	Current	302,196	2,274,814	26,532,671	56,891	460,714	4,780,372	18.6%	26.4%	38.5%
	Natural Baseline	302,196	2,274,814	26,532,671	56,891	460,714	4,780,372			
Trinity River to Turwar Tributaries ▪ Pine Creek ▪ Tectah Creek ▪ Blue Creek	Current	65,205	366,410	3,287,612	11,972	67,277	603,640	4.0%	4.2%	4.8%
	Natural Baseline	65,205	366,410	3,287,612	11,972	67,277	603,640			

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4.2 Pollutant Source Area Loads

This section discusses the pollutant loads from the key source areas.

4.2.1 Stateline – Upper Klamath Basin

4.2.1.1 Temperature

The combined water temperature effects of sources of increased thermal loads in Oregon were evaluated by comparing the results of the current condition model scenario with the natural condition scenario at the California-Oregon border. The results, summarized in Figure 4.4, indicate that the sum of all sources upstream of California lead to significant temperature increases, possibly as much as 9 ^{o}F (5 ^{o}C), from approximately April to December. The combined sources include alterations due to discharge of irrigation return flows (Klamath Straits Drain, Lost River Diversion Channel) and changes in hydrodynamics resulting from reservoir operations (Keno, JC Boyle).

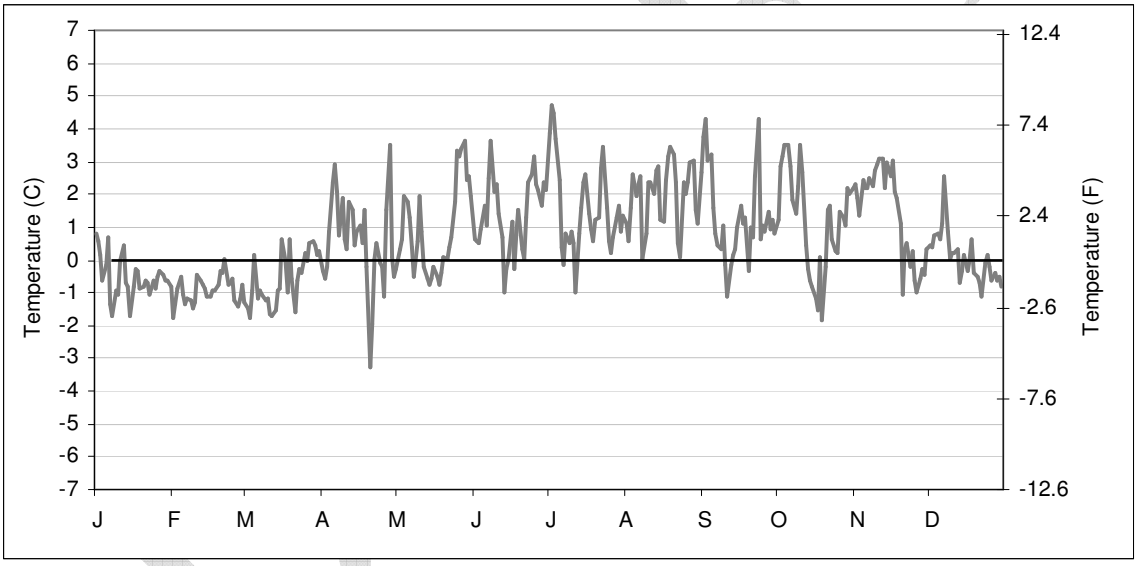

Figure 4.4: Estimated temperature changes at Stateline due to reservoirs and irrigation return flows upstream. Positive values represent an increase above the natural conditions baseline.

The diversion of water directly from the Klamath River and its tributaries, including Upper Klamath Lake, greatly alters the flow of the Klamath River, primarily in the spring. Reductions in flow can lead to increased diurnal temperature fluctuations, as well as increased daily average temperatures. These concepts are detailed in Section 2.4.3.3.

As described in Section 3.3.2, the natural conditions baseline scenario was developed using current flows from Upper Klamath Lake and the Klamath Project area, and therefore does not reflect thermal impacts caused by irrigation diversions. Thus, Figure 4.4 also does not reflect those thermal effects. Figure 4.5 presents the difference in daily

maximum temperature predicted to occur at the stateline solely from the diversion of water (i.e. no dam effects and no irrigation return flows). The temperature difference between the two scenarios is generally slight, but may account for as much as 2.7 ^{o}F (1.5 ^{o}C) increase in daily maximum temperature in early spring. The relatively minimal difference in stream temperatures at stateline is likely due to the fact that the source of the Klamath River, Upper Klamath Lake, is a relatively warm waterbody, reaching equilibrium temperatures irrespective of alteration in flow conditions.

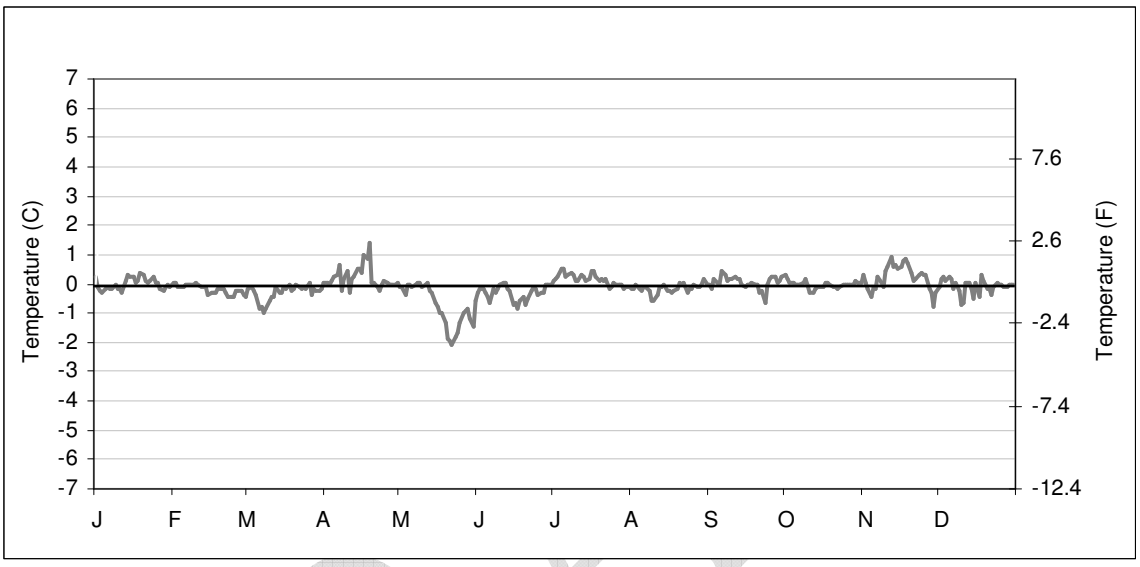

Figure 4.5: Estimated change in daily maximum temperature at Stateline resulting from altered flows, 2000 simulation year. Positive values represent an increase in temperatures due to reduced flow.

4.2.1.2 Nutrients and Organic Matter

The greatest nutrient and organic matter loads to the Klamath River originate in the Upper Klamath basin above stateline. Current TP and TN loads at Stateline comprise over 50% of the total nutrient loading to the Klamath River (Table 4.2). The fraction for CBOD is somewhat less at 28%. Figure 4.6 compares the current annual TP, TN, and CBOD loads at Stateline to those estimated loads under natural conditions baseline, reflecting 504%, 142%, and 70% increases in annual loads from natural conditions baseline for TP, TN, and CBOD, respectively.

All of the land use source categories identified in Section 4.1.1 contribute to the increased loads at Stateline. The Upper Klamath Lake Drainage TMDL (ODEQ 2002) analyzes the sources contributing loads to Upper Klamath Lake. In addition to irrigated agriculture, upland sources (e.g., gravel road surface erosion, timber harvest operations), nutrient flux from reclaimed wetlands, and internal nutrient loading from Upper Klamath Lake bottom sediments contribute to loading to Upper Klamath Lake. Irrigated agricultural practices within the Klamath Project area contribute loading to the Klamath River at Klamath Straights Drain and intermittently at the Lost River Diversion Channel. Those sources within the California portion of the Lost River are analyzed in the Lost River, California

TMDL (USEPA 2008). Finally, municipal and industrial point sources discharge to the Klamath River within Oregon. There are two municipal wastewater point sources that discharge to the Klamath River in Oregon: South Suburban Sanitation District and Spring Street Sanitation plant run by the City of Klamath Falls. There are two industrial wastewater point sources that discharge to the Klamath River in Oregon: Columbia Forest Products, and Collins Forest Products.

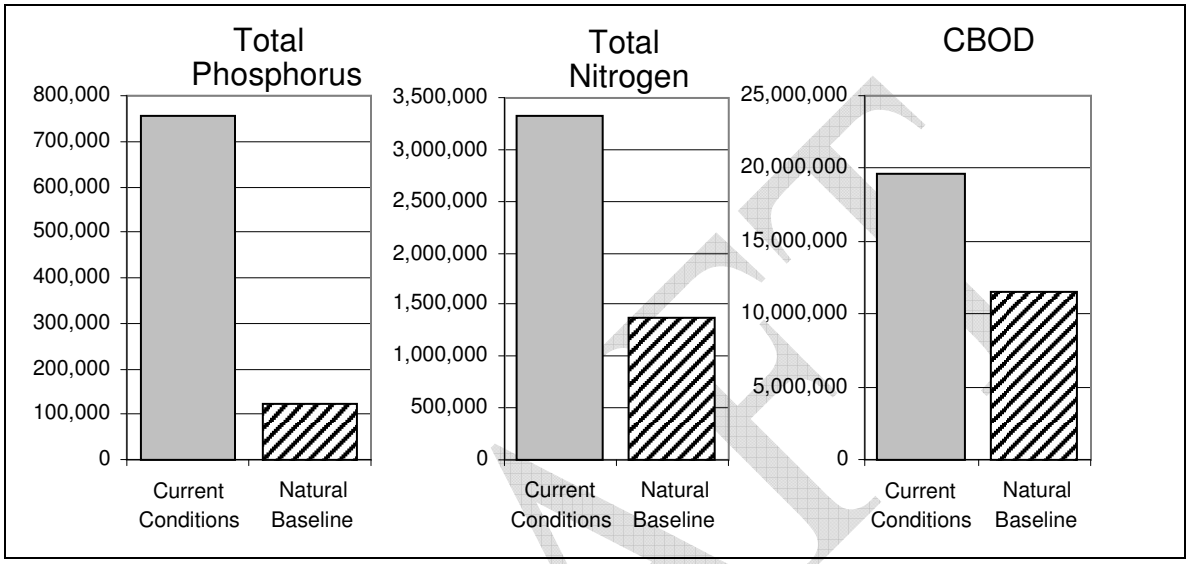

Figure 4.6: Comparison of Current Annual TP, TN, and CBOD Loads at Stateline to Natural Conditions Baseline Loads.

4.2.2 Copco 1 and 2 and Iron Gate Reservoirs

4.2.2.1 Temperature

An analysis of model results was prepared that isolates the effects of each reservoir (Copco 1 and 2 and Iron Gate), in order to evaluate the impacts of the reservoirs on Klamath River temperature. The effects of the reservoirs were isolated by calculating the change in river temperature between the upstream and downstream limits of each reservoir for both current and natural conditions baseline. The temperature impact of each reservoir was calculated by subtracting the change in temperature that would result from free-flowing conditions (i.e. in the absence of the reservoirs) in the reservoir reaches from the change in temperature that currently occurs in the reservoir reaches. The resulting calculation estimates the change in temperature due to the presence of the reservoirs, by subtracting the amount of heating expected to occur in a natural (free-flowing) state.

The results of the modeling analysis demonstrate that the presence of Copco 1 and 2 significantly influences the temperature of the Klamath River. Figure 4.7 presents the change in daily maximum temperature associated with the presence of the reservoir for the 2000 calendar year. These results indicate that the presence of Copco Reservoir increases Klamath River water temperatures by more than 5.4 ^{o}F (3.0 ^{o}C) during the late summer and fall months.

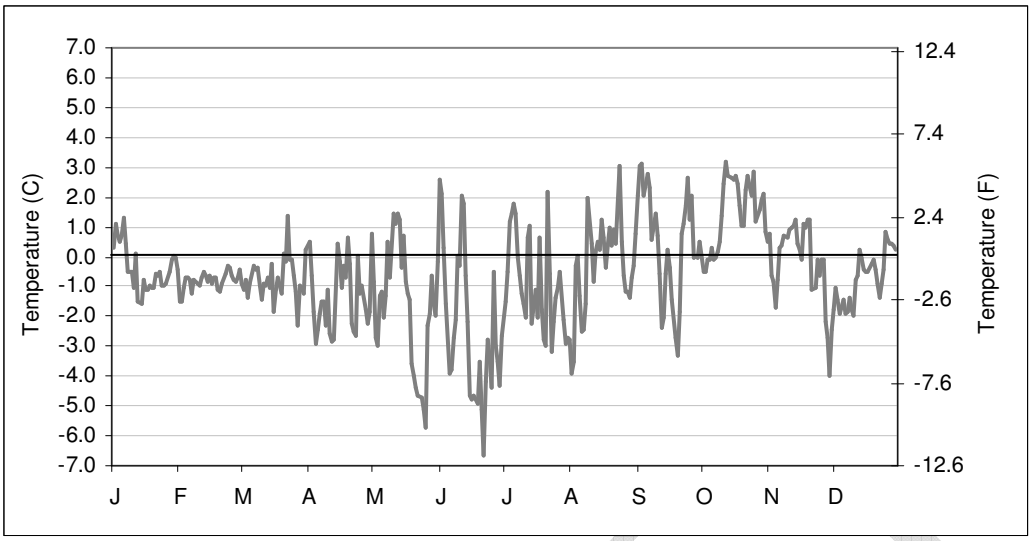

Figure 4.7: Calculated change in daily maximum Klamath River temperatures resulting from the presence of Copco Reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Copco 1 and 2.

The results of the Iron Gate modeling analysis are very similar to the Copco analysis results. The results also demonstrate that the presence of Iron Gate Reservoir significantly influences the temperature of the Klamath River. Figure 4.8 presents the change in daily maximum temperature associated with the presence of the reservoir for the 2000 calendar year. These results indicate that the presence of Iron Gate Reservoir increases Klamath River water temperatures by up to 6.3 ^{o}F (3.5 ^{o}C) during the fall months. The timing of this increase coincides with the time when Chinook salmon currently spawn in the Klamath River mainstem directly downstream of the reservoir.

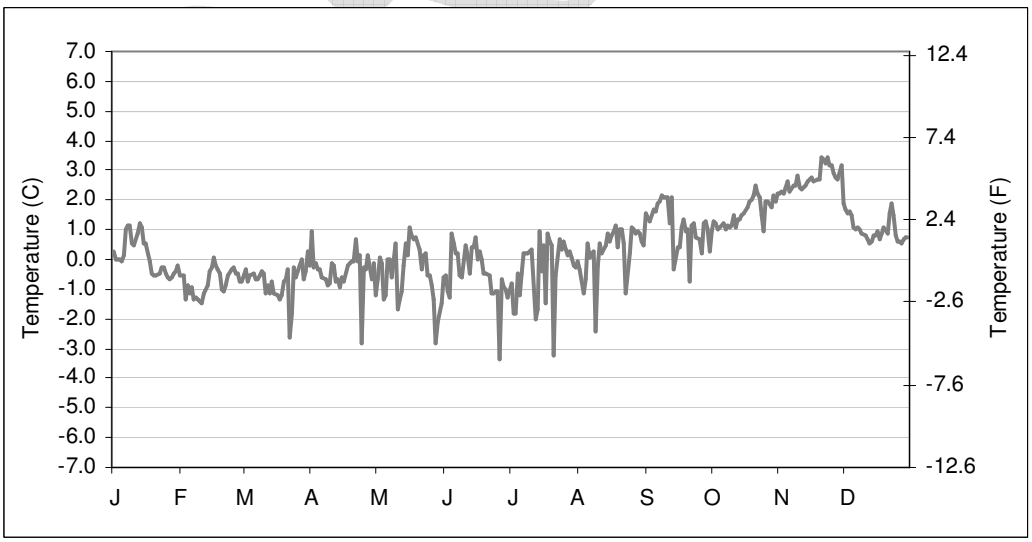

Figure 4.8: Calculated change in daily maximum Klamath River temperatures resulting from the presence of Iron Gate Reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Iron Gate Reservoir.

The analyses of Iron Gate and Copco Reservoirs indicate that each of these reservoirs can increase Klamath River temperatures by as much as 6.3 ^{o}F (3.5 ^{o}C). However, in reality the effects of the reservoirs are not additive and do not necessarily result in a total increase of up to 12.6 ^{o}F (7.0 ^{o}C). This is because Copco Reservoir heats the water to a level close to the equilibrium temperature, so the water is close to equilibrium when entering Iron Gate Reservoir. The rate of heating is proportional to the difference between the instantaneous temperature and the equilibrium temperature. This concept is taken into account and addressed in the load allocation and implementation recommendations for these facilities.

4.2.2.2 Nutrients, Organic Matter, and Dissolved Oxygen

The presence of Copco 1 and 2 and Iron Gate Reservoirs creates DO conditions that do not meet water quality standards. Iron Gate and Copco Reservoirs become stratified during the summer months with warm, dissolved oxygen-rich water near the surface and colder, dissolved oxygen-poor water near the bottom. There is no overlapping layer that has DO and temperature conditions that are both supportive of COLD for much of the summer season. In Iron Gate Reservoir, the levels of dissolved oxygen are only suitable for rainbow trout to a depth of 4 meters, on average (rainbow trout are assumed to be the most sensitive cold water-dependent species currently present). However, temperatures in Iron Gate Reservoir are not low enough to fully support rainbow trout above a depth of approximately 10 meters. Copco Reservoir similarly stratifies, with suitable dissolved oxygen above approximately 7.5 meters depth and suitable temperatures below 17 meters deep. By contrast, under free-flowing river and natural temperature conditions, there would be co-occurring temperature and DO conditions that meet standards.

The occurrence of DO conditions that do not meet standards within Copco 1 and 2 and Iron Gate Reservoirs during summer months is due to the physical characteristics of reservoirs and the nutrient and organic matter loads entering the reservoirs, but is exacerbated by internal nutrient and organic matter loading within the reservoirs.

Internal Nutrient Loading Within Reservoirs

Reservoirs alter the nutrient dynamics of a river system. By design, reservoirs represent areas of a river system in which velocity is decreased and residence time increased. This encourages the settling of particulate material, including both nutrient-bearing organic material and algae, and nutrients (i.e. PO_4 and NH_4) sorbed to inorganic sediment. In addition, the physical characteristics of reservoirs cause them to stratify during summer months, resulting in the bottom layer of the reservoir (i.e. hypolimnion) becoming devoid of oxygen (i.e. anoxic). Under these conditions organic debris (including dead algal detritus) that has settled to the bottom of the reservoir is subject to one or more of the following processes that can lead to the transfer of nutrients from the reservoir bottom sediments back into the water column, also known as internal nutrient loading:

- If the sediments are disturbed by wind-driven currents or by other means (organisms or degassing) interstitial nutrients can be transferred to the water column simply by agitation.

- Decrease in the redox potential (increase in the availability of electrons) in the surficial bottom sediments caused by intensive microbial respiration, as would be the case for highly organic sediment, can cause biogeochemical changes that result in accelerated release of mineralized or soluble organic phosphorus and ammonia from the sediments to the overlying water, even if the sediments are immobile.
- High pH at the sediment surface may cause release of adsorbed phosphorus from sediments, with or without agitation of sediments.
- In shallow lakes, suspended algae cells may, under calm conditions, sink to deeper waters at or below the thermocline, where phosphorus is more concentrated than in the surface waters where most photosynthesis occurs, and then be re-suspended either by wind or buoyancy control mechanisms after assimilating phosphorus, thus bringing phosphorus from the sediments to the water column.

These internal nutrient loading processes can occur simultaneously within a reservoir, and serve as an input (or source) of nutrients into the water column or the reservoir. In turn, phosphate (PO_4) and ammonia (NH_4), the dissolved inorganic nutrients that were once sequestered within the sediments, become available for uptake by planktonic algae within the reservoir, or can move out of the reservoir and be available for uptake by attached algae (i.e. periphyton) in downstream river reaches. This export of dissolved inorganic nutrients from the reservoir to the river can occur within the window of the critical growth period for periphyton within the river.

Nutrient Retention Within Free-Flowing Rivers

In support of Klamath River TMDL development, Tetra Tech assessed the nutrient dynamics of the Klamath River (see Appendix 1, TetraTech 2008). This assessment evaluated the nutrient retention capacity of the Klamath River reservoirs in California, as well as the potential nutrient retention capacity of the river under free-flowing conditions. This assessment is included as Appendix 1 of this report.

As described in Appendix 1 (TetraTech 2008), physical and biological processes in free-flowing river reaches can result in both net removal and temporary retention of nutrients. One of the major processes for temporary retention is uptake of nutrients by periphyton. Periphytic algae, as well as heterotrophic organisms, require nutrients for growth and remove inorganic nutrients from the water column, converting them to organic biomass. Heterotrophs also remove organic matter as foodstock. This storage, however, is temporary. In addition to normal dieoff and predation, periphyton is subject to scour and transport downstream during high flow events.

Temporary retention in river reaches also occurs as a result of settling and storage of particulate matter, including organic detritus. Inorganic orthophosphate and, to a lesser extent, ammonium can also sorb to sediment particles and settle out. These processes also largely constitute temporary retention, as the stored particulate matter can be remobilized by scouring flows.

Permanent removal of nutrient mass can also occur in several ways. For nitrogen, denitrification and conversion to nitrogen gas results in a permanent loss of nitrogen from

the water to the air. This may be balanced by fixation of atmospheric nitrogen by certain types of cyanophytes, but these are usually not dominant in flowing waters. Water lost to deep groundwater, agricultural diversions, or riparian wells can remove nutrients, and is more important for nitrogen, which is more soluble than phosphorus. Effective removal of phosphorus may also occur due to burial in deposits that are not readily remobilized (due, for instance, to stream meander and cutoffs), export to the floodplain, or conversion to tightly bound, insoluble mineral forms. These latter processes tend to be of less importance in higher gradient systems, such as the Klamath, so net rates of removal for TP are expected to be less than net rates of removal for TN in the Klamath.

TMDL Model Results

Figures 4.9 and 4.10 present a comparison of current and natural conditions baseline cumulative loads of TP, TN, and CBOD at the outlet of Copco 1 and 2 and Iron Gate Reservoirs. Cumulative loads used in this analysis include the total annual amount of mass generated from upstream sources that pass through the assessment location. The analysis is a model generated mass-balance calculation that sums all of the mass inputs and outputs to the assessment location on an annual basis including within stream and reservoir dynamics (e.g., losses, retention, and fluxes). Locations of the loading estimates for the natural conditions baseline scenario are consistent with the location on the river at the outlet of Copco 2 and Iron Gate. In addition to representing a free-flowing river (i.e. no impoundments present), the natural conditions baseline scenario represents natural water quality conditions. Therefore the differences in loadings are due to the difference in water quality conditions entering the river reaches occupied by the reservoirs, not simply by the presence of Copco 1 and 2 and Iron Gate under current conditions. Nonetheless, the figures illustrate the large increase in current nutrient loads, particularly total phosphorus, at these locations compared to natural conditions baseline.

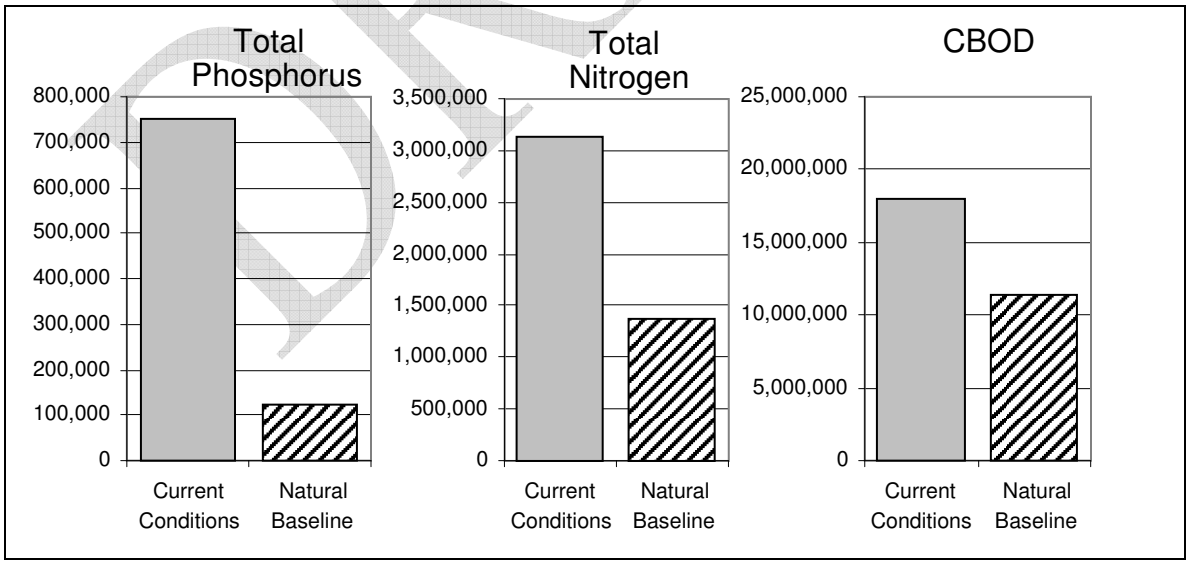

Figure 4.9: Comparison of Current Annual Loads of TP, TN, and CBOD with Natural Baseline Loads at Copco Reservoirs

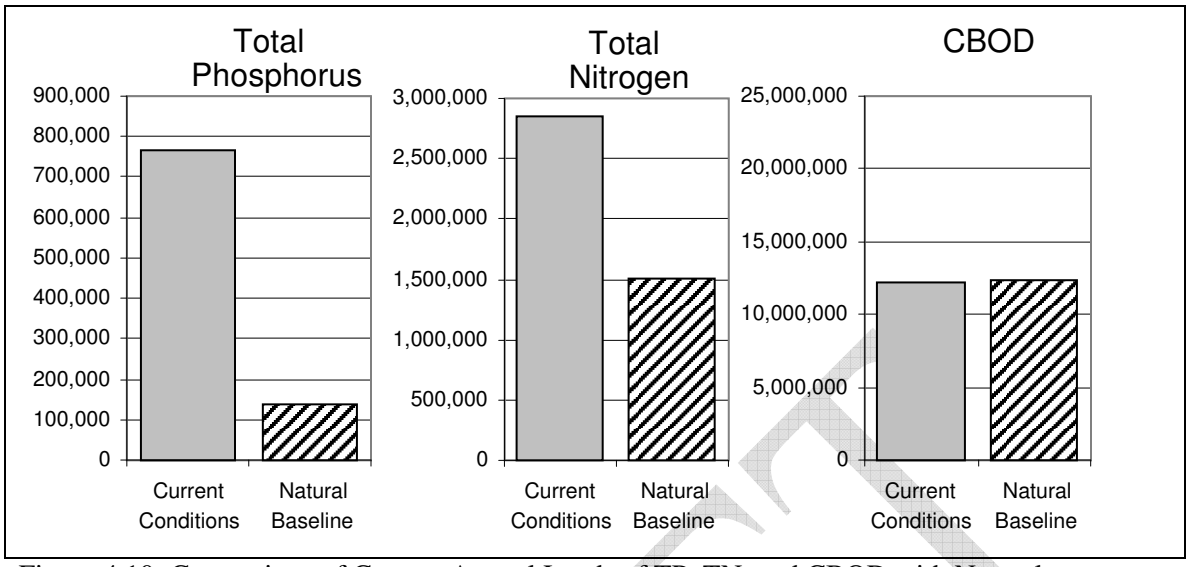

Figure 4.10: Comparison of Current Annual Loads of TP, TN, and CBOD with Natural Baseline Loads at Iron Gate Reservoir

The differences in CBOD load are smaller. In fact, the CBOD loading estimates indicate a slightly higher load at the location of the outlet of Iron Gate under natural conditions baseline. The estimated lower annual mass of CBOD at Iron Gate under current conditions is explained by the settling and trapping function of the reservoirs along with longer residence time with the dam in place that allows for greater decay of influent CBOD. In the pre-dam era organic matter such as decaying algal tissue generated in Upper Klamath Lake and other organic debris captured in storm runoff would largely be swept downstream and deposited in low gradient reaches or be washed out through to the estuary. With the placement of dams along the river the impoundments create low velocity conditions which allow for much of this organic material to settle out into the reservoir sediments. However a simple comparison of organic mass totals (as CBOD) does not tell the whole story. The reservoir impoundments create an environment favorable to increased suspended algae productivity. The increased algal growth offsets some of the organic matter loss through settling by fixing carbon from the atmosphere through growth and exporting this organic matter downstream through the reservoir outlets. The effect of this change in form and timing of organic matter loading is not completely understood but is addressed briefly in the Klamath nutrient conceptual model discussion in Section 2.4.2.1.

Table 4.3 presents the current TP, TN, and CBOD loadings at Stateline, Copco 2 outlet, and Iron Gate outlet based on model results, and identifies the change in loading for these parameters between Stateline to Copco and between Stateline and Iron Gate. Within the critical summer growth period (May – October), there is currently an approximate increase in TP loads of 1% from Stateline to Copco Reservoir, and from Stateline through Iron Gate Reservoir. These model results indicate that under current conditions the reservoirs increase TP loads delivered to the river. On the other hand, TN and CBOD

annual loads are currently decreased by 14% and 38%, respectively, within the river reach that occupies the reservoirs.

Table 4.3 Current Total Phosphorus, Total Nitrogen, and CBOD Loads at Stateline, Copco Outlet, and Iron Gate Outlet, and Associated Loading Changes

Current Conditions	**Annual Source Loads (lbs.)**			**Critical Period Source Loads (lbs.) May - October (six months)**		
Source Area	**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**
Klamath River - Stateline	756,036	3,317,844	19,587,128	336,092	1,384,030	6,057,025
Copco Reservoirs – tailrace	749,784	3,139,605	18,061,674	337,863	1,187,850	5,114,281
Iron Gate Reservoir – tailrace	764,018	2,846,774	12,197,870	340,710	921,302	3,390,355
Loading Change	**Annual Source Loads**			**Critical Period Source Loads May - October (six months)**		
Stateline to Copco Reservoir	-1%	-5%	-8%	1%	-14%	-16%
Stateline to Iron Gate Reservoir	1%	-14%	-38%	1%	-33%	-44%

In order to isolate the change in nutrient loads from Copco 1 and 2 and Iron Gate attributed to the release of nutrients from the bottom sediments under anoxic conditions, a sensitivity analysis was run using the Klamath TMDL model. The model includes a benthic flux term that simulates the release of nutrients from sediments at the bottom of the reservoir under anoxic conditions. When the benthic flux term is turned *off* for both reservoirs within the model, no nutrients are released from the bottom sediments, even when anoxic conditions in the hypolimnion are simulated in the model. A comparison of resulting nutrient concentrations at the outlet of Iron Gate under two scenarios (with the benthic flux term turned on or off for both reservoirs) indicates the relative contribution to nutrient concentration (and load) resulting from the release of nutrients from bottom sediments under stratified anoxic conditions.

The results of this comparison at Iron Gate Dam for inorganic phosphate (PO_4) are illustrated in Figure 4.11, and demonstrate an increase in downstream PO_4 concentrations beginning in early June (beginning of summer stratification) and tapering off in late November (post turnover – no stratification). Any peak above the mid-line (0.000) suggests higher concentrations of PO_4 being released during stratified anoxic conditions from sediments at the bottom of the reservoirs downstream through the reservoir outlet. This increase occurs during the critical growth period for downstream periphyton, contributing to biostimulatory conditions.

Results of this benthic flux sensitivity analysis are also used to quantify the annual nutrient loading to Copco 1 and 2 and Iron Gate attributed to nutrient release from bottom sediments. The total annual TP and TN loads from Copco 1 and 2 bottom sediments is 1,940 pounds and 9,041 pounds, respectively. The total annual TP and TN loads from

Iron Gate bottom sediments is 6,772 pounds and 29,927 pounds, respectively. While these loadings are small compared to the current loadings entering the reservoirs, they do represent an increase in nutrient loading that would not occur in the absence of anoxic conditions, created by the presence of the reservoirs.

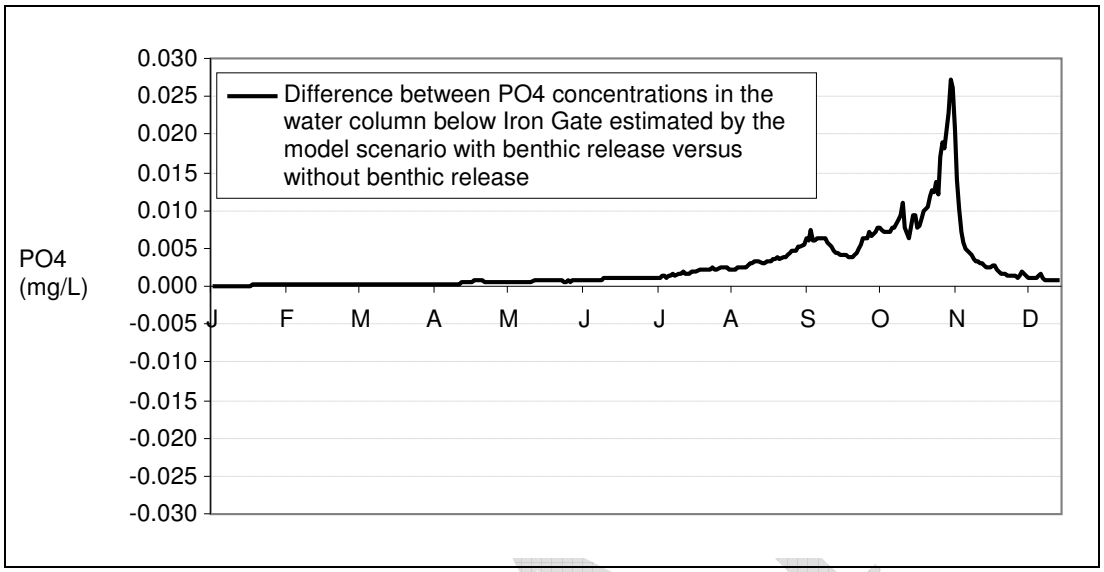

Figure 4.11: Comparison of PO_4 concentrations immediately downstream of Iron Gate Reservoir illustrating contribution of nutrient flux from reservoir sediments under anoxic conditions (summer stratification).

Annual and critical summer season bottom sediment TP and TN loads for both Copco and Iron Gate are presented in Table 4.2. A comparison of the current annual and critical season loads for Copco 1 and 2 and Iron Gate Reservoir bottom sediments demonstrates that the majority of these loads occur during the summer months. The summer months are the critical growing season, the period when an increase in biostimulatory conditions exacerbates the water quality impairments in the Klamath. Therefore, both the timing and form of this source load contribution contributes to the water quality impairments.

Available monitoring data for the stream reach immediately downstream of Iron Gate Dam demonstrates distinct seasonal differences in nutrient concentrations. Total phosphorus, ortho-phosphate, total nitrogen, and total inorganic nitrogen concentration data collected between 1990 to 2007 from below Iron Gate Dam to river mile 176 were compiled and grouped by season: March to June (pre-reservoir stratification), and July to October (during stratification and turnover). The Mann-Whitney ***U*** test (Reckhow and Chapra 1984) was applied. Mann-Whitney ***U*** is a non-parametric test for assessing whether two samples of observations come from the same distribution. As shown in Figures 4.12, 4.13, 4.14, and 4.15, the populations of the seasonal data sets are distinctly different for total phosphorus, ortho-phosphate, total nitrogen, and total inorganic nitrogen.

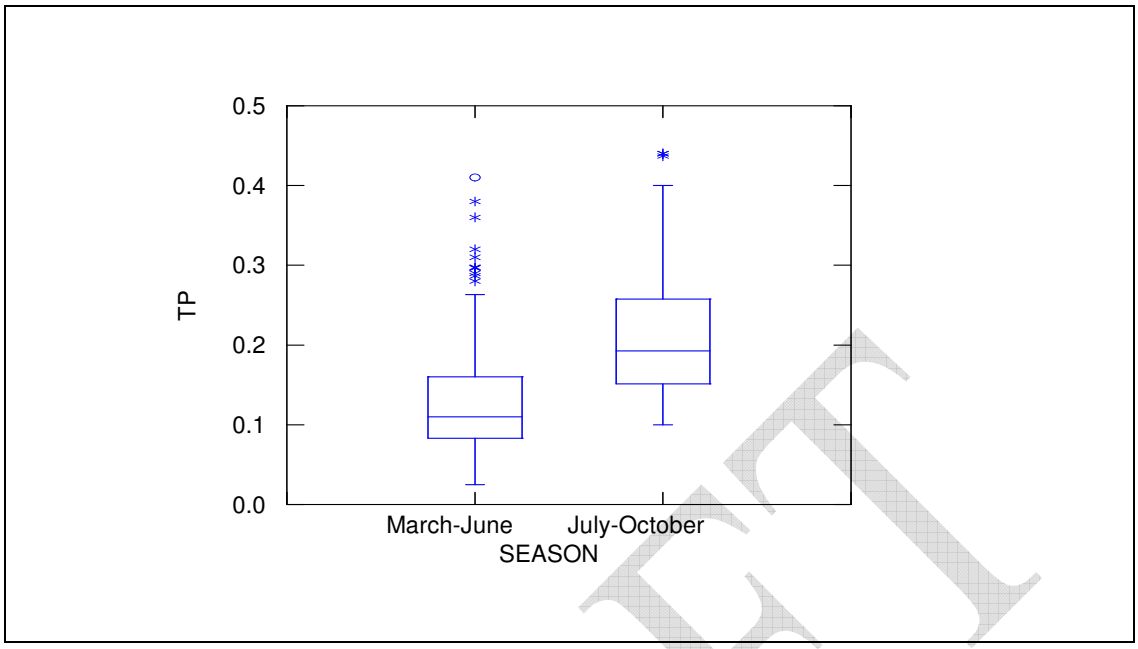

Figure 4.12: Box Plot presenting Seasonal Distribution (1990 to 2007) of Total Phosphorus (TP) Concentrations (mg/L) below Iron Gate Dam

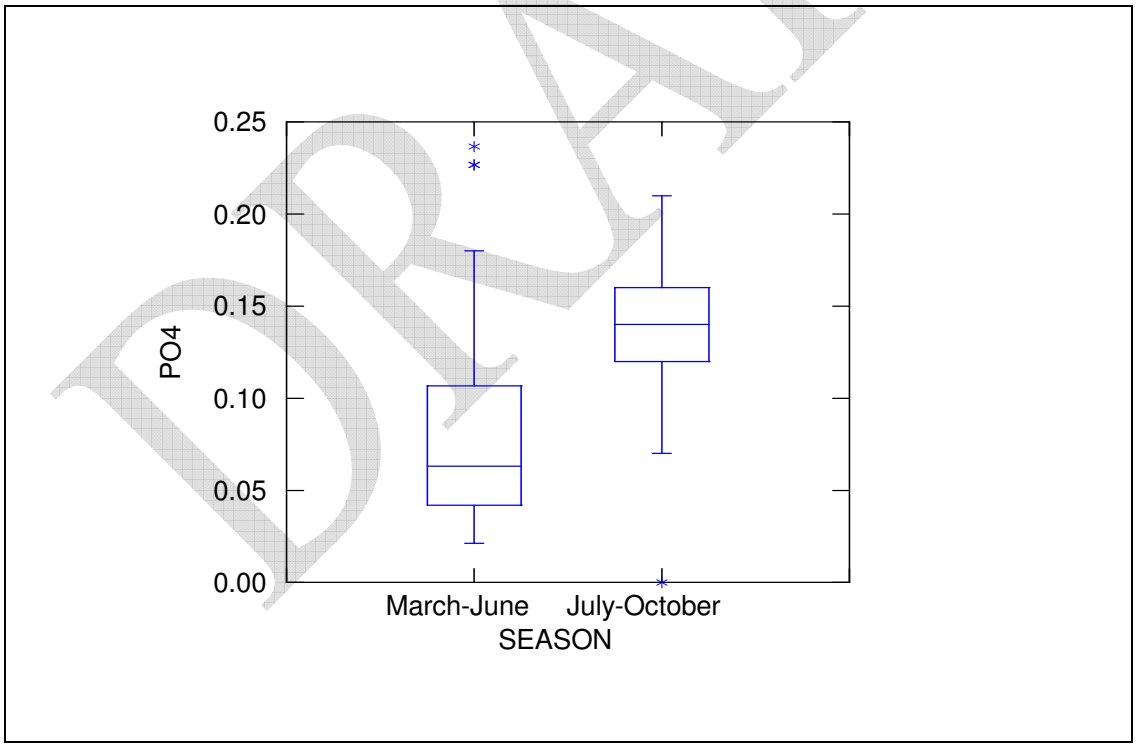

Figure 4.13: Box Plot presenting Seasonal Distribution of Ortho-Phosphate (PO4) Concentrations (mg/L) below Iron Gate Dam

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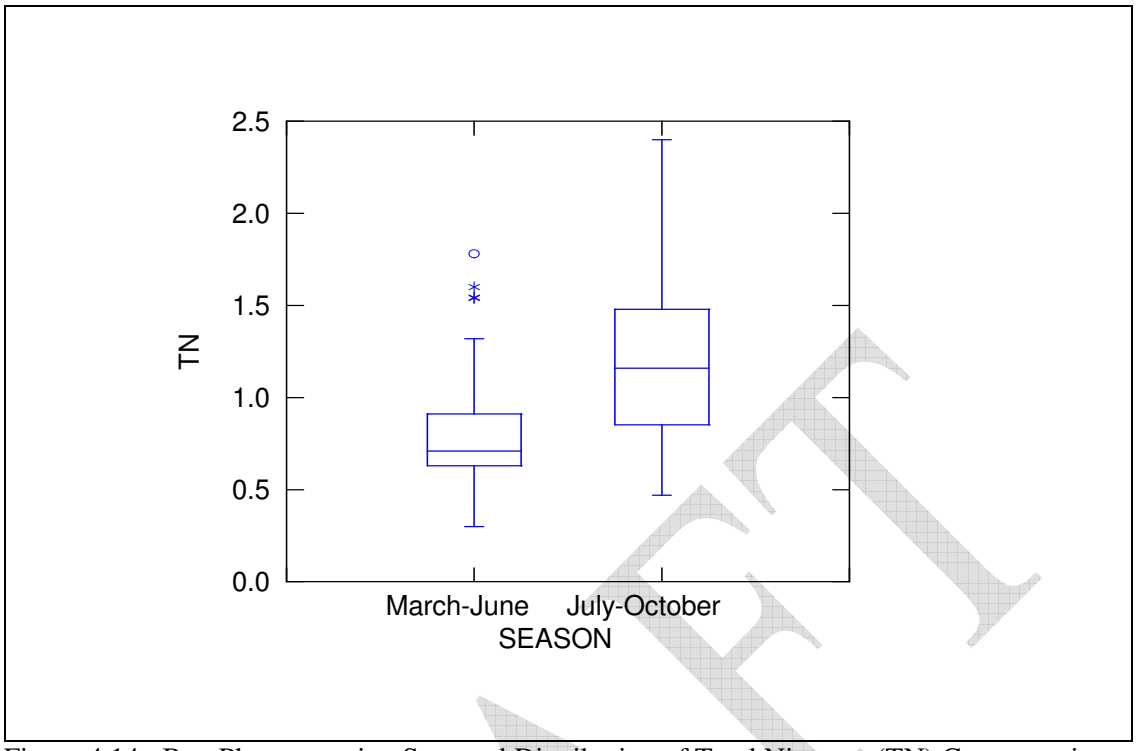

Figure 4.14: Box Plot presenting Seasonal Distribution of Total Nitrogen (TN) Concentrations (mg/L) below Iron Gate Dam

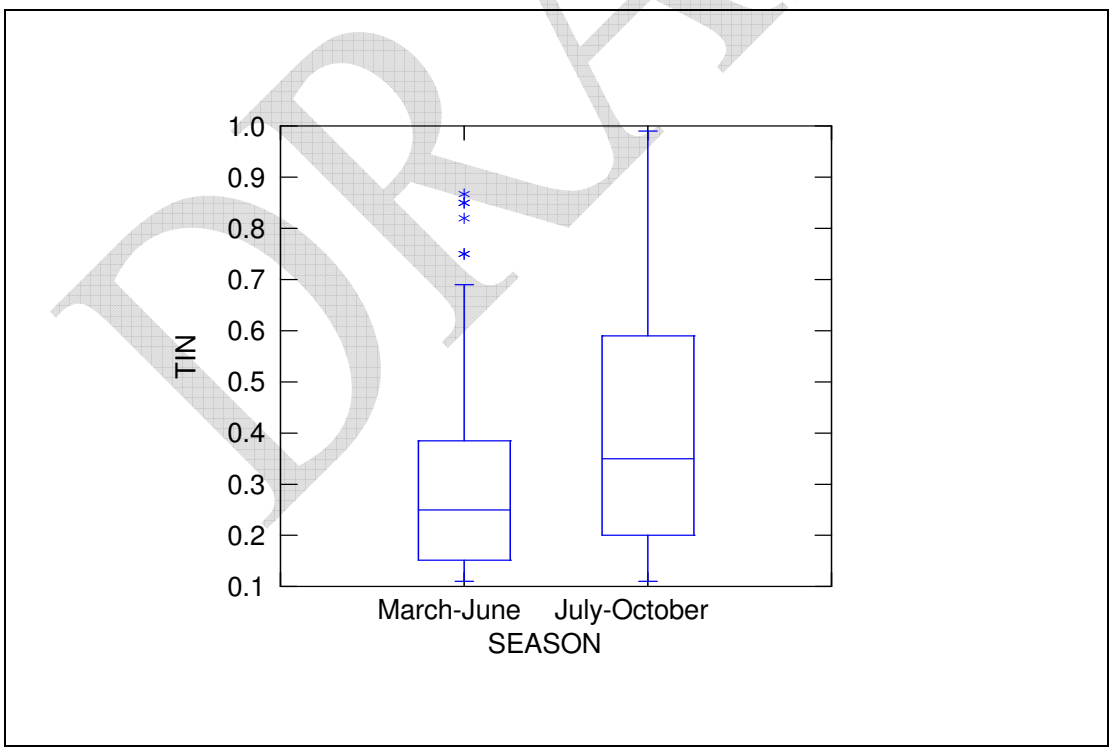

Figure 4.15: Box Plot presenting Seasonal Distribution of Total Inorganic Nitrogen (TIN) Concentrations (mg/L) below Iron Gate Dam

The higher concentrations of nutrients during the July to October period, compared with those during the March to June period, contribute to biostimulatory conditions of the river, and are due in part to the release of nutrients from the reservoir bottom sediments. This monitoring data appears to confirm the model predictions of reservoir benthic nutrient flux presented in Figure 4.11.

4.2.3 Iron Gate Hatchery

The California Department of Fish and Game operates a salmonid fish hatchery and rearing facility immediately downstream from Iron Gate Dam. Iron Gate Dam was constructed without volitional fish passage capabilities. Thus, the hatchery was completed concurrently with Iron Gate Dam in 1962 to mitigate for migrating salmonid stocks that would no longer have access to spawning and rearing habitat upstream from Iron Gate Dam. Since the hatchery is part of the mitigation required of PacifiCorp due to the blockage by the dam of salmonid habitat upstream of the dam, they are responsible for shared funding of hatchery operations.

Water for hatchery operations is supplied from Iron Gate Reservoir. There are two intakes from the reservoir which deliver water to the fish hatchery: one at a depth of approximately 18 feet and the other at a depth of approximately 74 feet below normal pool elevation (actual depths vary depending on the water level in the reservoir). During the cooler months water is withdrawn from 18 feet, though as water temperatures in the reservoir warm the intake point is moved to the lower depth (74 feet). Average flows through the hatchery system are 16.1 million gallons per day (mgd) (1494.6 cubic feet per second [cfs]), while maximum flows are 31.9 mgd (2961.4 cfs). The hatchery consists of a production pond system, where juvenile fish are reared, and two settling ponds. During daily operations, flows ranging from 7.75 to 15.5 mgd (719.5 to 1438.9 cfs) pass through the production and settling ponds and discharge directly into the Klamath River. These flows carry waste generated during the feeding and care of the fish including suspended solids, settleable solids, and chemicals used in disease control. When the fish production ponds are cleaned flows ranging from 1.9 mgd to 5.5 mgd, comprised of metabolic wastes, unconsumed food, algae, silt, and detritus, is released to settling ponds, and then into the Klamath River.

Due to the relatively small discharge flows from Iron Gate Hatchery, and the minimal water quality data characterizing the quality of the discharge, the Klamath TMDL model does not represent hatchery inputs. Therefore, the analysis of loads from the hatchery are based solely on empirical data.

4.2.3.1 Temperature

The current monitoring and reporting program for Iron Gate Hatchery does not require temperature monitoring. Thus, no temperature data are available to evaluate the effects of the hatchery effluent on the Klamath River. Regardless, because the discharge of elevated temperature waste is not allowed per the interstate water quality objective for temperature, any effluent discharged to the river at a higher temperature than the river exceeds the objective.

4.2.3.2 Nutrients and Organic Matter

Regional Water Board staff conducted a study during September through November 2004 to evaluate the hatchery discharge. Water to support hatchery operations is taken from the Iron Gate Reservoir from the deeper water layer. This water is aerated during transport to the hatchery. Flow through the hatchery remains relatively constant at 7.5 million gallons per day. The hatchery discharges water at two locations: (1) the rearing pens and (2) the settling ponds. Nutrient concentrations measured from these two discharges were statistically compared.

The *Mann-Whitney U Test* was used to assess the difference between the two hatchery discharges[3]. The test found there was no significant difference between the two discharges for both total phosphorus concentrations ($p = 0.689$) and total nitrogen concentration ($p = 0.479$). Based on these results, the two discharges were combined and treated as a single discharge for the hatchery nutrient loading estimates.

There are two potential sources of loading associated with the hatchery operations. Nutrient loads may be added to the downstream Klamath River due to within-hatchery processes such as stock feeding. Nutrient loads may also be added to the downstream Klamath River due to the withdrawal of water from the deeper, nutrient-enriched water layer in Iron Gate Reservoir for hatchery operations.

To estimate the total nutrient loading for the hatchery, concentrations measured upstream of Iron Gate Reservoir were used as background to compare to the combined discharge concentrations for the rearing and settling pond discharges. Daily loads were determined for each date of the 2004 study. These daily loads were extrapolated to the next date that samples were collected. The total load for the study period (69 days) was determined and normalized to a daily load. Annual loads for total phosphorus and total nitrogen were calculated from these daily load estimates.

The annual load to the Klamath River due to hatchery operations was estimated to be 1360 lbs of total nitrogen and 365 lbs of total phosphorous. These results suggest that the hatchery is a relatively minor source of nutrients to the Klamath River. Organic matter loading was not estimated of hatchery operations since measurements of CBOD were not collected during the 2004 study.

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[3] The *Mann-Whitney U test* is a non-parametric test for assessing whether two samples of observations come from the same distribution. The method is also known as the Wilcoxon Rank-Sum test. This statistical test is a nonparametric (i.e., distribution-free) inferential statistical method. Nonparametric methods are most appropriate approach for assessing water quality data which can have widely varying frequency distributions. The test null hypothesis is that the two samples are drawn from a single population. The test is similar to performing an ordinary parametric two-sample *t* test, but is based on ranking the data set.

4.2.4 Tributaries

4.2.4.1 Temperature

Regional Water Board staff evaluated whether the major Klamath River tributaries (Shasta, Scott, Salmon, and Trinity Rivers) are contributing to the temperature impairment of the Klamath River by analyzing the influence those tributaries have on the temperature of the Klamath River itself, as well as the potential for those tributaries to provide thermal refugia for salmonids and other cold water species. The approach to analyzing these issues required the estimation of natural tributary flows and temperatures.

Two Klamath River model scenarios (TCT1 and TCT2) were developed to evaluate the effects of the major Klamath River tributaries on the temperatures of the Klamath River, as described in Section 3.3.3.2. Additional analyses were conducted to further understand how water management in the Shasta and Scott basins affect Klamath River temperature conditions, also described in Section 3.3.3.2. No additional analysis was conducted to evaluate effects of Salmon River on the Klamath River because the Salmon River TMDL found that current temperatures at the mouth of the Salmon River are consistent with natural baseline conditions.

The natural baseline conditions scenario represents estimated natural flows and temperatures in the Shasta, Scott, and Trinity Rivers, as well as estimated natural temperatures in the Klamath River upstream of the major tributaries. A range of natural Scott River flows estimates were evaluated due to the uncertainty of the natural flow estimates included in the natural baseline conditions scenario. The development of these scenarios is described in Section 3.3.3.2.

The California compliance scenario represents conditions expected from full compliance with: 1) the Scott and Shasta TMDLs, 2) the Trinity Record of Decision (ROD), and 3) attainment of water quality standards in the Klamath River upstream (i.e. at stateline, Iron Gate, and Copco). The Shasta, Scott, and Trinity River natural temperature estimates used in this analysis are meant to depict the absence of all anthropogenic impacts, representing full natural flows and site potential riparian shade conditions. The development of these scenarios is described in Section 3.3.3.2.

Shasta River

The California compliance scenario (TCT2) results indicate that the Shasta River would have a negligible temperature effect on the Klamath River. Figure 4.16 presents the difference in maximum daily Klamath River temperatures downstream and upstream of the Shasta River for both the current condition and California compliance scenarios. Figure 4.16 shows that the Shasta River could have a slight warming effect on the Klamath River in the fall months under California compliant conditions, but there is only a small temperature difference between the two simulation results otherwise.

The results of the natural conditions baseline scenario modeling analysis indicate that given natural temperature and flow conditions in the Klamath and Shasta Rivers, the

Shasta River may cool the daily maximum temperature of the Klamath River by as much as 1.0 °C (1.8 °F) during the summer season, with an average reduction of 0.5 °C (0.9 °F) from June through September. Figure 4.17 presents the difference in maximum daily Klamath River temperatures downstream and upstream of the Shasta River for both current and natural conditions.

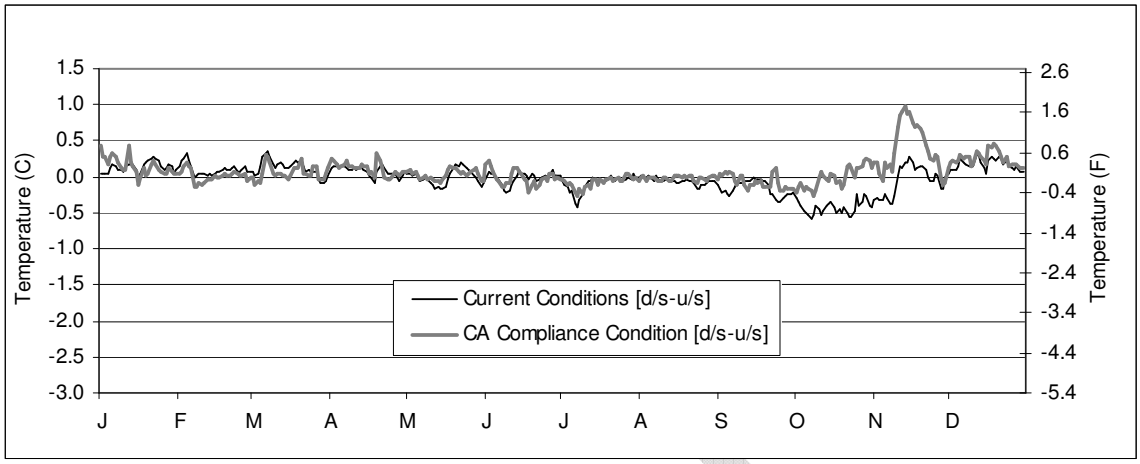

Figure 4.16: Change in Klamath River daily maximum temperatures resulting from current and Shasta TMDL compliant Shasta River conditions. Negative values indicate that the Shasta River is cooling the Klamath River.

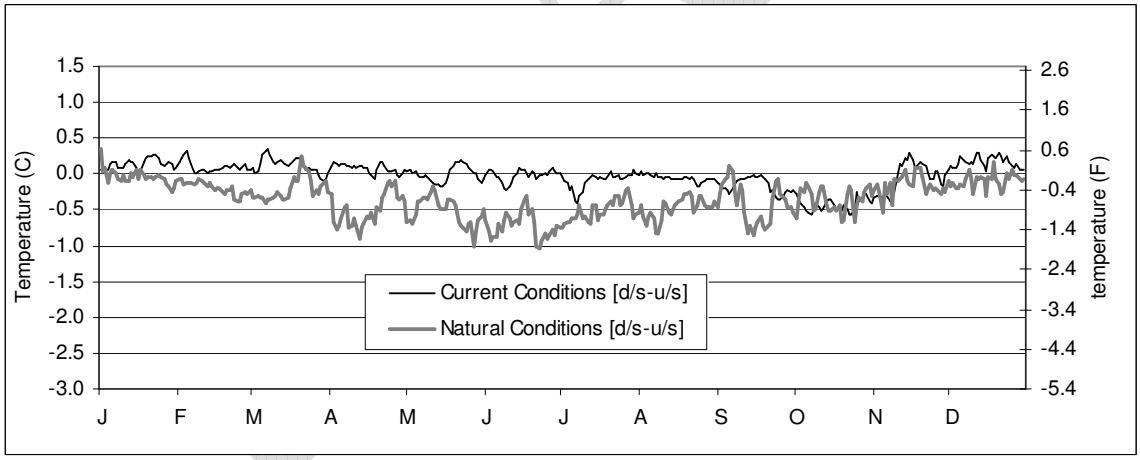

Figure 4.17: Change in Klamath River daily maximum temperatures resulting from current and estimated natural Shasta River conditions. Negative values indicate that the Shasta River is cooling the Klamath River.

Currently, Shasta River temperatures are too warm in the summer months to provide a thermal refuge for Klamath River salmonids. The California compliance scenario assumes a 1.6 °C (2.9 °F) daily average temperature reduction relative to current conditions at the mouth of the Shasta River, based on the Shasta TMDL temperature analysis (Regional Water Board 2006). The1.6 °C (2.9 °F) Shasta River temperature reduction depicted in the California compliance scenario improves conditions, but daily

average temperatures are 20 °C (68 °F) or greater from mid-June to early September, as seen in Figure 4.18. The Shasta River temperature conditions depicted in the natural conditions baseline scenario, however, only exceed 20 °C (68 °F) for a few days during the year. Daily average temperatures greater than 20 °C (68 °F) are significant because temperatures above 20 °C (68 °F) have been shown to inhibit adult Chinook migration (see Appendix 3 [Carter 2008], Section 1.3.2). Thus, the results of this analysis indicate that the Shasta River would provide a thermal refuge for Klamath River salmonids under natural conditions, but would only provide a thermal refuge for a short time in the spring and fall under Shasta TMDL compliant conditions.

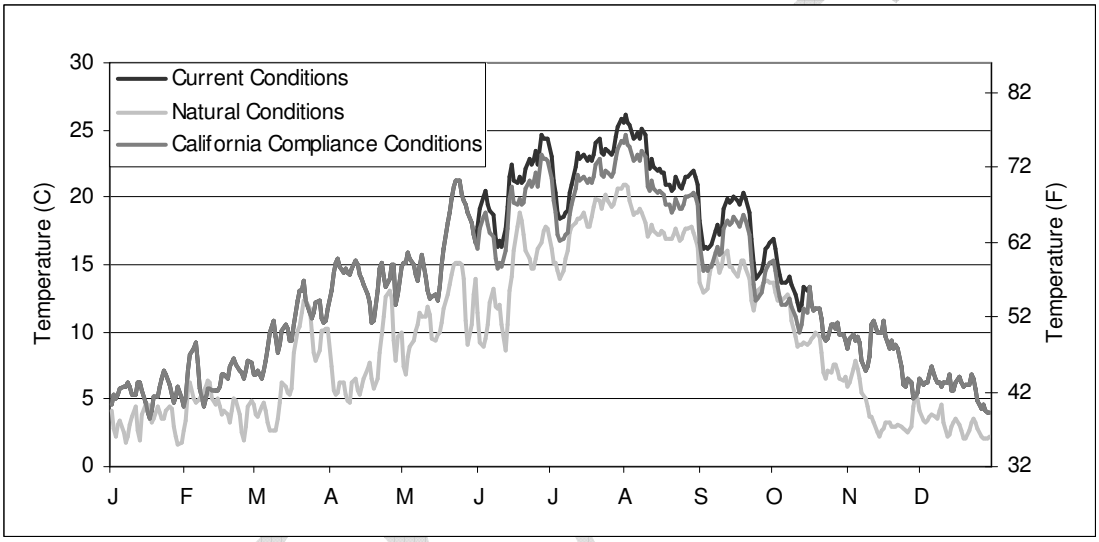

Figure 4.18: Estimated daily average Shasta River temperatures at the mouth of the Shasta River for the three management scenarios evaluated.

Scott River

The results of the California compliance condition scenario indicate that, given the conditions represented in the scenario, the Scott River would not change the Klamath River temperature much more than it currently does (Figure 4.19). An exception occurs during the height of the spring snow melt, in late May, when the Scott River cools the Klamath River an additional 1.0 °C (1.8 °F) in the California compliance scenario. Another exception occurs in the fall when the Scott River currently reduces the Klamath River temperature slightly, whereas it increases the Klamath River temperature slightly in the California compliance scenario. The difference is a result of the fact that in the California compliance scenario the Klamath River is much cooler during those months, compared to the current conditions scenario. The Scott River has nearly the same effect on the Klamath River in the two scenarios during the remainder of the season.

The results of the natural conditions baseline scenario indicate the Scott River could potentially have a significant temperature influence on the Klamath River, reducing temperatures by over 1.5 °C (2.7 °F) in June, and reducing temperatures by 0.5 - 1.0 °C (0.9 – 1.8 °F) during the remainder of the summer season (Figure 4.20). These results,

however, reflect the most generous estimates of natural Scott River flows and temperatures. Given Regional Water Board staff concerns about the natural conditions baseline scenario estimates of Scott River Flows and temperatures, staff have developed more refined estimates of natural flow and temperatures, as described in Section 3.3.3.2. Staff evaluated how the Klamath River would be affected, given these refined Scott River natural flow and temperature estimates. The effect on Klamath River temperatures was assessed outside of the Klamath TMDL models, and were calculated using the mixing equation. The result of this additional analysis is presented in Figure 4.21. The results indicate that the Scott River would likely have a more negligible effect on Klamath River temperatures under these refined natural flow and temperature conditions than depicted in the natural conditions baseline scenario.

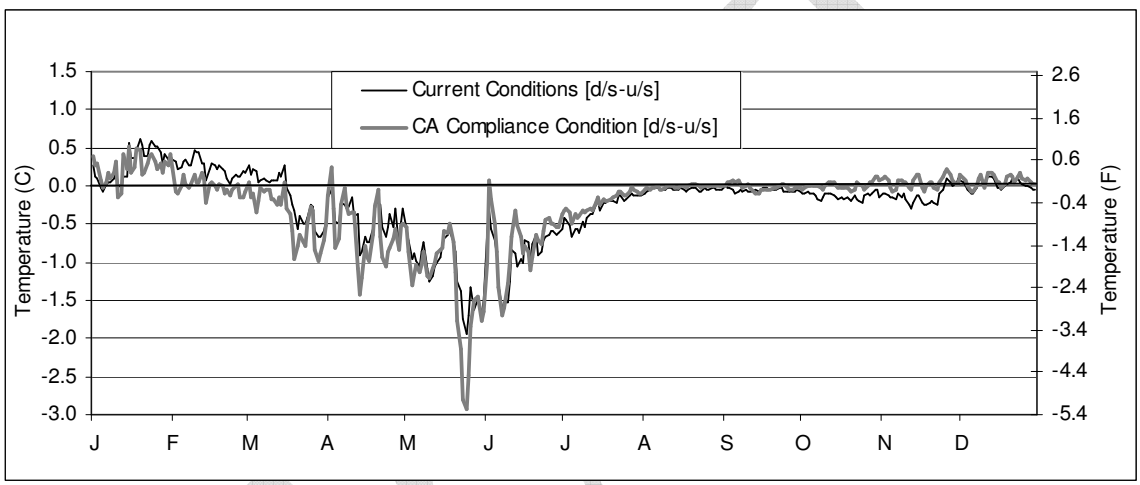

Figure 4.19: Change in Klamath River daily maximum temperatures resulting from current and Scott TMDL compliant Scott River conditions. Negative values indicate that the Scott River is cooling the Klamath River.

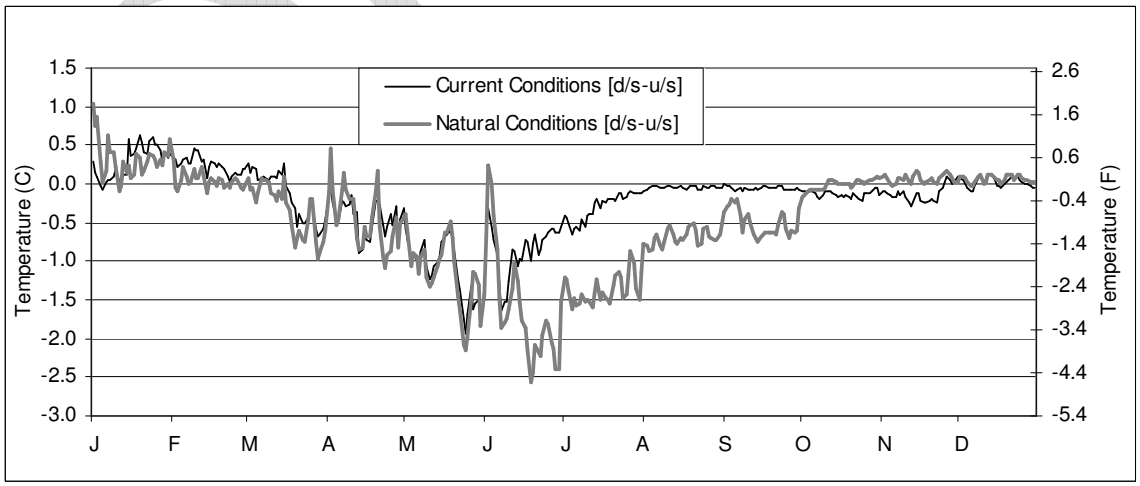

Figure 4.20: Change in Klamath River daily maximum temperatures resulting from current and originally estimated natural Scott River conditions. Negative values indicate that the Scott River is cooling the Klamath River.

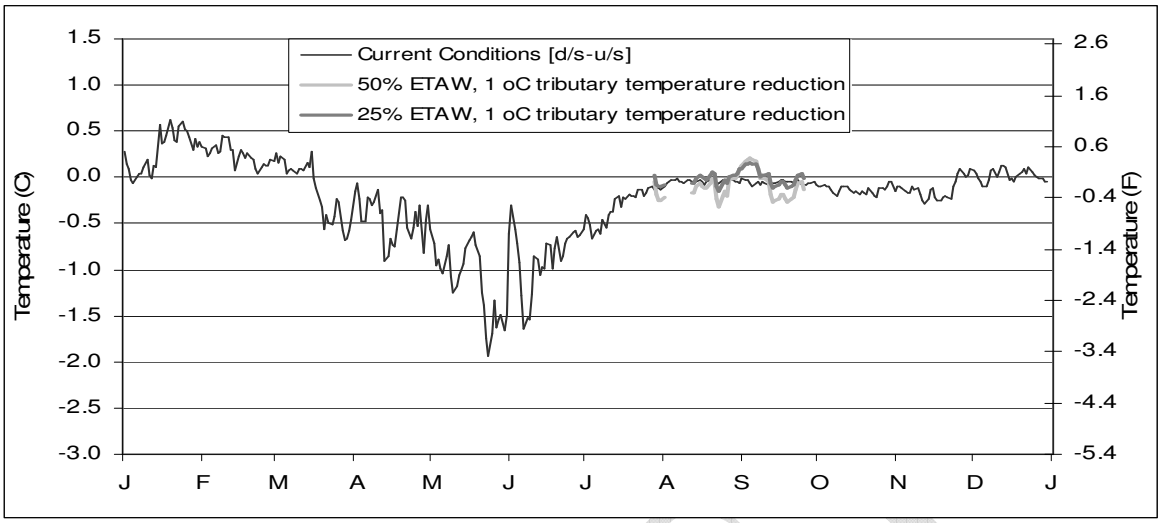

Figure 4.21 Change in Klamath River daily maximum temperatures resulting from current and revised natural Scott River conditions estimates. Negative values indicate that the Scott River is cooling the Klamath River.

Current Scott River temperatures are too hot to offer salmonids a thermal refuge from the high temperatures of the Klamath River. The results of the natural baseline conditions scenario indicate the Scott River would provide a marginal thermal refuge under those conditions (Figure 4.22). The additional analysis conducted by Regional Water Board staff indicates the conditions depicted in the natural baseline conditions are likely to overestimate natural flows and underestimate natural temperatures.

The natural flow estimate developed using the"50% ETAW" flow estimate and 1.0 ^{o}C (1.8 ^{o}F) reduction in tributary temperatures (50% ETAW) provides a more likely estimate of natural flow and temperature conditions. Figure 4.23 presents temperature estimates for two of the Scott River scenarios, as well as the temperatures compliant with California water quality standards in the Klamath River upstream of the Scott River. The results of the 50% ETAW estimate indicate the Scott would provide marginal thermal refuge during the late summer when adult salmonids are preparing for spawning.

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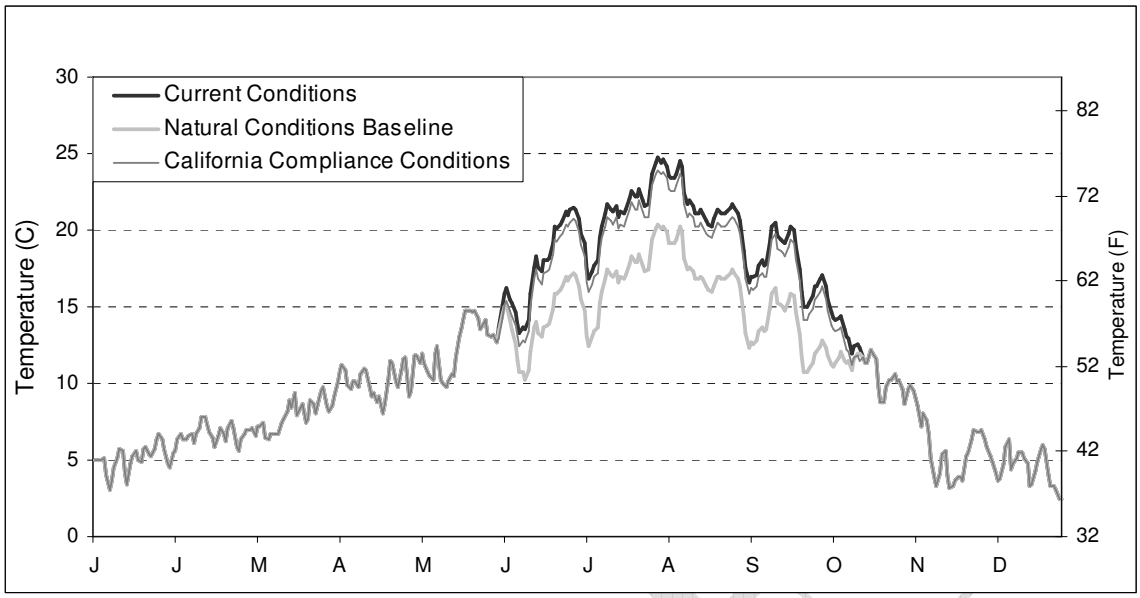


Figure 4.22: Estimated daily average Scott River temperatures at the mouth of the Scott River for three scenarios.

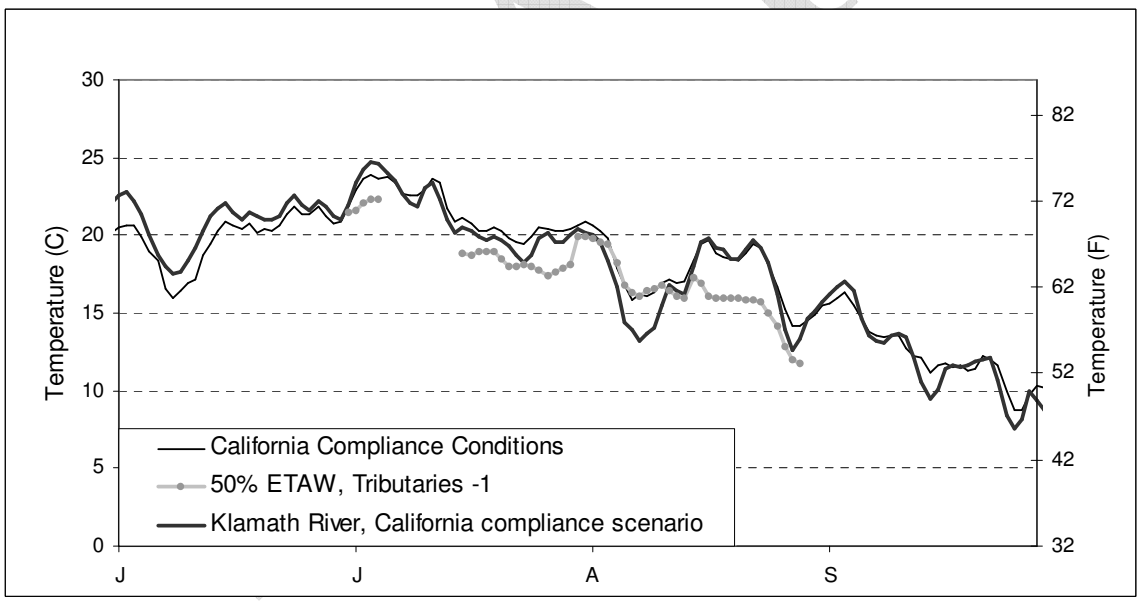


Figure 4.23: Comparison of estimated Scott River Temperature conditions to estimated Klamath River conditions.

Trinity River

The California compliance scenario modeling analysis indicates that natural Trinity River flows, as well as those prescribed by the ROD, have a moderate cooling effect on the Klamath River downstream of the Trinity River. Figure 4.24 presents the difference in daily maximum Klamath River temperatures downstream and upstream of the Trinity

River for both current and natural conditions. Similarly, Figure 4.25 presents the difference in daily maximum Klamath River temperatures downstream and upstream of the Trinity River for both current and Trinity ROD flow (i.e., California compliance scenario) conditions.

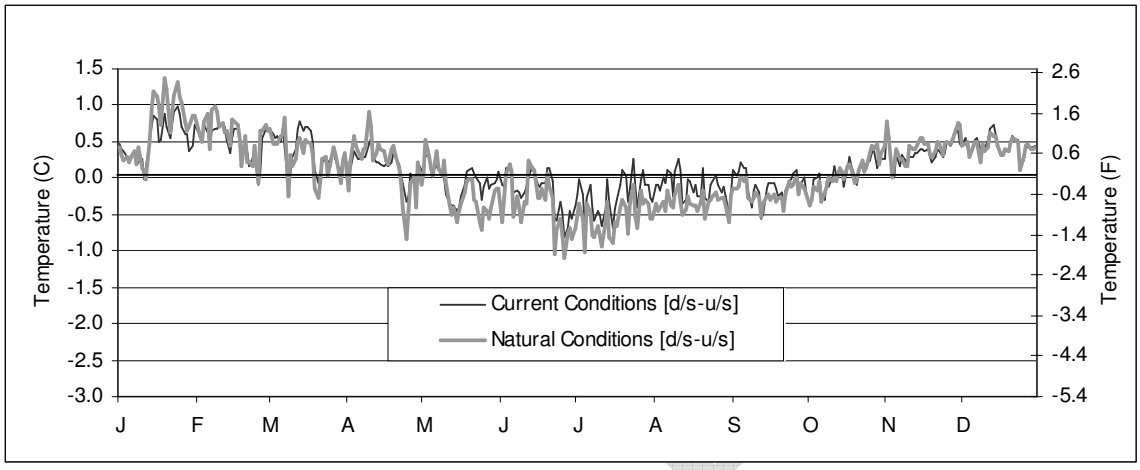


Figure 4.24: Change in Klamath River daily maximum temperatures resulting from current and estimated natural Trinity River conditions. Negative values indicate that the Trinity is cooling the Klamath River.

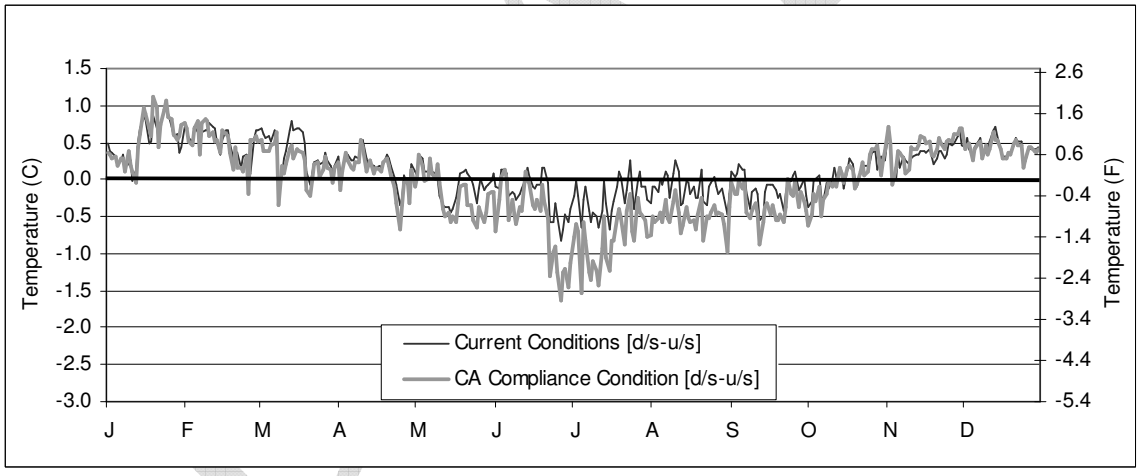


Figure 4.25 Change in Klamath River daily maximum temperatures resulting from current and Trinity ROD compliant Trinity River conditions. Negative values indicate that the Trinity River is cooling the Klamath River.

It is important to note that the upstream temperatures in the natural conditions baseline and California compliance scenarios reflect the absence of upstream reservoirs, as well as the effects of the estimated natural Shasta and Scott River inputs. These results are most apparent when comparing the difference between the estimated natural and Trinity ROD flow (i.e. California compliance) conditions. As discussed in Section 3.3.3.2, the estimated natural Trinity River flows and the Trinity ROD flows are equal during the summer months. However, the Trinity ROD flow scenario has a bigger effect

downstream because the Klamath River temperatures upstream are warmer in comparison to the natural conditions scenario.

Effects of Shade on Klamath River Tributaries

Temperature TMDLs have been established for twelve watersheds in the north coast region of California. These watersheds include three of the major Klamath River tributaries: the Salmon, Scott, and Shasta River watersheds. All twelve temperature TMDLs have evaluated the effects of shade on stream temperatures and each of these analyses have consistently reached the same conclusion regarding stream shade: the temperature of a stream is significantly influenced by the amount of solar radiation the stream receives. A second conclusion of these analyses is that changes in streamside vegetation affect shade (and thus, temperature) to a greater degree in smaller streams than in large streams. This is largely due to the fact that the height of trees is greater in relation to stream width in smaller streams, whereas trees are less effective at casting shade on larger streams. These conclusions are consistent with published literature and temperature analyses conducted in the Pacific northwest (Independent Multidisciplinary Science Team, 2000; Johnson, 2004; Miner and Godwin, 2003; ODEQ, 2002).

Regional Water Board staff evaluated the sensitivity of Klamath River tributaries to the effects of solar radiation using the USGS stream reach temperature model SSTEMP. That analysis of six moderate-sized tributaries (Indian, Elk, Clear, Dillon, Red Cap, and Bluff Creeks) confirms the importance that solar radiation loads have in determining stream temperatures.

Given the similarity of Klamath River tributaries to other north coast watersheds, and the universal nature of the laws of thermodynamics, Regional Water Board staff have determined that the conclusions of shade-related analyses from previous temperature TMDLs stated above apply region-wide, and especially to Klamath tributaries not already assigned TMDL shade allocations. Riparian shade controls are needed in many Klamath River tributaries not subject to an existing TMDL Action Plan.

Effects of Sediment Loads on Klamath River Tributaries

Historic increases in sediment loads have resulted in the widening of stream channels, reduction of riparian shade, and consequent elevation of stream temperatures. The primary causes of increased sediment loads are both natural and human-caused mass wasting. The US Forest Service has estimated that 446 of the 2260 (20%) total stream miles evaluated within Klamath National Forest lands were significantly altered during the flood of 1997 (De la Fuente and Elder, 1998). Much of the damage done to stream channels happened when debris slides that had initiated in the headwater areas resulted in debris torrents that traveled long distances up to many miles, and in the process severely disrupted stream channels and removed riparian vegetation. Temperature data from one of the affected streams, Elk Creek, showed that in the summer after the flood, the peak temperature was the highest of seven years of record, and was 2.1 ^{o}C (3.8 ^{o}F) higher than the average from 1990-1995. Likewise, the diurnal variation increased to 6.9 ^{o}C (12.5^{o}F), 2.7 ^{o}C (4.9 ^{o}F) higher than the 1990-1995 average.

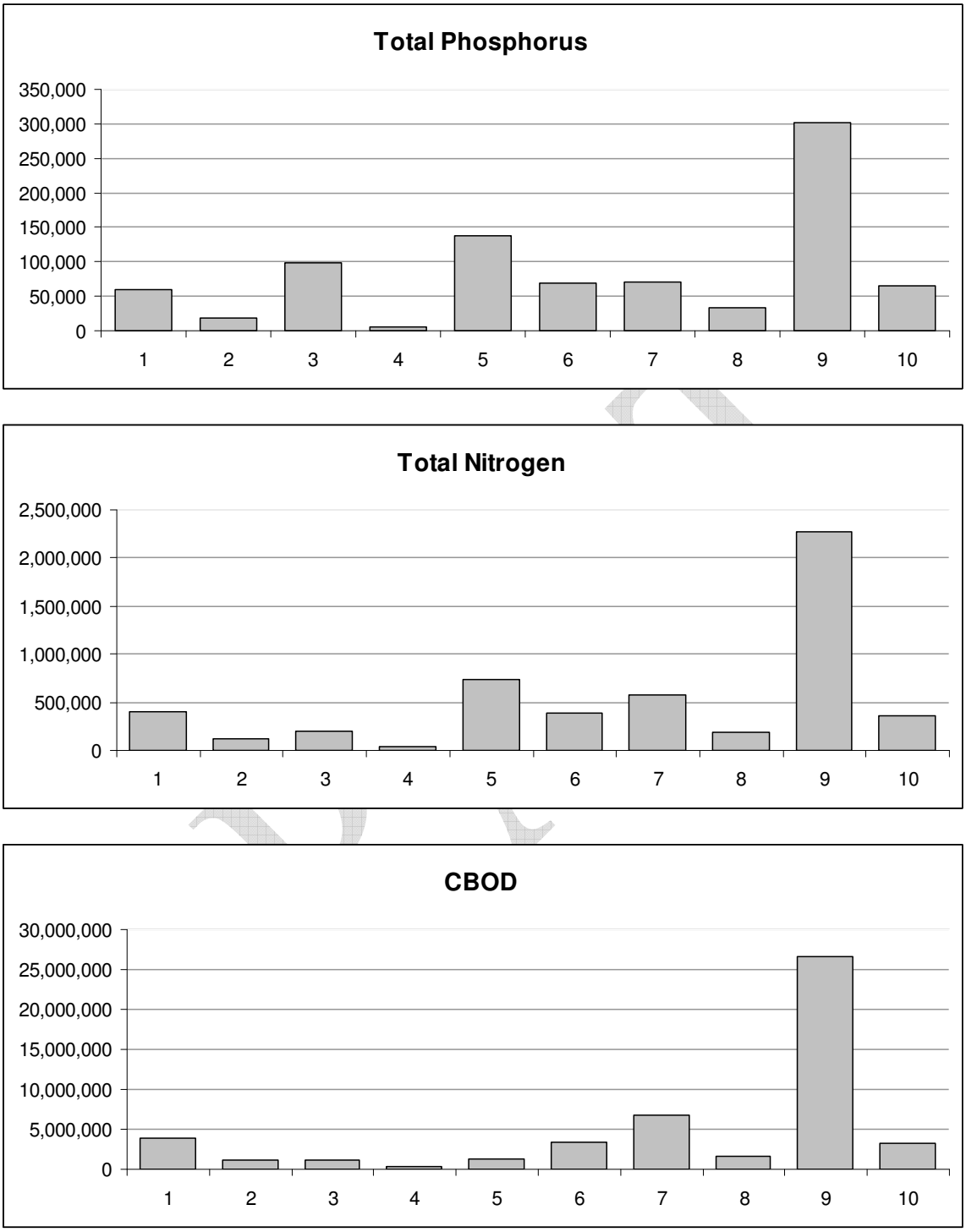
Regional Water Board staff evaluated the sensitivity of Klamath River tributaries to the effects of channel widening, using the USGS stream reach temperature model SSTEMP. The results of that analysis show that daily average stream temperatures can increase in the range of 1 ^{o}C to 2 ^{o}C when the wetted channel width doubles. However, these results are conservative given that the analysis only evaluated the effects of a change in wetted width and did not consider the loss of riparian vegetation (and consequent decrease in shade) that occurs when the active channel increases in width following a debris torrent or aggradation event. Furthermore, because the downstream endpoints of the modeled reaches are near the mouths of the streams where streams are already near equilibrium, it is likely that even larger temperature increases would occur in some reaches upstream where the difference between the current temperature and the equilibrium temperature is greater. Regional Water Board staff have also identified an apparent correlation of decreases in temperature with decreases in channel width in thermal infrared survey data (Watershed Sciences, LLC 2004).

Increased sediment loads in tributary streams also create temperature impacts associated with loss of thermal refugia in the Klamath mainstem. Because the daily maximum temperatures of the Klamath mainstem are at lethal levels through most of the summer, the opportunity for salmonids to rear in the mainstem during those times depends on access to thermal refugia. The majority of thermal refugia in the Klamath mainstem are located at the mouths of cold tributaries where they mix with the Klamath River (Belchik 1997). The volume of thermal refugia at tributary mouths can be greatly affected by the sediment loads of the tributaries. Higher sediment loads can cause tributaries to infiltrate into gravels before reaching the river, create barriers that restrict fish from entering tributaries, and fill in pools where cold water exists. Three of the four largest (>1000 ft^2) thermal refugia areas are created by tributaries that were significantly impacted by sediment loads during the 1997 flood event.

4.2.4.2 Nutrients and Organic Matter

Current annual nutrient and CBOD loads from the California tributaries to the Klamath River are presented in Figure 4.26. Loads are presented for the Shasta, Scott, Salmon, and Trinity Rivers, and for groups of tributaries located between each of the major tributaries. These loads were calculated based on the best available quality assured concentration data from 2000 through 2007 and flows from the 2000 calendar year. Cumulatively the California tributaries account for 48.4%, 48%, and 71%, respectively, of the current annual TP, TN, and CBOD loads to the Klamath River in California.

The Shasta River TMDL, which addresses temperature and DO impairments, requires reductions in nutrient and organic matter loads within the Shasta River watershed. For the Klamath River TMDL source analysis, the nutrient and CBOD loads from the Shasta River were calculated based on Shasta River TMDL compliant conditions. These TMDL compliant Shasta River loads reflect the expected annual loads to the Klamath River when the Shasta River TMDL is fully implemented and nutrient/ biostimulatory substances and DO water quality objectives within the Shasta River are achieved. For the



Stations List:

1- Stateline to Iron Gate Tributaries
2- Iron Gate to Shasta Tributaries
3- Shasta River
4- Shasta to Scott Tributaries
5- Scott River
6- Scott to Salmon Tributaries
7- Salmon River
8- Salmon to Trinity Tributaries
9- Trinity River
10- Trinity River to Turwar Tributaries

Figure 4.26: Current Total Annual Loading (Pounds/Year) of Total Phosphorus, Total Nitrogen, and CBOD to the Klamath River from California Tributaries

Klamath River TMDL source analysis, these Shasta River TMDL compliant nutrient and CBOD loads are considered to represent natural conditions baseline. Figure 4.27 compares current and natural conditions baseline TP, TN, and CBOD loads from the Shasta River. The Shasta TMDL compliant conditions represent 72%, 59%, and 18% reductions, respectively, from current TP, TN, and CBOD loads.

For purposes of the Klamath River TMDL source analysis, the current nutrient and CBOD loads from the other California tributaries are considered to be consistent with natural conditions baseline. The nonpoint source control measures identified in the implementation plan will, however, apply to these tributaries.

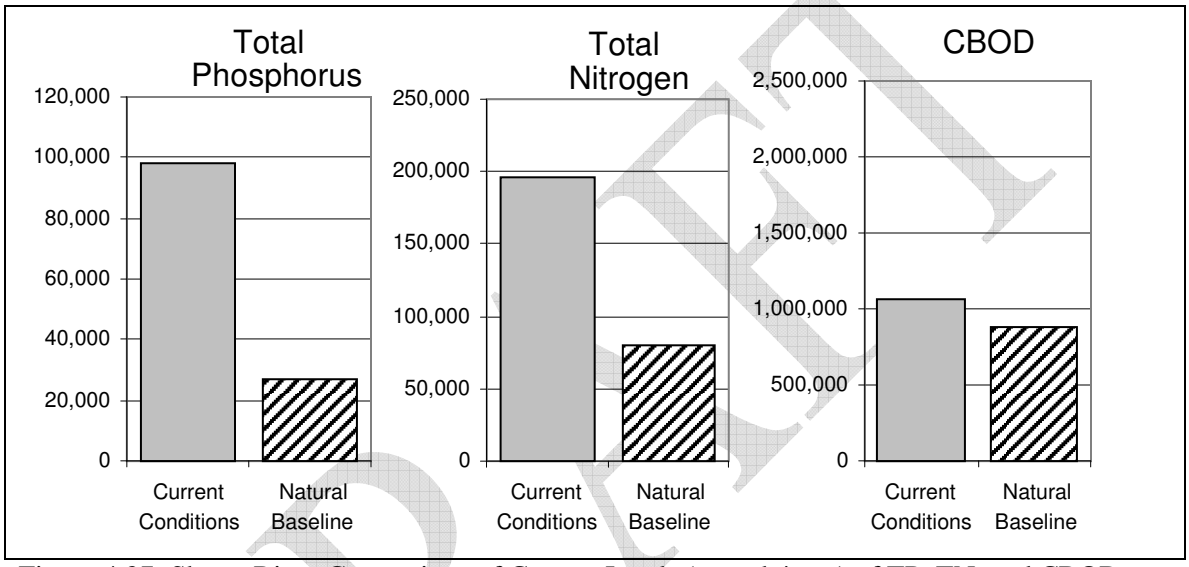


Figure 4.27: Shasta River Comparison of Current Loads (pounds/year) of TP, TN, and CBOD with Natural Conditions Baseline Loads.

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CHAPTER 5. KLAMATH RIVER TMDLs – ALLOCATIONS and NUMERIC TARGETS

5.1 Introduction

This chapter presents the numeric targets, loading capacity, and load and waste load allocations for the Klamath River in California. This chapter consists of three sections. Section 5.1 describes the numeric targets, loading capacity, load and waste load allocations, and margin of safety associated with the temperature, dissolved oxygen, and nutrient-related water quality impairments of the Klamath River in California. Section 5.2 presents the specific temperature-related numeric targets, and load and waste load allocations for the Klamath River by river reach and associated source areas. Section 5.3 presents the specific dissolved oxygen and nutrient-related numeric targets, and load and waste load allocations for the Klamath River by river reach and associated source areas. Table 5.1 summarizes the temperature, dissolved oxygen, and nutrient-related numeric targets and allocations.

5.1.1 Numeric Targets

Numeric targets are the numeric water quality conditions that represent attainment of the water quality standards. Numeric targets serve as the goal post from which TMDLs and associated load and waste load allocations are developed. Numeric targets refer to the desired water quality conditions, and serve as good indicators of progress towards TMDL compliance and beneficial use support. In some cases numeric targets can equal a numeric water quality objective. In other cases, numeric targets are a numeric interpretation of the conditions that meet a narrative water quality objective. Numeric targets are typically instream water quality measures, but in some cases are measures of landscape conditions that effect instream water quality conditions. Targets are set at levels associated with well-functioning stream systems. In all cases numeric targets are used in the calculation of a TMDL.

5.1.1.1 Temperature Numeric Targets

The primary temperature numeric targets for the Klamath River temperature TMDL are monthly average temperatures calculated from the estimated natural temperature regime of the Klamath River, and are presented in Section 5.2. In addition, secondary targets are established for riparian shade and sediment related channel alteration, also presented in Section 5.2. The riparian shade targets are expressed as effective shade, which is a measure of the percentage of total daily direct beam solar radiation that is blocked by vegetation or topography before reaching the ground or stream surface, and takes into account the differences in solar intensity that occur throughout a day. Instream and watershed targets are established associated with sediment related channel alteration.

The instream target associated with *Substantial Human-Caused Sediment-Related Channel Alteration* is:

0 miles of substantial human-caused sediment-related channel alteration.

Table 5.1: Summary of Klamath River TMDLs Numeric Targets and Allocations

Location	Parameter	Target	Allocation
Watershed-wide	Temperature	Riparian Shade: site-potential effective shade. Effective shade is a measure of the percentage of total daily direct beam solar radiation that is blocked by vegetation or topography before reaching the ground or stream surface, and takes into account the differences in solar intensity that occur throughout a day (Approximated in Figures 5.4, 5.5, and 5.6) Instream Target: 0 miles of substantial human-caused sediment-related channel alteration <1% of all road-stream crossings divert or fail as a result of a 100-year or smaller flood Decreasing trend of road related landslides	Riparian Shade: the shade provided by topography and full potential vegetation conditions at a site, with an allowance for natural disturbances such as floods, wind throw, disease, landslides, and fire Human-caused discharges of sediment: zero temperature increase caused by substantial human-caused sediment-related channel alteration
Stateline	Temperature	Estimated natural temperature, expressed as monthly average (See Table 5.5)	Zero increase above natural temperature
	Dissolved Oxygen	Dissolved oxygen concentrations at 85% saturation under natural temperature conditions expressed as monthly average and monthly minimum concentrations (See Table 5.9)	N/A
	Nutrients/ Organic Matter	N/A	Allocations to TN, TP, and CBOD expressed as monthly average concentrations (See Table 5.10)
Reservoirs	Temperature /Dissolved Oxygen	Overlapping temperature and dissolved oxygen conditions within layers in Copco 1 and 2 and Iron Gate Reservoir, where dissolved oxygen = 85% saturation and temperature = natural (~18.7 ^{o} C) during summer (May - October)	Temperature and dissolved oxygen "Compliance Lens": dissolved oxygen instantaneous mass in Copco = 32,398 lbs; dissolved oxygen instantaneous mass in Iron Gate = 47,624 lbs
	Nutrients/ Organic Matter	TP, TN, and CBOD concentrations expressed as monthly means at mid-point reservoir locations (Table 5.13) and reservoir tailraces (Table 5.12) Chlorophyll-a – growing season average of 10 µg/L *Microcystis aeruginosa* cell density $\leq$ 50% of the blue-green algae biomass, or $\leq$ 20,000 cells/L (which ever is lower) Microcystin toxin < 4 µg/L	Zero nutrient loading from reservoir bottom sediments
	Temperature	Estimated natural temperature at reservoir tailrace – expressed as monthly average temperature (See Table 5.6)	Temperature increase expected to naturally occur in the river reach occupied by the reservoirs (See Table 5.7)
	Dissolved Oxygen	DO concentrations at 85% saturation at reservoir tailraces expressed as monthly mean and minimum (See Table 5.11)	N/A
Iron Gate Hatchery	Temperature	Expressed as monthly average temperatures at Iron Gate Hatchery discharge (See Table 5.8)	Zero increase above natural temperature
	Dissolved Oxygen	Expressed as monthly mean and minimum dissolved oxygen concentrations at Iron Gate Hatchery discharge (See Table 5.14)	N/A
	Nutrients/ Organic Matter	TP, TN, and CBOD concentrations expressed as monthly mean concentrations at Iron Gate Hatchery discharge (See Table 5.15)	Zero net increase of nutrient and organic matter loads between influent water (intake) and effluent (discharge).
Tributaries	Dissolved Oxygen	Expressed as monthly mean and minimum concentrations equal to 85% saturation below Salmon River (See Table 5.16)	N/A
	Nutrients/ Organic Matter	Expressed as monthly mean concentrations of TP, TN, and CBOD below the Salmon River (Table 5.17) Reach-averaged maximum density of 150 mg of chlorophyll-a /m^2 below the Salmon River	Zero increase above natural nutrient and organic matter concentrations. TN, TP, and CBOD concentrations expressed as monthly mean concentrations (See Table 5.18 and 5.19)

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The watershed target for *Stream Crossings with Diversion Potential or Significant Failure Potential* is:

> <1% of all stream crossings divert or fail as a result of a 100-year or smaller flood.

The watershed target associated with *Road-Related Landslides* is:

> Decreasing trend.

5.1.1.2 Dissolved Oxygen and Nutrient-Related Numeric Targets
The numeric DO targets are monthly average and monthly minimum DO concentrations calculated at 85% DO saturation under natural temperatures, and are presented in Section 5.3. Numeric targets are also established for nutrients (TN and TP) and organic matter (CBOD) for the reservoirs, and are expressed as monthly average concentrations in Section 5.3. Additional numeric targets are established to reflect compliance with the narrative biostimulatory substances and toxicity objectives. These additional numeric targets are set for suspended algae chlorophyll-a, benthic algae biomass, *Microcystis aeruginosa* cell density, and microsystin concentration. The suspended algae chlorophyll-a numeric target is 10 µg/L. The benthic algae biomass numeric target is 150 mg chlorophyll-a / m^2. The targets for *Microcystis aeruginosa* and microsystin are 20,000 cells/mL and 4 µg/L, respectively.

5.1.2 Loading Capacity, Allocations, and Margin of Safety

The *loading capacity* refers to total amount of pollutant loads that a waterbody can receive and meet water quality standards. In order to achieve the loading capacity (i.e. the Total Maximum Daily Load [TMDL]), allocations are attributed to the natural background, non-point sources, and point sources of the applicable pollutants. *Waste load allocations* are contributions of a pollutant from permitted point sources while *load allocations* are contributions from management-related non-point sources.

The starting point for the load allocation analysis is the equation that describes the Total Maximum Daily Load or loading capacity:

$$\text{TMDL} = \text{Loading Capacity} = \Sigma\text{WLAs} + \Sigma\text{LAs} + \text{Natural Background} + \text{MOS}$$

where Σ = the sum, WLAs = waste load allocations, LAs = load allocations, and MOS = margin of safety.

A margin of safety in a TMDL is required in the Clean Water Act to account for uncertainty and to assure that the TMDL will achieve water quality standards. The Clean Water Act directs states to develop a margin of safety "which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." TMDLs can be developed with explicit and/or implicit margins of safety. An explicit margin of safety is established by withholding an explicit fraction of the loading capacity

available for allocation. An implicit margin of safety is established by incorporating conservative assumptions in the calculation of the loading capacity.

5.1.2.1 Temperature Loading Capacity, Allocations, and Margin of Safety

For the temperature TMDL, two separate water quality objectives apply, as described in Section 2.2.1.2. The temperature objective for *interstate* waters prohibits the discharge of elevated temperature waste, whereas the *intrastate* temperature objective states that temperatures must be maintained as natural, unless a proposed increase is less than 5 ^{o}F and doesn't adversely impact the beneficial use. Because water temperatures in Klamath basin streams already adversely affect the beneficial uses during critical time periods, the natural receiving water condition becomes the temperature objective.

The loading capacity provides a reference for calculating the amount of pollutant load reduction required to bring a water body into compliance with standards. Because the applicable objectives do not allow for the discharge of elevated temperature waste, or increases in water temperature, the temperature loading capacity equals the natural receiving water condition, and in turn no increase is permissible and all sources are allocated a temperature load of zero.

The Klamath River watershed temperature TMDL addresses the heat loads that arise from seven sources:

1. Conditions of Klamath River water crossing the Oregon-California border.
2. Thermal discharges from Copco 2 and Iron Gate dams.
3. The impoundment of water in the reservoirs.
4. Temperature effects of Iron Gate Hatchery.
5. Temperature effects of major tributaries on Klamath River temperatures.
6. Effects of excess solar radiation.
7. Effects of excess sediment loads.

The TMDL equation for temperature is:

Temperature TMDL = Loading Capacity = ΣWLAs + ΣLAs + Natural Background + MOS

The Klamath River temperature TMDL for California relies on an implicit *margin of safety*. As stated in Section 2.2.1.2, the intrastate Water Quality Objective for Temperature allows for temperature increases of up to 2.8 ^{o}C (5 ^{o}F) if beneficial uses of water are not adversely affected. For most of the year the Klamath River is too hot to accommodate more heat without beneficial uses of water being adversely affected. There are periods in the winter and spring months, however, when temperatures increases of 2.8 ^{o}C (5 ^{o}F) or less may occur without beneficial uses of water being adversely affected. The timing of those periods changes from year to year and is difficult to predict. Therefore, this TMDL takes a conservative approach, allocating no temperature increases year-round. This conservative approach constitutes an implicit *margin of safety*.

Substitution of the allocations results in the following temperature TMDL for the Klamath River watershed in California:

Temperature TMDL = Loading Capacity
= 0 increase above natural background
= 0 anthropogenic heat load at Stateline
+ 0 heat load discharged from Copco 2 and Iron Gate Reservoirs
+ 0 heat load discharge from Iron Gate Hatchery
+ 0 heat load from excess solar radiation
+ 0 heat load from anthropogenic sediment loads
+ natural background.
= natural background

Section 5.2 details the load and waste load allocations for these sources.

5.1.2.2 Dissolved Oxygen, Nutrient and Organic Matter Loading Capacity, Allocations, and Margin of Safety

The TMDLs addressing dissolved oxygen and nutrient-related water quality impairments are closely interrelated because of the strong relationship between biostimulatory conditions, decomposition of organic matter, and resulting dissolved oxygen conditions. The DO targets are the primary driver in establishing the nutrient and organic matter loading capacity for the Klamath River in California. Allocations for nutrients (TN and TP) and organic matter (CBOD)[1,2] were set to ensure that Basin Plan dissolved oxygen objectives[3] are met. In addition, the numeric targets set for suspended algae chlorophyll-a, benthic algae biomass, *Microcystis aeruginosa* cell density, and microsystin concentration also influenced the calculation of the loading capacity for nutrients and organic matter.

The loading capacity and associated load and waste load allocations for total phosphorus (TP), total nitrogen (TN), and organic matter (CBOD) for the Klamath River in California are presented in Figures 5.1, 5.2, and 5.3, respectively. These figures present

[1] The Monitoring Plan (Chapter 7) specifies analytic methods for evaluation of compliance with TMDL allocations and numeric targets for nutrients and organic matter.
[2] The allocations for organic matter are expressed as CBOD, and refer to CBOD- ultimate. The water quality models represent CBOD as organic matter; it is converted to CBOD-ultimate for TMDL allocation calculations.
[3] The Regional Water Quality Control Board will consider a proposal to update the salmonid life cycle requirements contained in the Basin Plan for dissolved oxygen (DO) to include 7-day moving averages of the daily mean as an augmentation of the existing daily minimum objectives (e.g., 8.0 mg/L in the water column throughout the year and 8.0 mg/L in spawning gravels during spawning and early development). In addition, it will consider the inclusion of a "natural conditions clause" to replace most Basin Plan Table 3-1 site specific DO minima with an alternate method for establishing site-specific background conditions using percent saturation and natural temperatures (e.g., 85% DO saturation calculated using natural temperatures and applied as daily minima) in those waterbodies where salmonid life cycles requirements can not be achieved due to natural conditions. In any event, a 6.0 mg/L daily minimum will apply.

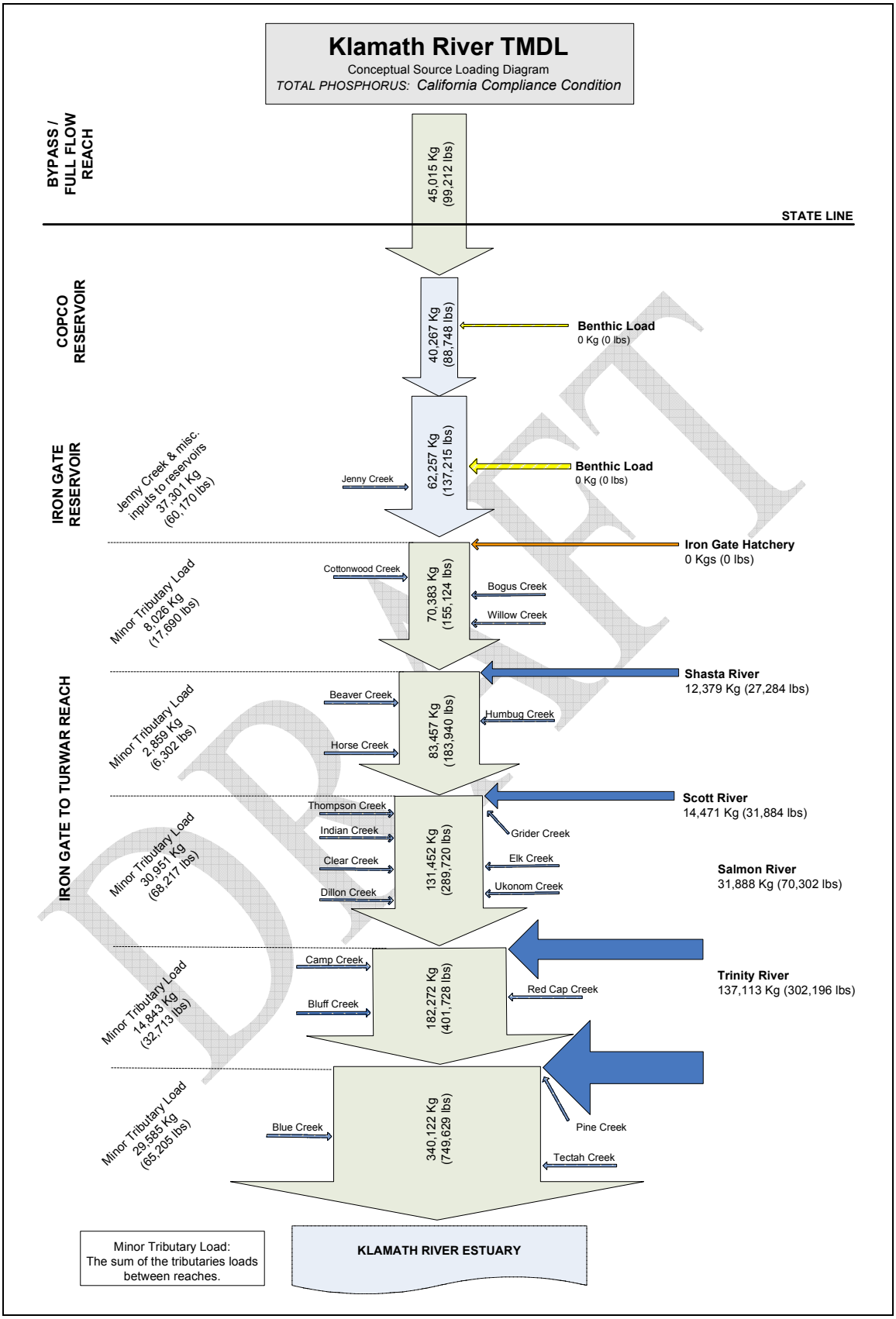

Figure 5.1: Total Phosphorous Loading Capacity and Allocations for the Klamath River Consistent with Assimilative Capacity and Beneficial Use Support.

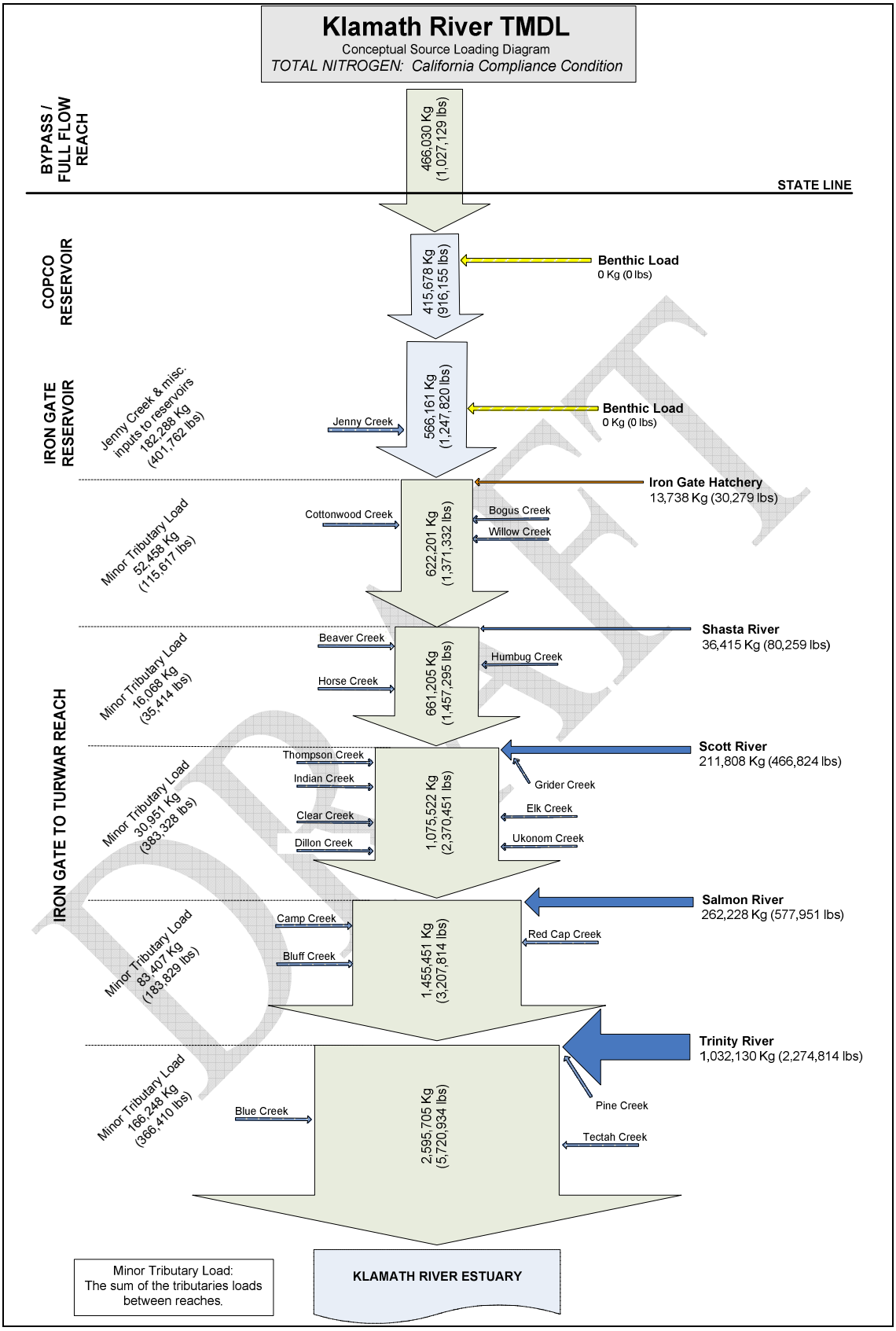

Figure 5.2: Total Nitrogen Loading Capacity and Allocations for the Klamath River Consistent with Assimilative Capacity and Beneficial Use Support.

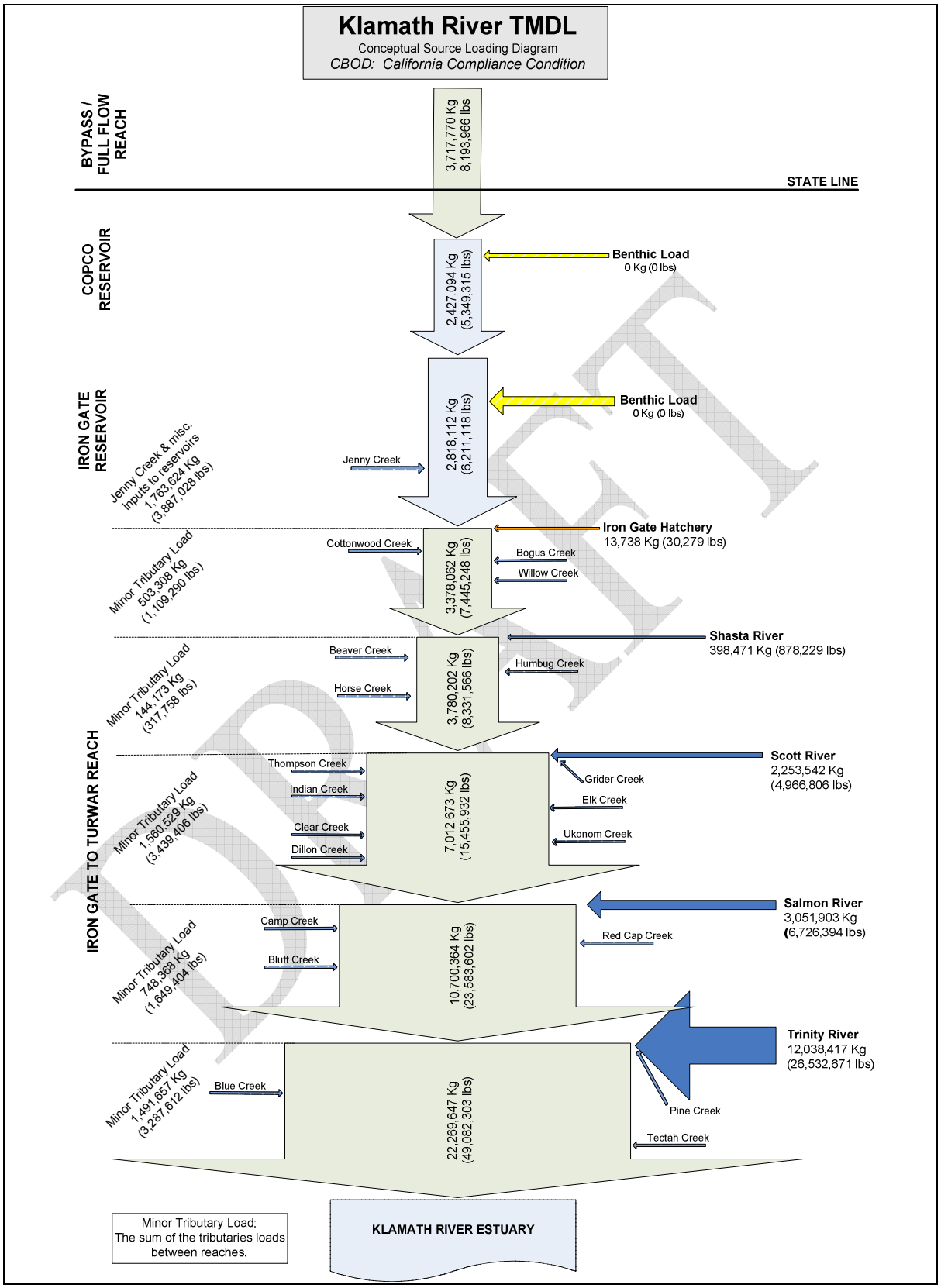

Figure 5.3: Organic Matter Loading Capacity and Allocations for the Klamath River Consistent with Assimilative Capacity and Beneficial Use Support.

the loading capacities divided into various reaches of the Klamath River in California, and also present the load and waste load allocations assigned the different sources necessary to achieve the loading capacity. For most Klamath River compliance locations allocations have been set as monthly mean concentrations for nutrients (TP and TN) and organic matter (CBOD). In order to summarize the Total Maximum Daily Load for these parameters, the allocations are also expressed as daily loads (concentration x flow = mass). The contribution of natural background nutrient and organic matter loads is incorporated into the compliance load for each source area.

Achievement of the nutrient and organic matter allocations will not result in compliance with the DO and temperature targets within Copco 1 and 2 and Iron Gate Reservoirs during periods of thermal stratification. Therefore, additional temperature and dissolved oxygen load allocations are assigned to the reservoirs for the period of May through October, as described in Section 5.3.

The Klamath River nutrient, organic matter, and dissolved oxygen TMDLs for California rely on an implicit *margin of safety*. An implicit margin of safety was deemed appropriate because uncertainty was greatly reduced in the analysis by applying a comprehensive, dynamic numerical model. The model takes advantage of available data collected over multiple years, and deterministically represents the cause-effect relationship between discrete sources and water quality conditions throughout the Klamath's riverine, reservoir, and estuarine portions. By representing conditions in great detail spatially and temporally, the model effectively considers a spectrum of conditions that may be overlooked by a simpler analysis. It was determined that the largest source of uncertainty in this system is the highly variable and dominant loading from Upper Klamath Lake rather than the numeric water quality model. Conservative assumptions that make up the implicit margin of safety are as follows:

- The numeric model used to predict the impact of allocations assumes that sediment oxygen demand (SOD) does not improve in the riverine sections following upstream load reductions. The magnitude of SOD will likely decrease with the decrease of organic loading allocated by the TMDL and result in a shorter season of DO concentrations less than numeric criteria.

- Predicted conditions in the Klamath River are strongly influenced by the predicted variable conditions of the Upper Klamath Lake TMDL. Conservative allocations were set by using a combination of the predicted conditions. The timing of the allocations within Oregon is based on the scenario which represents the greatest loading from Upper Klamath Lake (i.e. results in the longest period of water quality not meeting numeric criterion). The magnitudes of the allocations are based on median loading conditions from Upper Klamath Lake. This is conservative because allocations are based on the difference from a baseline condition. The closer the concentration or temperature is to the numeric criteria, the less loading is necessary to cause a measurable degradation.

- Allocations to non-point source (NPS) are for all nutrients (N, P, OM), not just the predicted limiting nutrient.

- Year 2000 flows are less than more recent flow requirements (i.e. USBR Klamath Project Operations and PacifiCorp Klamath Hydro Project biological opinion flows).

The TMDLs for total phosphorous, total nitrogen, and organic matter (CBOD) to the Klamath River in California are the sum of waste load allocations, load allocations, and natural background for each parameter. The only waste load allocations assigned for these TMDLs is to the Iron Gate Hatchery. The contribution of natural background total phosphorus, total nitrogen, and organic matter (CBOD) loads is incorporated into the load allocations for each source area. Accordingly, the TMDL equations for total phosphorous is:

Total phosphorus TMDL = Loading Capacity = ΣWLAs + ΣLAs

The load and waste load total phosphorus allocations for the Klamath River in California are presented in Table 5.2.

Table 5.2: Total Phosphorus TMDL (lbs.)

TMDL Parameter	**Source Area**	**Daily Load (lbs.)**
Total phosphorus TMDL =		
Loading Capacity (1852.5 lbs.) =		
	Δ Iron Gate Hatchery	0 +
	Stateline	271.8 +
	Stateline to Iron Gate inputs	164.8 +
	Iron Gate to Shasta tributaries	48.5 +
	Shasta River	74.8 +
	Shasta to Scott tributaries	17.3 +
	Scott River	46.7 +
	Scott to Salmon tributaries	186.9 +
	Salmon River	131.9 +
	Salmon to Trinity tributaries	89.6 +
	Trinity River	641.6 +
	Trinity River to Turwar tributaries	178.6+
	Total	**1,852.5**

The TMDL equation for total nitrogen is:

Total nitrogen TMDL = Loading Capacity = ΣWLAs + ΣLAs

The load and waste load total nitrogen allocations for the Klamath River in California are presented in Table 5.3.

Table 5.3: Total Nitrogen TMDL (lbs.)

TMDL Parameter	Source Area	Daily Load (lbs.)
Total nitrogen TMDL =		
Loading Capacity (10,839 lbs.) =		
	Δ Iron Gate Hatchery	0 +
	Stateline	2,814 +
	Stateline to Iron Gate inputs	1,101 +
	Iron Gate to Shasta tributaries	317 +
	Shasta River	220 +
	Shasta to Scott tributaries	97 +
	Scott River	655 +
	Scott to Salmon tributaries	1,050 +
	Salmon River	775 +
	Salmon to Trinity tributaries	504 +
	Trinity River	2,303 +
	Trinity River to Turwar tributaries	1,004 +
	Total	**10,839**

The TMDL equation for organic matter is:

Organic matter TMDL = Loading Capacity = ΣWLAs + ΣLAs

The load and waste load organic matter (CBOD) allocations for the Klamath River in California are presented in Table 5.4.

Table 5.4: Total Organic Matter TMDL (lbs.)

TMDL Parameter	Source Area	Daily Load (lbs.)
Total organic matter TMDL =		
Loading Capacity (156,154 lbs.) =		
	Δ Iron Gate Hatchery	0 +
	Stateline	22,449 +
	Stateline to Iron Gate inputs	10,649 +
	Iron Gate to Shasta tributaries	3,039 +
	Shasta River	2,406 +
	Shasta to Scott tributaries	871 +
	Scott River	10,357 +
	Scott to Salmon tributaries	9,423 +
	Salmon River	18,459 +
	Salmon to Trinity tributaries	4,519 +
	Trinity River	64,975 +
	Trinity River to Turwar tributaries	9,007 +
	Total	**156,154**

5.2 Temperature-Related Numeric Targets and Allocations

This section presents the temperature-related numeric targets, and load and waste load allocations for the Klamath River by river reach and associated source areas.

5.2.1. Watershed-Wide Temperature-Related Targets and Load Allocations in California

There are two temperature-related load allocations that apply watershed-wide, i.e. to the entire Klamath River watershed, including all tributaries, in California. These allocations are for excess solar radiation and human-caused discharges of sediment. For clarity of presentation the numeric targets are presented after presentation of these allocations.

5.2.1.1 Riparian Shade

Regional Water Board staff have concluded that the load allocation for excess solar radiation assigned in previous TMDLs (e.g. Navarro, Mattole, Scott, Shasta, and Eel River Temperature TMDLs), is also an appropriate allocation for excess solar radiation in the Klamath River watershed in California. The load allocation for solar radiation is expressed as its inverse: shade. Accordingly, the **temperature load allocations for shade** are equal to:

> the shade provided by topography and full potential vegetation conditions at a site, with an allowance for natural disturbances such as floods, wind throw, disease, landslides, and fire.

The targets for riparian shade are expressed as effective shade. Effective shade is a measure of the percentage of total daily direct beam solar radiation that is blocked by vegetation or topography before reaching the ground or stream surface, and takes into account the differences in solar intensity that occur throughout a day. The effective shade curves in Figures 5.4, 5.5, and 5.6 graphically present the levels of effective shade that are expected to naturally occur for a given type of vegetation, aspect, and stream width. These curves constitute the numeric targets for riparian shade within the Klamath River in California.

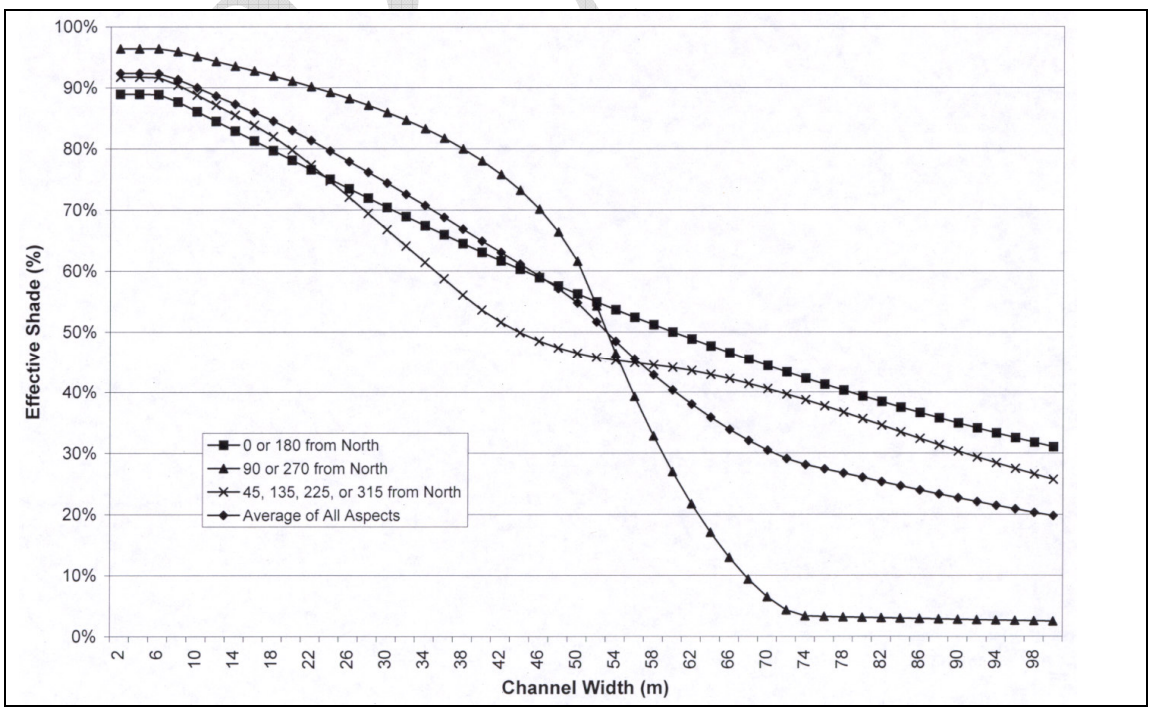

Figure 5.4: Effective shade vs. channel width for various channel orientations, Douglas Fir and mixed hardwood-conifer forests. Assumed vegetation height = 40 meters (131.2 feet).

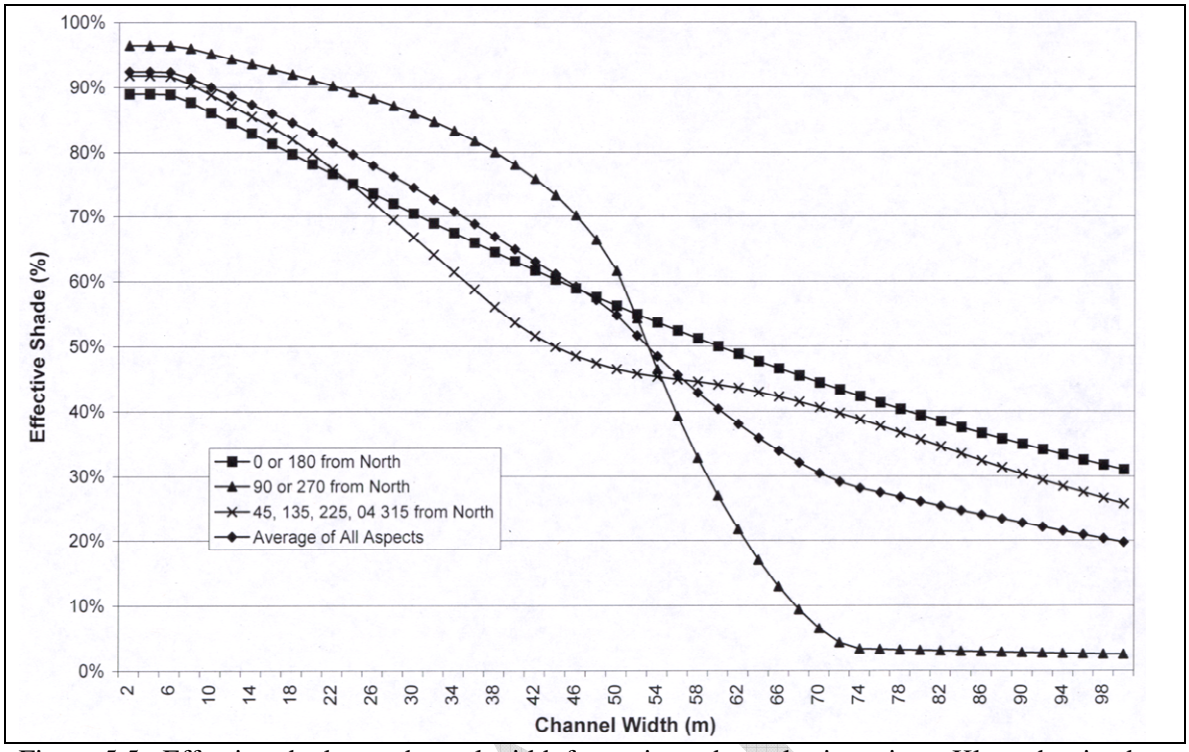

Figure 5.5: Effective shade vs. channel width for various channel orientations, Klamath mixed conifer and Ponderosa Pine forests. Assumed vegetation height = 35 meters (114.8 feet).

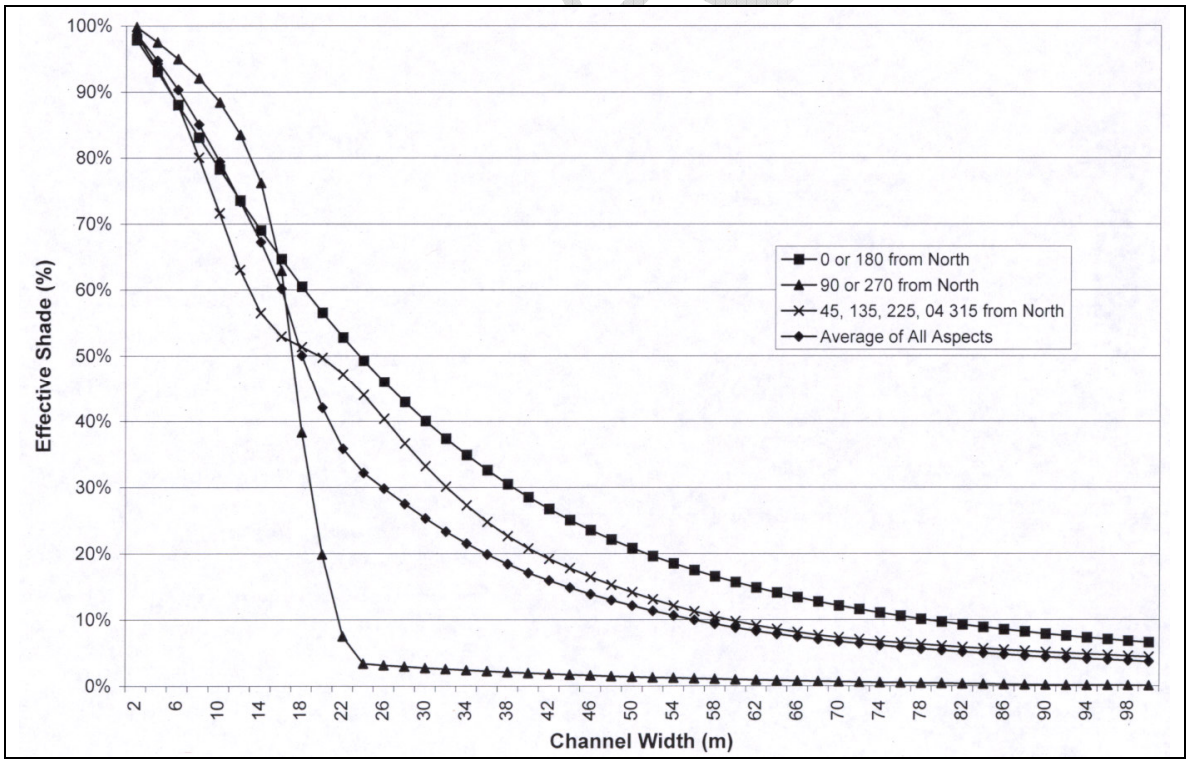

Figure 5.6: Effective shade vs. channel width for various channel orientations, oak woodland forest. Assumed vegetation height = 20 meters (65.6 feet).

5.2.1.2 Excess Sediment

Regional Water Board staff have concluded that stream temperature increases in the Klamath River watershed cannot be accommodated without adverse effects to beneficial uses. Therefore, stream temperature increases that result from human-caused discharges of sediment constitute an exceedence of the water quality objective for temperature. Accordingly, the **temperature-related load allocation for human-caused discharges of sediment** equals:

> zero temperature increase caused by substantial human-caused sediment-related channel alteration.

For this purpose, the following definition is used to define *substantial human-caused sediment-related channel alteration*:

> Substantial human-caused sediment-related channel alteration: "A human-caused alteration of stream channel dimensions that increases channel width, decreases depth, or removes riparian vegetation to a degree that alters stream temperature dynamics and is caused by increased sediment loading"

Two types of targets are designated for this category, an instream target and watershed targets.

The instream target associated with *Substantial Human-Caused Sediment-Related Channel Alteration* is:

> 0 miles of substantial human-caused sediment-related channel alteration.

The watershed target for *Stream Crossings with Diversion Potential or Significant Failure Potential* is:

> <1% of all stream crossings divert or fail as a result of a 100-year or smaller flood.

Most roads, including skid trails, cross ephemeral or perennial streams. Crossings are built to capture the stream flow and safely convey it through, under, or around the roadbed. However, stream crossings can fail, adding sediment from the crossing structure (i.e., fill), or from the roadbed, directly into the stream. Stream crossing failures are generally related to culverts that are undersized, poorly placed, plugged, or partially plugged. When a crossing fails, the total sediment volume delivered to the stream usually includes both the volume of road fill associated with the crossing and sediment from collateral failures such as debris torrents that scour the channel and stream banks.

Diversion potential is the potential for a road to divert water from its intended drainage system across or through the road fill, thereby delivering road-related sediment to a watercourse. Generally, less than one percent of stream crossings have conditions where modification is inappropriate because it would endanger travelers or where modification

is impractical because of physical constraints (D. Hagans, pers. comm., 1998, in USEPA 1998a).

The watershed target associated with *Road-Related Landslides* is:

Decreasing trend.

Since road failures usually occur many years after roads are constructed and are often unpredictable, it is expected that the rate of road-related landslides is not likely to decrease until roads in problem areas are treated or decommissioned. Appropriate location, design, construction and maintenance of roads is expected to result in a reduction of the rate of road failures.

5.2.2 Temperature Numeric Targets and Load Allocations at Stateline

The ODEQ has identified the Klamath River in Oregon on its CWA section 303(d) list as failing to meet Oregon temperature criteria. Accordingly in 2009, ODEQ intends to issue, in 2009, and implement TMDLs for temperature for the Klamath River in the state of Oregon. These Oregon-issued TMDLs will be based on Oregon's water quality standards. Because these TMDLs (and their anticipated load allocations and wasteload allocations) are being developed by Oregon as part of a comprehensive multistate analysis of pollutant loadings to the Klamath River, they are also being designed to meet California water quality standards at the Oregon/California border. It is appropriate for the Regional Water Board to account for these anticipated upstream load reductions in Oregon when developing the TMDLs for the segments of the Klamath River that are downstream in California. For ease of reference, these anticipated reductions in Oregon-source loads are identified in this TMDL in California as load allocations that reflect anticipated water quality at the Oregon/California border once the Oregon TMDLs are fully implemented. Thus, the temperature allocations at Stateline identified in Table 5.5 reflect an understanding and acknowledgement that improvements in water quality in Oregon represent a critical part of the solution in meeting water quality objectives in California.

The temperature targets at Stateline are expressed as monthly average temperatures and are presented in Table 5.5.

Table 5.5: Temperature Numeric Targets (°C) at Stateline, Expressed as Monthly Averages.

May	June	July	August	September	October
13.7	17.3	18.7	18.0	14.0	9.7
November	**December**	**January**	**February**	**March**	**April**
3.9	2.6	3.4	6.2	8.8	11.2

The allocation for temperature at Stateline is zero increase above natural, in accordance with water quality objectives.

5.2.3 Temperature Numeric Targets and Load Allocations to Copco 2 and Iron Gate

The numeric temperature targets assigned to Iron Gate and Copco 2 tailraces are calculated from the California compliance scenario, and are expressed as monthly average temperatures in Table 5.6.

Table 5.6: Temperature Numeric Targets for Iron Gate and Copco Reservoir Tailrace Waters, Expressed as Monthly Averages.

	May	June	July	August	September	October
Copco 1&2	14.1 °C 57.4 °F	17.7 °C 63.9 °F	19.1 °C 66.4 °F	18.4 °C 65.1 °F	14.3 °C 57.7 °F	9.8 °C 49.6 °F
Iron Gate	14.5 °C 58.1 °F	18.0 °C 64.3 °F	19.5 °C 67.1 °F	18.8 °C 65.9 °F	14.7 °C 58.4 °F	10.0 °C 50.0 °F
	November	**December**	**January**	**February**	**March**	**April**
Copco 1&2	3.8 °C 38.8 °F	2.5 °C 36.5 °F	3.3 °C 37.9 °F	6.2 °C 43.2 °F	8.8 °C 47.8 °F	11.0 °C 51.8 °F
Iron Gate	3.7 °C 38.7 °F	2.4 °C 36.3 °F	3.3 °C 37.9 °F	6.1 °C 43.0 °F	8.9 °C 48.0°F	10.9 °C 51.6 °F

Iron Gate and Copco Reservoirs discharge elevated temperature waste, as defined by the Thermal Plan. The discharge of elevated temperature waste to the Klamath River is prohibited by the Thermal Plan. Furthermore, temperature alterations caused by the reservoirs adversely effect beneficial uses. Thus, there is no allowable temperature increase that can be allocated to Iron Gate and Copco 1 and 2 Reservoirs. Accordingly, the temperature load allocation for these reservoirs equals zero temperature increase above natural temperatures.

The determination of compliance with water quality objectives for temperature is complicated by the fact that under current conditions the temperature of water entering Copco 1 Reservoir (the most upstream California reservoir) carries an anthropogenic heat load from upstream sources. The upstream heat sources are also allocated temperature loads through the State of Oregon's Klamath River TMDL, although these allocations are expected to be achieved gradually over time. Because the upstream heat loads are outside of the control of the dam operators (PacifiCorp), the allocations apply to the condition of the water as it enters the reservoirs.

Another complicating factor is that even without the presence of the reservoirs the Klamath River would be expected to naturally change temperature through the reaches currently occupied by the reservoirs. Thus, to account for natural processes, the temperature load allocation for the reservoirs includes an allowance for natural temperature increases. The allowable temperature increase was developed from model data that predicts the natural temperature increases through the free flowing river reaches occupied by the reservoirs for the year 2000.

The temperature increase that would be expected to occur in the reach of the Klamath River occupied by the Copco 1 and 2 Reservoirs is presented in Figure 5.7. These results indicate that the daily average temperature would naturally increase by approximately 0.3 °C (0.5 °F) through the Copco reach. Similarly, the results indicate that the daily maximum temperatures periodically increase slightly; however, from approximately June through December the daily maximum temperature actually decreases through the Copco reach. The increase in daily average temperatures, coupled with a decrease in daily maximum temperatures indicates a reduced daily range of temperatures. The reduced daily range may be due to more topographic shading in this reach in comparison to upstream reaches.

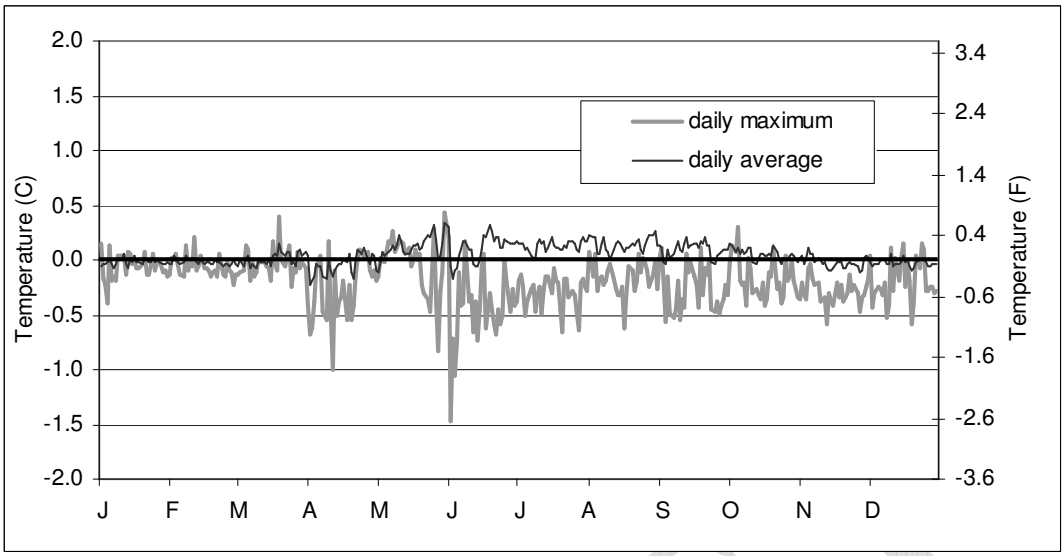

Figure 5.7: Natural temperature change through the Copco Reservoir reaches. Calculated as difference of downstream and upstream daily maximum and daily average temperatures; a positive value indicates warming through the reach.

The temperature increase that would be expected to occur in the reach of the Klamath River occupied by Iron Gate Reservoir is presented in Figure 5.8. These results indicate that the daily average temperature would naturally increase by approximately 0.1 ^{o}C (0.2 ^{o}F) through the Iron Gate reach. Similarly, the results indicate that the daily maximum temperatures would naturally increase by approximately 0.1 ^{o}C (0.2 ^{o}F) in the same reach.

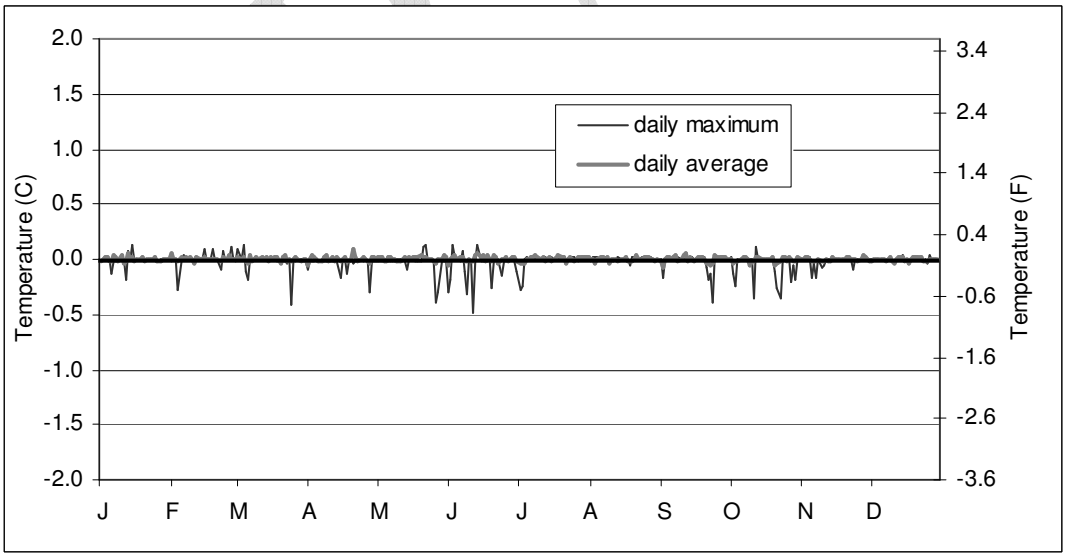

Figure 5.8: Natural temperature change through the Iron Gate Reservoir reach. Calculated as difference of downstream and upstream daily maximum and daily average temperatures; a positive value indicates warming through the reach.

Given that the water quality objectives for temperature do not allow for temperature increases above natural, the water released from Iron Gate and Copco 2 Reservoirs to the

Klamath River are allocated temperature increases that correspond to natural temperature increases, as presented in Table 5.7. The temperature allocation is intended to be added to the in-flowing temperature of the river immediately upstream of each reservoir.

Table 5.7: Temperature Load Allocations for Reservoir Tailrace Waters, Expressed as Increase Relative to Inflow

Facility	Daily Average	Daily Maximum
Iron Gate	0.1 °C (0.18 °F)	0.1 °C (0.18 °F)
Copco 1 & 2	0.3 °C (0.54 °F)	0.5 °C (0.9 °F)

5.2.4 Temperature Numeric Targets and Waste Load Allocations to Iron Gate Hatchery

The numeric temperature targets assigned to the Iron Gate Hatchery (Table 5.8) are expressed as monthly average temperatures, equal to the temperatures associated with the Klamath River downstream of Iron Gate Dam, and are calculated from the California compliance scenario.

Table 5.8: Temperature Numeric Targets for Iron Gate Hatchery, Expressed as Monthly Averages.

May	June	July	August	September	October
14.5 °C 58.1 °F	18.0 °C 64.3 °F	19.5 °C 67.1 °F	18.8 °C 65.9 °F	14.7 °C 58.4 °F	10.0 °C 50.0 °F
November	**December**	**January**	**February**	**March**	**April**
3.8 °C 38.8 °F	2.5 °C 36.5 °F	3.3 °C 37.9 °F	6.2 °C 43.2 °F	8.8 °C 47.8 °F	11.0 °C 51.8 °F

The discharge of elevated temperature waste to the Klamath River is prohibited by the state Thermal Plan. Iron Gate Hatchery discharges elevated temperature waste when the hatchery discharge is warmer than the Klamath River. Thus, there is no allowable temperature increase that can be allocated to Iron Gate Hatchery. Accordingly, the temperature load allocation for the Hatchery equals zero temperature increase above natural temperatures.

5.3 Dissolved Oxygen and Nutrient-Related Numeric Targets and Allocations

This section presents the dissolved oxygen and nutrient-related numeric targets, and load and waste load allocations for the Klamath River by river reach and associated source areas.

5.3.1 Dissolved Oxygen and Nutrient-Related Numeric Targets and Load Allocations at Stateline

The ODEQ has identified the Klamath River in Oregon on its CWA section 303(d) list as failing to meet certain Oregon water quality standards. Accordingly in 2009, ODEQ intends to issue and implement TMDLs for chlorophyll-a, dissolved oxygen, organic matter, and ammonia for the Klamath River in the state of Oregon. These Oregon-issued TMDLs will be based on Oregon's water quality standards. Because these TMDLs (and their anticipated load allocations and wasteload allocations) are being developed by Oregon as part of a comprehensive multistate analysis of pollutant loadings to the

Klamath River, they are also being designed to meet California water quality standards at the Oregon/California border. It is appropriate for the Regional Water Board to account for these anticipated upstream load reductions in Oregon when developing the TMDLs for the segments of the Klamath River that are downstream in California. For ease of reference, these anticipated reductions in Oregon-source loads are identified in this TMDL as load allocations at Stateline that reflect anticipated water quality at the Oregon /California border once the Oregon TMDLs are fully implemented. Thus, the load reductions identified in Figures 5.1, 5.2, and 5.3 and the following allocations and numeric targets reflect an understanding and acknowledgement that improvements in water quality upstream represent a critical part of the solution in meeting water quality objectives in California.

Allocation values are based on model output and significant digits have been set based on consideration of analytical method detection limits and criteria / objective reporting requirements. The following convention has been used for each of the following parameters: dissolved oxygen (DO) – tenths of mg/L; nutrients (total nitrogen and total phosphorous) – thousandths mg/L; and whole units for carbonaceous oxygen demand (CBOD).

The dissolved oxygen targets at Stateline are expressed as monthly average and monthly minimum DO concentrations (Table 5.9). These dissolved oxygen targets are consistent with the DO concentrations at Stateline under the California compliance scenario and achieve 85% saturation under natural temperature conditions.

Table 5.9: Dissolved Oxygen Numeric Targets (mg/L) at Stateline.

	May	June	July	August	September	October
Mean	8.6	8.2	8.2	8.2	8.9	9.7
Minimum	7.9	7.1	6.9	7.0	8.0	8.4
	November	**December**	**January**	**February**	**March**	**April**
Mean	11.2	11.5	11.1	10.2	9.5	8.9
Minimum	9.9	11.0	10.7	9.8	9.0	8.4

Nutrient and organic matter allocations at Stateline are set to control their biostimulatory and oxygen consuming effect on DO and to achieve the DO objective/targets. These allocations are expressed as monthly mean concentrations (mg/L) for total phosphorous (TP), total nitrogen (TN), and organic matter (CBOD) as shown in Table 5.10.

Table 5.10: Nutrient and Organic Matter Monthly Mean Concentrations (mg/L) Allocations at Stateline.

	May	June	July	August	September	October
TP	0.033	0.040	0.044	0.040	0.029	0.028
TN	0.353	0.418	0.434	0.406	0.230	0.265
CBOD	3	3	3	3	1	2
	November	**December**	**January**	**February**	**March**	**April**
TP	0.029	0.031	0.027	0.028	0.029	0.034
TN	0.269	0.300	0.304	0.330	0.338	0.370
CBOD	2	2	2	3	3	3

5.3.2 Dissolved Oxygen and Nutrient-Related Numeric Targets and Load Allocations to Copco 1 and 2 and Iron Gate Reservoirs

Dissolved oxygen and nutrient-related numeric targets and load allocations are set for the Copco 2 and Iron Gate tailraces as well as for the reservoirs themselves.

5.3.2.1 Copco 2 and Iron Gate Reservoir Targets

Copco 2 and Iron Gate tailrace targets for dissolved oxygen are calculated from the California compliance scenario, and are expressed as monthly mean and monthly minimum DO concentrations (Table 5.11).

Table 5.11: Dissolved Oxygen Numeric Targets (mg/L) for Copco 2 and Iron Gate Tailraces.

Copco 2 Tailrace						
	May	**June**	**July**	**August**	**September**	**October**
Mean	8.7	8.3	8.2	8.3	9.0	9.8
Minimum	7.8	7.0	6.8	6.8	7.9	8.4
	November	**December**	**January**	**February**	**March**	**April**
Mean	11.4	11.7	11.3	10.3	9.7	9.1
Minimum	10.0	11.2	10.8	9.9	9.1	8.5
Iron Gate Tailrace						
	May	**June**	**July**	**August**	**September**	**October**
Mean	8.9	8.3	8.2	8.2	9.0	9.9
Minimum	7.9	7.3	7.2	7.2	8.1	8.6
	November	**December**	**January**	**February**	**March**	**April**
Mean	11.6	11.9	11.5	10.6	9.9	9.4
Minimum	10.4	11.4	11.0	10.1	9.3	8.7

Numeric targets for nutrients (TP and TN) and organic matter (CBOD) are also established for Copco 1 and 2 and Iron Gate Reservoirs, and are expressed as monthly mean concentrations. These nutrient and organic matter targets are established both for the tailraces of Copco 2 and Iron Gate (Table 5.12) and for mid-point locations with Copco 1 and Iron Gate Reservoirs (Table 5.13).

In addition to receiving high nutrient and organic matter loadings from upstream, the Copco and Iron Gate impoundments also provide slower movement and unshaded water that allow greater expression of nutrient impacts. Environmental conditions within the impoundments create an increased susceptibility to nuisance blooms of suspended algae (e.g., green algae, diatoms, and blue-green algae). Nutrient conditions in Iron Gate and Copco 1 and 2 Reservoirs, along with the physical conditions of the reservoirs, are associated with the formation of summer algal blooms, including the formation of extensive blooms of the blue-green algae *Microcystis aeruginosa*, as detailed in Chapter 2. For the TMDL to be successful in restoring water quality conditions and supporting beneficial uses, numeric targets are set for both suspended algae chlorophyll-a and nuisance blue-green algae blooms (*Microcystis aeruginosa* cell density and associated concentrations of the toxin microcystin), applicable to Copco 1 and 2 and Iron Gate Reservoirs. These targets are both responsive to nutrient loading upstream and controllable environmental factors within the reservoirs. The suspended algae chlorophyll-a numeric target is 10 µg/L. The targets for *Microcystis aeruginosa* and microsystin are:

Table 5.12: Nutrient and Organic Matter Monthly Mean Concentration Targets (mg/L) for Copco 2 and Iron Gate Tailraces.

Copco 2 Tailrace						
	May	**June**	**July**	**August**	**September**	**October**
TP	0.025	0.025	0.028	0.030	0.025	0.022
TN	0.251	0.216	0.193	0.201	0.162	0.131
CBOD	2	1	1	1	1	1
	November	**December**	**January**	**February**	**March**	**April**
TP	0.023	0.027	0.032	0.023	0.023	0.026
TN	0.170	0.211	0.558	0.258	0.267	0.264
CBOD	1	1	1	2	2	2
Iron Gate Tailrace						
	May	**June**	**July**	**August**	**September**	**October**
TP	0.032	0.030	0.031	0.035	0.034	0.028
TN	0.276	0.225	0.202	0.198	0.176	0.135
CBOD	1	1	1	1	1	1
	November	**December**	**January**	**February**	**March**	**April**
TP	0.027	0.031	0.044	0.033	0.034	0.040
TN	0.156	0.209	0.751	0.297	0.311	0.322
CBOD	1	1	1	2	2	2

Table 5.13: Nutrient and Organic Matter Monthly Mean Concentration Targets (mg/L) for Mid-Point of Copco 1 and Iron Gate Reservoirs.

Mid-Point Copco 1 Reservoir						
	May	**June**	**July**	**August**	**September**	**October**
TP	0.024	0.027	0.023	0.021	0.023	0.024
TN	0.267	0.276	0.223	0.155	0.123	0.130
CBOD	1	1	1	1	1	1
	November	**December**	**January**	**February**	**March**	**April**
TP	0.023	0.025	0.028	0.025	0.024	0.027
TN	0.171	0.202	0.423	0.281	0.267	0.276
CBOD	1	1	1	2	2	2
Mid-Point Iron Gate Reservoir						
	May	**June**	**July**	**August**	**September**	**October**
TP	0.034	0.030	0.034	0.034	0.034	0.029
TN	0.279	0.206	0.182	0.155	0.170	0.140
CBOD	2	1	1	1	1	1
	November	**December**	**January**	**February**	**March**	**April**
TP	0.028	0.002	0.038	0.035	0.035	0.044
TN	0.166	0.012	0.585	0.315	0.320	0.356
CBOD	1	0	1	3	3	3

- *Microcystis aeruginosa* concentrations that are equal to or less than 50% of the blue-green algal biomass or 20,000 cells per liter (whichever is lower); and
- Microcystin toxin levels below 4 µg/L (World Health Organization and the California Blue-Green Algae Work Group Voluntary Guidelines).

See Section 2.3.2.2 for detailed background information regarding the selection of these numeric targets.

5.3.2.2 Copco 1 and 2 and Iron Gate Reservoir Load Allocations

Copco 1 and 2 and Iron Gate Reservoirs, as constructed facilities, are responsible for the flux of nutrients (e.g., ammonia and orthophosphate) from sediments under anoxic conditions during the critical period May through October. The nutrient-related allocation for Copco 1 and 2, and Iron Gate Reservoirs is zero nutrient loading from reservoir bottom sediments.

Achievement of the nutrient and organic matter allocations will not result in compliance with the DO and temperature targets within Copco 1 and 2 and Iron Gate Reservoirs during periods of thermal stratification. Therefore, additional temperature and dissolved oxygen load allocations are assigned to the reservoirs for the period of May through October to ensure compliance with the DO and temperature targets within the reservoirs, and ensure support of COLD. The temperature and DO allocations for waters within Copco 1 and 2 and Iron Gate Reservoirs are dual allocations, wherein achievement of the water quality objective for temperature is dependent on dissolved oxygen conditions and vice versa. Allocations for dissolved oxygen and temperature are equal to a "compliance lens" where both DO and temperature conditions meet Basin Plan objectives for water temperature and DO and are therefore protective of COLD. The concept of the compliance lens where both DO and temperature objectives are met is illustrated in Figure 5.9.

The allocation is for the critical period of May through October and requires overlapping DO concentrations consistent with 85% saturation, at temperatures consistent with natural water temperatures at the point of entry to the reservoirs within a lens throughout the reservoir.

The volume of each reservoir compliance lens is equal to the average hydraulic depth of the river in a free-flowing state for the width and length of the reservoir. The depth at which the compliance lens occurs within the reservoirs will vary. For Copco 1 and 2 and Iron Gate Reservoirs the instantaneous DO mass that achieves the DO allocation equals 39,398 pounds (7.64 mg/L) and 47,624 pounds (7.60 mg/L), respectively[4].

4 The instantaneous DO mass for Copco and Iron Gate was calculated from the depth within each reservoir at which temperatures achieved California compliance scenario temperatures. The volume within the compliance lens was calculated from the depth at which compliance is achieved to the thickness associated with the reach-average depth of the free-flowing river channel for the entire width of the reservoir at these depths. This volume estimate was then multiplied by the average 85% DO saturation concentration calculated from the California compliance scenario to get the instantaneous DO mass for each reservoir.

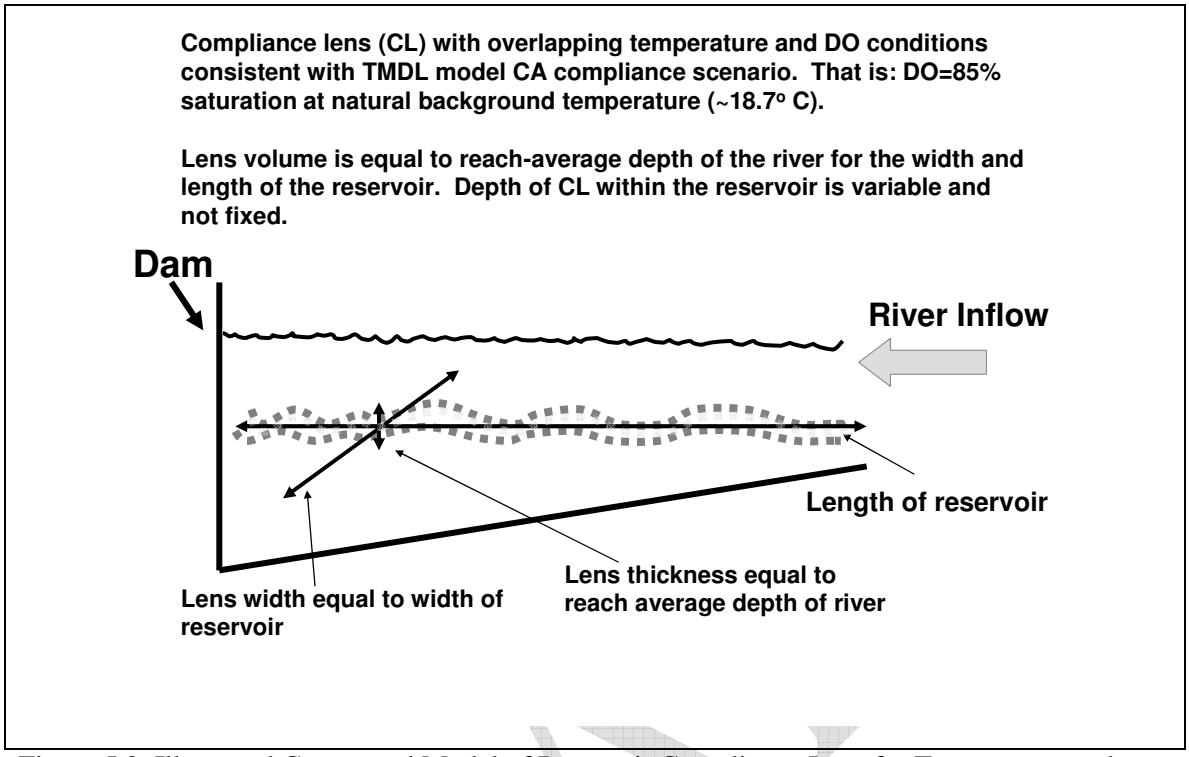

Figure 5.9: Illustrated Conceptual Model of Reservoir Compliance Lens for Temperature and Dissolved Oxygen

5.3.3 Dissolved Oxygen and Nutrient-Related Numeric Targets and Waste Load Allocations to Iron Gate Hatchery

The DO targets for Iron Gate Hatchery discharge are monthly mean and monthly minimum DO concentrations (Table 5.14). The targets apply to the Iron Gate Hatchery discharge location just above the mouth of Bogus Creek. The target concentrations were calculated from the California compliance scenario, and reflect compliance DO conditions immediately downstream of Iron Gate Dam.

Table 5.14: Dissolved Oxygen Numeric Targets (mg/L) for Iron Gate Hatchery Discharge.

	May	June	July	August	September	October
Mean	8.9	8.3	8.2	8.2	9.0	9.9
Minimum	7.9	7.3	7.2	7.2	8.1	8.6
	November	**December**	**January**	**February**	**March**	**April**
Mean	11.6	11.9	11.5	10.6	9.9	9.4
Minimum	10.4	11.4	11.0	10.1	9.3	8.7

Iron Gate Hatchery draws its water from depth within Iron Gate Reservoir. The allocation to this facility is zero net increase of nutrient and organic matter between influent water (intake) and effluent (discharge). The facilities discharge water quality must equal the water quality of the inflow water. Table 5.15 presents the Iron Gate Hatchery nutrient and organic matter targets, expressed as monthly mean concentrations.

These concentration targets reflect California compliance conditions within the Iron Gate Reservoir, at the approximate location where the Hatchery receives its inflow.

Table 5.15 Nutrient and Organic Matter Monthly Mean Concentration Targets (mg/L) for Iron Gate Hatchery.

	May	June	July	August	September	October
TP	0.034	0.030	0.034	0.034	0.034	0.029
TN	0.279	0.206	0.182	0.155	0.170	0.140
CBOD	2	1	1	1	1	1
	November	**December**	**January**	**February**	**March**	**April**
TP	0.028	0.002	0.038	0.035	0.035	0.044
TN	0.166	0.012	0.585	0.315	0.320	0.356
CBOD	1	0	1	3	3	3

5.3.4 Dissolved Oxygen and Nutrient-Related Numeric Targets and Load Allocations to California Tributaries

The primary targets associated with California tributary nutrient and organic matter loadings are dissolved oxygen concentrations within the Klamath River mainstem. The monthly mean and monthly minimum DO targets are calculated from the California compliance scenario. The primary DO target compliance location is located downstream of the Salmon River immediately upstream of the boundary of the Hoopa Valley Indian Reservation; these targets are presented in Table 5.16.

Table 5.16: Dissolved Oxygen Numeric Targets (mg/L) for the Klamath River Mainstem Below the Salmon River.

	May	June	July	August	September	October
Mean	10.0	9.1	8.5	8.4	8.9	10.0
Minimum	9.3	8.1	7.7	7.6	8.2	8.8
	November	**December**	**January**	**February**	**March**	**April**
Mean	11.7	12.4	12.3	11.8	11.4	10.7
Minimum	10.7	11.9	11.9	11.5	10.8	10.3

Nutrient and organic matter numeric targets are also set for the Klamath River mainstem downstream of the Salmon River. The TP, TN, and CBOD numeric targets are expressed as monthly mean concentrations (mg/L); consistent with the California compliance scenario (Table 5.17).

Table 5.17: Nutrient and Organic Matter Monthly Mean Targets (mg/L) for Klamath River Below the Salmon River.

	May	June	July	August	September	October
TP	0.023	0.024	0.026	0.029	0.032	0.029
TN	0.208	0.200	0.185	0.168	0.181	0.163
CBOD	2	2	2	2	1	1
	November	**December**	**January**	**February**	**March**	**April**
TP	0.028	0.027	0.027	0.023	0.025	0.026
TN	0.161	0.170	0.333	0.181	0.199	0.208
CBOD	1	1	1	1	2	2

The final numeric target for the Klamath River mainstem downstream of the Salmon River is for periphyton biomass. The periphyton biomass numeric target selected for the Klamath mainstem at this location is a reach-averaged maximum density of 150 mg of chlorophyll-a / m^2. This value was developed through the California NNE analysis for the Klamath River[5] (Appendix 1, TetraTech 2008).

Allocations for all Klamath River tributaries in California, can be summarized as zero increase above concentrations for TP, TN, and CBOD as defined in the natural baseline conditions scenario. Allocations for minor tributaries are set as monthly mean concentrations (mg/L) that apply year-round. The Shasta, Scott, Salmon, and Trinity Rivers allocations are monthly mean concentrations (mg /L) but are different for wet (November through April) and dry (May through October) seasons. The allocations are calculated from the California compliance scenario, and are summarized in Tables 5.18 and 5.19. The Shasta River TN, TP, and CBOD allocations are consistent with the existing approved Shasta River TMDL. No additional load reductions are required from the Shasta River.

Table 5.18: Nutrient and Organic Matter Seasonal Monthly Mean Concentration Allocations (mg/L) for Tributaries to the Klamath River

Tributary	Season	TP	TN	CBOD
Shasta River	Dry: May – October	0.071	0.21	2
	Wet: November – April	0.071	0.21	2
Scott River	Dry: May – October	0.014	0.21	4
	Wet: November – April	0.016	0.21	3
Salmon River	Dry: May – October	0.010	0.10	2
	Wet: November – April	0.020	0.10	2
Trinity River	Dry: May – October	0.020	0.10	2
	Wet: November – April	0.030	0.10	3

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[5] Compliance with this target shall be assessed by calculating the average periphyton chlorophyll-a from not less than ten samples collected within the Klamath River downstream of the Salmon River and upstream of the Trinity River.

Table 5.19: Nutrient and Organic Matter Annual Monthly Mean Concentration Allocations (mg/L) for Tributaries to the Klamath River

Tributary	TP	TN	CBOD
Willow Creek	0.014	0.077	1
Cottonwood Creek	0.014	0.077	1
Humbug	0.014	0.077	1
Beaver Creek	0.014	0.077	1
Horse Creek	0.014	0.077	1
Grider Creek	0.014	0.077	1
Thompson Creek	0.014	0.077	1
India Creek	0.014	0.077	1
Elk Creek	0.014	0.077	1
Clear Creek	0.014	0.077	1
Ukonom Creek	0.014	0.077	1
Dillon Creek	0.014	0.077	1
Camp Creek	0.014	0.077	1
Red Cap Creek	0.014	0.077	1
Bluff Creek	0.014	0.077	1
Pine Creek	0.014	0.077	1
Tectah Creek	0.014	0.077	1
Blue Creek	0.014	0.077	1

DRAFT

CHAPTER 5 REFERENCES

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DRAFT

Klamath Hydroelectric Project
(FERC Project No. 2082)

Response to November 10, 2005, FERC AIR GN-2

Klamath River Water Quality Model Implementation, Calibration, and Validation

PacifiCorp
Portland, Oregon

Version: December 2005
December 16, 2005, FERC filing

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A RMA-11 Modification for Modeling Labile Organic Matter

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EXECUTIVE SUMMARY

To support studies for the relicensing of the Klamath Hydroelectric Project, PacifiCorp has used a hydrodynamic and water quality model of the Klamath River from Link dam to Turwar developed by Watercourse Engineering, Inc. Because of dramatically varying conditions along the river, and especially considering the very different hydrodynamics of steep river sections and reservoirs, different modeling systems were used to simulate river and reservoir reaches. River reaches were modeled with the Resource Management Associates (RMA) suite of finite-element hydrodynamic and water quality models. Reservoirs were modeled with U.S. Army Corps of Engineer's CE-QUAL-W2. Use of these two numerical models takes advantage of each model's strengths.

The Klamath River model developed for these studies is comprised of four river and four reservoir reaches. During simulation, the sub-models of each reach are run in series to produce linked results for the entire river system under varying hydrologic, water quality, and meteorological boundary conditions. The RMA water quality model RMA-11 was modified to improve linkage between the models. This report describes model selection, implementation, calibration, and validation.

The Klamath River model has been calibrated with data from 2000 and 2001 and validated considering data from 2002 through 2004. Over these five calendar years (2000–2004), simulation results are compared with observed data from 17 locations along its approximately 250-mile length running from Upper Klamath Lake, in Oregon, to the California coast. Calibration and validation included assessment of flow, temperature, dissolved oxygen, nutrients, and algae representation. Model performance varies among constituents with simulated flow and temperature conditions matching field observations well. The remaining constituents illustrate various degrees of departure from field data, depending on the reach and time of year. In some cases day to day conditions are not represented in the model, while longer-term conditions are generally replicated. The chemical and biological parameters often do not perform as well as the physical parameters of flow and temperature, because of the complex interaction among nutrients, primary production, dissolved oxygen, and other constituents. Not all of these processes are well defined for many river systems, the Klamath River included. Overall, model performance for the validation period – for all parameters – was consistent with calibration period performance. Because calibration of the model is a time intensive exercise, and because model performance during the validation period was consistent with performance during the calibration period, recalibration using the entire period has not been completed at this time.

Subsequently, the calibrated model has been applied to several management scenarios to assess existing conditions, effects of hydropower operations, or complete removal of hydropower facilities. These scenarios are described briefly here and in detail in other documents. Application and testing of the model have improved understanding of Klamath River limnology and provided insight into key processes and characteristics that affect water quality along the river's length. In particular, the model indicates that water quality of releases from Upper Klamath Lake to the Klamath River has a dominating effect on water quality throughout the system.

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1.0 INTRODUCTION

To support studies for relicensing of the Klamath Hydroelectric Project (Project) (FERC No. 2082), PacifiCorp has used a hydrodynamic and water quality model of the Klamath River from Link dam to Turwar developed by Watercourse Engineering, Inc. This report describes model selection, implementation, calibration, and validation. Supporting documentation is found in attached appendices.

PacifiCorp conducted numerous meetings with the Water Quality Work Group (WQWG) over the last 2-plus years related to the water quality modeling processes. PacifiCorp has supplied detailed reports describing water quality methods, assumptions, and results. These documents were passed out at the meetings, and have also been placed on PacifiCorp's relicensing web site at (http://www.pacificorp.com/Article/Article1152.html). The WQWG retained Dr. Scott Well's of Portland State University to conduct a comprehensive peer review of the water quality model. Updates and modifications to the model were subsequently done in response to Dr. Wells' comments. PacifiCorp's responses to Dr. Wells' comments are documented in the FERC submittal GN-2. Also, the model has also been reviewed by Tetra Tech and additional modest modifications have been made. Watercourse Engineering, through discussions with EPA and other TMDL agents, is working closely with Tetra Tech to produce a single model version for all modeling activities in the basin (e.g., FERC, TMDL, others).

After selecting appropriate numerical models with which to represent the system, the models have been implemented in a process that includes gathering necessary descriptive data (including geometry, hydrology, water quality, and meteorology), formatting the data for input, and initiating model runs. In the course of implementation, default model parameters were selected and general model testing was done. During calibration, model parameters (e.g., rate constants and coefficients) were modified to fit the model to field observations. In validation, the model was tested on an independent set of boundary conditions to assess its ability to replicate system response using parameter values determined in calibration.

The calibrated and validated model has been applied to selected management strategies or scenarios. These scenarios represent varied flow or water quality conditions, and include the incremental removal of project facilities to identify potential impacts and outcomes. Results of this application help to demonstrate the relative response of the system to change with respect to existing conditions, and determine what effect, if any, the Project has on water quality. Results of model application and testing also provide insight into important characteristics and processes within the system.

Model implementation, calibration, and validation are described in this report. Application of the validated model to four scenarios is also described. Supporting information (including an overview of the model framework, model descriptions, geometry, boundary conditions, and procedures for processing data used in the models) is included in the appendices to this report.

1.1 STUDY AREA

The Klamath Hydroelectric Project (Project) is located along the upper Klamath River in Klamath County, south-central Oregon, and Siskiyou County, north-central California. The

Klamath River is one of only three rivers that bisect the Cascades mountain range, flowing from the interior of Oregon through California's coastal rain forest to the Pacific Ocean. The Klamath River begins at the outlet of Upper Klamath Lake at River Mile (RM) 254 in Oregon at elevation 4,139 feet and flows southwest to the Pacific Ocean at Requa, California. Upper Klamath Lake is a shallow, regulated, natural lake, which serves as a storage reservoir for irrigation of approximately 250,000 acres in the basin.

From Upper Klamath Lake, water flows into a relatively short 1.3-mile reach of the upper Klamath River called Link River located in the city of Klamath Falls. Downstream of Link River, the river flows through Keno Reservoir (including a section known as Lake Ewauna), which is the diked channel of what was once part of Middle and Lower Klamath Lake. An extensive array of canals feeds water to and from the river and surrounding farmland. The Lost River diversion channel, other diversions, and other major irrigation drains enter Keno reservoir. Keno dam controls water level in the reservoir.

Below Keno dam at Keno, Oregon, the river enters the Klamath River canyon at elevation 4,000 feet. The river in this reach is free flowing for about 5 miles to J.C. Boyle reservoir (elevation 3,800 feet). Spencer Creek is a small tributary that enters J.C. Boyle reservoir. From below J.C. Boyle dam, the river is free flowing for the remaining 22 miles of canyon before entering Copco reservoir in northern California (elevation 2,600 feet). Copco reservoir is about 4.3 miles long. Shovel Creek is another small but important trout-producing tributary that enters the river near the downstream end of the canyon.

Leaving Copco reservoir the Klamath River flows through a short section of canyon before entering Iron Gate reservoir. Iron Gate reservoir is about 6.0 miles long. Below Iron Gate dam, the river flows unimpounded the remaining 190 miles to the ocean. Fall Creek, a relatively small tributary, enters the Klamath River near the upstream end of Iron Gate reservoir. Jenny Creek is another small tributary that enters Iron Gate reservoir about 2 miles downstream of the mouth of Fall Creek

1.2 PROJECT FACILITIES

The existing Project facilities are located along a 64-mile length of the Klamath River between RM 190 and RM 254. The existing Project consists of six generating facilities along the main stem of the upper Klamath River, a re-regulation dam with no generation facilities, and one generating facility on Fall Creek, a tributary to the Klamath River at about RM 196. The Project that PacifiCorp proposes for relicensing consists of fewer facilities and will occur along a shorter 38-mile length of the river from RM 190 to RM 228. The upstream-most Eastside and Westside facilities will be decommissioned, and Keno dam will no longer fall under PacifiCorp's license because it serves no hydropower function.

Link River dam, located at RM 254, was completed in 1921. It provides regulation of Upper Klamath Lake, diverts water from the lake to the Eastside and Westside powerhouses, and releases a minimum flow to the Link River reach between the dam and the Eastside powerhouse. U.S. Bureau of Reclamation (USBR) owns Link River dam, but PacifiCorp operates the dam to maintain lake levels and release flows according to a contract between PacifiCorp and USBR. Operations must balance the requirements for threatened and endangered species found in Upper

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Klamath Lake and downstream, irrigation, and power generation, while maintaining sufficient carryover storage. Should operations threaten irrigation supplies, USBR reserves the right to take over facility operation. As previously mentioned, these particular facilities are not part of PacifiCorp's proposed Project.

Keno dam is a re-regulating facility located at about RM 233, approximately 21 miles downstream of Link River dam. Construction of Keno dam was completed in 1967. PacifiCorp built the facility intending to produce hydroelectric power, but the facilities were never developed. The Keno development operates as a diversion dam to control elevations of Keno Reservoir for the USBR's Klamath Irrigation Project. The dam maintains a constant reservoir level that allows irrigators to withdraw water during the growing season despite fluctuation in discharge from variable agricultural return flows. Reservoir levels rarely fluctuate more than 6 inches seasonally, although the reservoir may be drawn down about 2 feet annually for 1-2 days to provide an opportunity for irrigators to conduct maintenance on their pumps and canals. As required in the existing FERC license (FPC 1956), PacifiCorp has an agreement with Oregon Department of Fish and Wildlife (ODFW) to release a minimum 200 cfs flow at the dam. Flows through Keno generally mimic instream flows downstream of Iron Gate dam and approach minimum flow levels only during critically dry water years. As previously mentioned, Keno dam is not part of PacifiCorp's proposed Project.

Below Keno dam the Klamath River is free-flowing for about five miles to J.C. Boyle reservoir. The J.C. Boyle development consists of a reservoir, dam, diversion canal, and powerhouse on the Klamath River between about RM 228 and RM 220. Construction was completed in 1958. The impoundment formed upstream of the dam (J.C. Boyle Reservoir) covers 420 acres and contains about 3,495 acre-feet of total storage capacity and 1,724 acre-feet of active storage capacity. The powerhouse is located about 4.3 RM downstream of the dam.

The J.C. Boyle development generally operates as a load-factoring facility when flow is not adequate to allow continuous operations. Generation occurs when there is sufficient water available for efficient use of one or both turbines. As a result, flows downstream from the powerhouse may fluctuate on an hourly basis, based on the amount of water available to the powerhouse. River flows in excess of powerhouse hydraulic capacity can allow continuous operation of the powerhouse. During cold weather, the plant generates power around the clock, not necessarily at peak efficiencies, to prevent freeze damage to the canal or equipment. The load-factoring operation allows commercial and recreational rafting opportunities from the powerhouse to Copco reservoir from May to mid-October. During that period, timing of flow releases may be determined in part by rafting use in the downstream reach.

The minimum flow requirement from J.C. Boyle dam established in the FERC license is 100 cfs. However, large springs a short distance below the dam supply an estimated additional 225 cfs of accretion flow, so actual minimum flows in most of the reach between the dam and the powerhouse are approximately 325 cfs or greater. River fluctuation downstream of the dam and the powerhouse is limited to a 9-inch-per-hour ramp rate, as measured at the U.S. Geological Survey (USGS) gage 0.25 mile downstream of the J.C. Boyle powerhouse and established in the existing FERC license (FPC 1956). Operating conditions can result in a fluctuation of about 3.5 feet between minimum and full pool elevations in the J.C. Boyle reservoir, but the average daily fluctuation is about 2 feet.

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The Klamath River is free-flowing for about 22 miles from J.C. Boyle dam to Copco reservoir. The Copco No. 1 development consists of a reservoir, dam, and powerhouse located on the Klamath River between about RM 204 and RM 199 near the Oregon-California border. Generation at Copco No. 1 began in 1918. The impoundment formed upstream of the dam is approximately 1,000 surface acres containing about 40,000 acre-feet of total storage capacity and 6,235 acre-feet of active storage capacity. Copco No. 1 powerhouse is located at Copco dam.

Copco No. 1 operates for power generation, flood control, and control of water surface elevations of Copco and Iron Gate reservoirs. Like the J.C. Boyle development, Copco No. 1 generally operates as a load-factoring facility, usually from spring through summer and fall. Typical operation is to generate during the day when energy demands are highest and store water during non-peak times (weeknights and weekends). When river flows are near or in excess of turbine hydraulic capacity, the powerhouse generates continuously and excess water is spilled through spill gates. Copco reservoir can fluctuate 5.0 feet between normal minimum and full pool elevations, but the average daily fluctuation is about 0.5 foot. There are no specific requirements established for reservoir fluctuations.

The Copco No. 2 development consists of a diversion dam, small impoundment, and powerhouse located just downstream of Copco No. 1 dam between about RM 199 and RM 198. The reservoir created by the dam has minimal storage capacity (73 ac ft).

Copco No. 2 operation follows that of Copco No. 1. Water spills over the spillway crest when flows from Copco No. 1 exceed either the hydraulic capacity or the limited storage capacity of this facility. There are no “minimum instream flow” or “ramp rate” requirements for the relatively short (about 1.4 mile) downstream reach between Copco No. 2 dam and Iron Gate reservoir, but a flow of 5 to 10 cfs due to leakage and incidental releases is common. Water surface elevations of the reservoir rarely fluctuate more than several inches. No specific requirements have been established for reservoir fluctuations.

The Iron Gate development consists of a reservoir, dam, and powerhouse located on the Klamath River between about RM 197 and RM 190 about 20 miles northeast of Yreka, California. Iron Gate dam was completed in 1962 and is 173 feet high. The impoundment formed upstream of the dam is approximately 944 surface acres and contains about 50,000 ac ft of total storage capacity and approximately 3,790 acre-feet of active storage capacity. An ungated spillway 730 feet long leads to a large canal, allowing the transport of high flows past the structure. The powerhouse is located at the base of the dam.

The Iron Gate facility is operated for base load generation and to provide stable flows in the Klamath River downstream of the dam. It also provides the required minimum flows downstream of the facility. During periods of high flow, when storage is not possible, water in excess of generating capacity passes through the spillway.

FERC has stipulated minimum instream flow requirements to protect downstream aquatic resources as a condition of PacifiCorp’s current Project license. FERC minimum flows are 1,300 cfs from September through April, 1,000 cfs in May and August, and 710 cfs in June and July. Since 1996, however, USBR’s annual Project Operation Plans have dictated instream flow

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releases. During that time, instream flow releases from Iron Gate dam, as required by USBR's annual project operation plans have generally exceeded the required FERC instream flows.

2.0 MODEL SELECTION

Flow and water quality conditions in the Klamath River basin vary dramatically along the approximately 250 river miles from Link dam (RM 254) near Klamath Falls Oregon to Turwar, California (RM 5), where the coastal estuary begins. There are a wide range of natural and anthropogenic influences affecting water quality along this long stretch of river. Significant influences on water quality in the system are induced by upstream inflows from hypereutrophic Upper Klamath Lake, the existence of four mainstem reservoirs, agricultural, municipal, and industrial discharges above Keno dam, and large tributary inflows in the lower reaches of the river.

Because of varying conditions along the river, and especially considering the very different hydrodynamics of steep river sections and reservoirs, different modeling systems were used to simulate river and reservoir reaches. River reaches were modeled with the Resource Management Associates (RMA) suite of finite-element hydrodynamic and water quality models. Reservoirs were modeled with U.S. Army Corps of Engineer's CE-QUAL-W2.

RMA models were chosen for river reaches because they are capable of accurately simulating flow and transport in steep river reaches. These models have been used historically on the Klamath River with good results (Deas and Orlob, 1999). The RMA suite includes RMA-2 and RMA-11, along with various utility programs. Flow is represented with RMA-2, a finite element hydrodynamic model capable of modeling highly dynamic flow regimes in short space- and time-steps. Output from this hydrodynamic model (including velocity, depth, and representative surface and bed areas) is passed to the water quality model RMA-11. RMA-11 is a finite element water quality model simulating the fate and transport of a wide range of physical, chemical, and biological constituents. These two linked river models are applied on hourly or sub-hourly time steps to capture the short-term response of state variables such as temperature and dissolved oxygen. For this application, the RMA models are applied in one-dimension, representing variations along the longitudinal axis of the river while averaging vertical and lateral details.

Reservoirs along the Klamath River are represented by the two-dimensional, longitudinal/ vertical hydrodynamic and water quality model CE-QUAL-W2. This model is produced and maintained by the US Army Corps of Engineers (USACE), and has also seen historic use on this river (ODEQ, 1995). Because the model assumes lateral homogeneity, it is well suited for reservoirs along the Klamath River, i.e., relatively long and narrow water bodies exhibiting longitudinal and vertical, but not strong lateral, water quality gradients. The CE-QUAL-W2 model is capable of representing a wide range of physical, chemical, and biological processes affecting water quality. The model can simulate selective withdrawal, sediment nutrient release dynamics, nitrogen inhibition under anoxic conditions, internal weirs and curtains, and other options useful in assessing a wide range of existing and possible future conditions of the system. To interface with the river model, time steps on the same scale as those of the river models have been employed.

For this application, the RMA water quality model (RMA-11) was modified to model labile organic matter. This modification allowed modeling results to be transferred easily from one model to the next so that the entire river could be reasonably modeled as one system. Details of

this modification to RMA-11 are presented in Appendix A. Other changes were made to both RMA-11 and to CE-QUAL-W2 to better represent river and reservoir water quality during the course of this study. Benthic algae concentrations in RMA-11, which have no limiting factors in the model, were given a maximum value to prevent excessive growth. To mimic its representation in CE-QUAL-W2, phytoplankton was given both respiration and mortality rates in RMA-11. Additional logic to assess topographic shading in river reaches was also implemented. Model simulations were completed in metric units, but are largely presented in English units herein, with the exception of water quality constituents.

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3.0 MODEL IMPLEMENTATION

Model implementation required construction of appropriate system geometry, description of flow and water quality conditions, description of meteorological data, and definition of model parameters and constants. Flow and water quality conditions were described both initially throughout the system (initial conditions) and along the model's boundaries throughout the course of simulation (boundary conditions). After implementation, the model was calibrated and verified to observed data before being considered final and representative of the system.

- Geometry data includes a description of configuration (i.e., a set of points defined by latitude and longitude, UTM, or similar coordinate system), bed slope, and cross-section data. For reservoirs, bathymetric information and facilities information (such as stage-volume relationships, intake structure configurations, elevations, and locations of diversion structures and return points) are also included.
- Flow and water quality information includes system inflow (headwater, tributary, and return flows), outflow (diversions), reservoir storage change, and facilities operations. Water quality data for all inflows, as well as in-river and reservoir conditions, are also included.
- Meteorological data include standard parameters for heat budget calculation, e.g., air temperature, wet bulb temperature (or dew point temperature), solar radiation, cloud cover, wind speed, and/or barometric pressure.
- Other model parameters include selection of time step, spatial resolution, identified periods of analysis, and selection of default model constants and coefficients.

The current model has been through an external review (Wells, 2004) and modifications have been made to the original formulation. Detailed responses to the external review are provided in PacifiCorp (2005). PacifiCorp's modeling effort also has been an actively managed project wherein new information was incorporated into the framework as it became available. An example of this is the latest extension of the model to include calendar years 2002 through 2004.

3.1 RIVER-RESERVOIR REACHES (COMPONENTS OF KLAMATH RIVER MODEL)

The Klamath River Model represents the Klamath River as a series of river and reservoir reaches. In this configuration, each of the four mainstem reservoirs is modeled separately, as are each of the river sections that combine with them to comprise the entire river system. All together, there are eight distinct reaches of the river, four river reaches and four reservoirs, modeled separately but linked as one comprehensive model of the system. These eight distinct reaches are presented in Table 1 and shown on a map of the river in Figure 1.

Table 1. River Reaches and Representation in the Modeling Framework

Reach	Existing Representation	Model(s)
Link River	River	RMA-2/RMA-11
Lake Ewauna-Keno Dam	Reservoir	CE-QUAL-W2
Keno Dam to J.C. Boyle Reservoir	River	RMA-2/RMA-11
J.C. Boyle Reservoir	Reservoir	CE-QUAL-W2
Bypass-Peaking Reach[a]	River	RMA-2/RMA-11
Copco Reservoir[b]	Reservoir	CE-QUAL-W2
Iron Gate Reservoir	Reservoir	CE-QUAL-W2
IG Dam to Turwar	River	RMA-2/RMA-11

[a] The Bypass and Peaking sections are modeled as a single reach
[b] Copco 2 is not represented in the framework

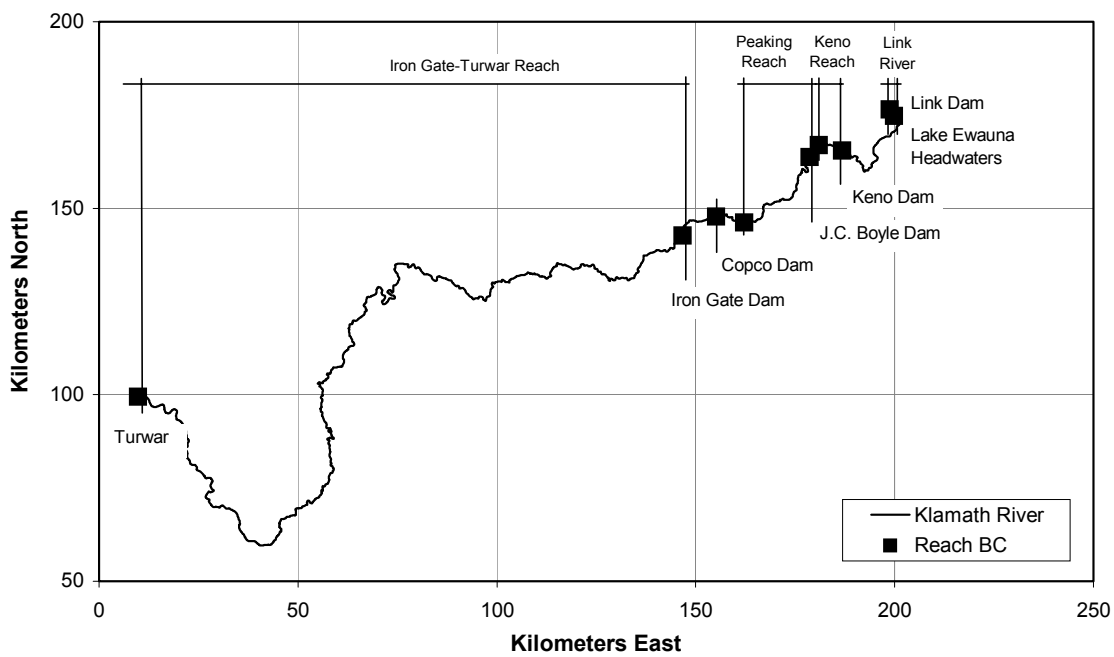

Figure 1. Designated River Reaches and Reservoirs

To create a systemwide simulation, the models are applied in series. Starting with the uppermost reach, Link River, flow and water quality are passed from one reach to the next. In other words, output from the Link River model forms the upstream boundary condition for the Lake Ewauna/ Keno reservoir model. Similarly, output from the Lake Ewauna/Keno reservoir model forms the headwater boundary condition for the model representing the Klamath River from Keno dam to J.C. Boyle dam (called the "Keno River" reach), and so on down the river.

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Flow from the river hydrodynamics model RMA-2 is passed directly to CE-QUAL-W2, which models both hydrodynamics and water quality in the reservoir reaches. Likewise, flow from CE-QUAL-W2 is passed directly to RMA2. Most important water quality constituents are also passed directly between CE-QUAL-W2 and the river water-quality model RMA-11. These constituents, common to both models, include water temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia (NH_3), nitrate (NO_3), orthophosphate (PO_4), and phytoplankton algae. Values for other constituents are either assumed or derived. Details of these assumptions and derivations are given in the Boundary Conditions section of this report.

3.2 GEOMETRY

The numerical models used in this study require a detailed description of the system's physical characteristics. This description, the system "geometry," includes a map (i.e., a set of points given in latitude and longitude, UTM, or similar coordinate system that describes the system in plan view), bed slope, and cross-section data. For reservoirs, bathymetric information and facilities information (such as stage-volume relationships, intake structure locations, elevations, and locations of diversion structures and return points) are also required. In this section, the geometries of each river reach are presented and discussed.

Locations and orientations of river and reservoir reaches were determined from digitized versions of 1:24,000 USGS topographic quadrangles as discussed in Appendix B. Coordinates from these quadrangles were translated into a network of river nodes and elements and reservoir segments for use by the numerical models. All coordinates presented in this report are referenced to UTM 400000E 4500000N, NAD27 (typical).

Inflow can be represented in the geometry of an RMA reach in two ways. For inflows (e.g., tributaries) that form a large percentage of the base flow in the main stem, that inflow is represented as a small branch attached to the main stem with a junction. Junctions are placed at a single point, or node, in the model. For inflows to the main stem that are relatively modest, they may be represented as element side flows. An element side flow is distributed over the length of an element[1]. Both ways were used to represent inflows in the models used in this study as described in the reach-specific descriptions below.

3.2.1 Link River Reach

The Link River reach starts at Link dam (RM 254) and terminates 1.3 miles downstream at Lake Ewauna (RM 253). The Link River reach is simulated with two junctions, representing separate powerhouse discharges into the reach, and no element side flows. Link River Reach geometry is summarized in Table 2. The Link River reach and important locations within the reach are shown in Figure 2 and presented in Table 3. This reach is modeled with the RMA-2 and RMA-11 models.

[1] For more information on nodes and elements refer to RMA-2 model documentation (King, 2001).

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Table 2. Link River Reach Geometry Summary

Node spacing	75 meters
Number of nodes	29 nodes in length; 37 nodes total including junctions
Length	1.31 miles from RM 252.57-253.88
Elevations	Range: 1245-1259 meters
Widths	Constant widths: 5 meters main stem; 20 meters junction elements
Side slopes	20:1 main stem; 1:1 junctions
Data sources	UTM coordinates from CH2M HILL; Elevations estimated from USGS topographic maps
Notes	2 junctions: East side, West side; Nodes 30-33 at East side; 34-37 at West side

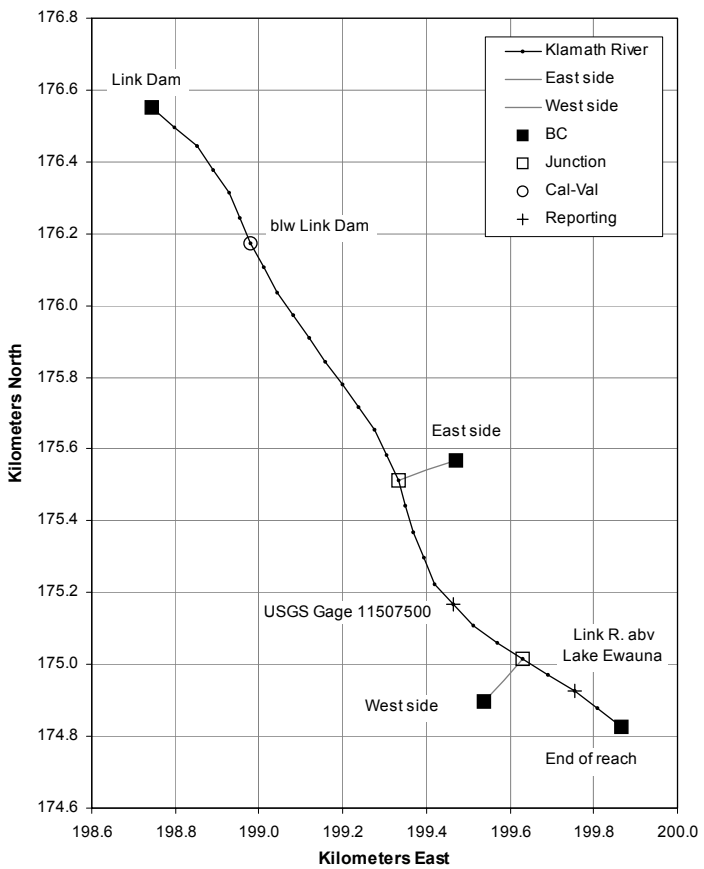

Figure 2. Map of Link River Representation

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Table 3. Geometry Information for Link River

Location	Node	Element	x-coord	y-coord	Site type
Link Dam	1	1	198.8	176.6	BC
East Side	17	9	199.9	174.8	BC
West Side	25	13	199.5	175.6	BC
End Link R reach	29	14	199.5	174.9	BC
East Side	30	15	199.3	175.5	Junction, inflow
West Side	34	16	199.6	175.0	Junction, inflow
USGS Gage 11507500	22	-	199.5	175.2	Reporting Point
Link River above Lake Ewauna	27	-	199.8	174.9	Reporting Point

3.2.1.1 Bed Elevations/Slope

Bed slope for the Link River reach was estimated from USGS topographic maps and assumed Lake Ewauna elevations. Elevations were estimated from topographic contours to preserve the general slope of the river. Upstream reach elevation was set at 4131 ft (1259 m) MSL and downstream reach elevation was set at 4085 ft (1245 m) MSL.

3.2.1.2 Cross-sections

Link River widths were obtained from 1:7,500-scale aerial photos taken July 21, 1988. Daily average flow for that day was 920 cfs. For numerical stability in this short and steep reach, bottom width of the main stem was set to a constant 5 meters. These widths were assumed to represent bottom widths of trapezoidal cross-sections with twenty-to-one side slopes on the main stem and one-to-one side slopes in tributaries.

3.2.2 Lake Ewauna-Keno Reservoir

The Lake Ewauna to Keno dam reach extends from the headwaters of Lake Ewauna (RM 253) 20 miles downstream to Keno dam (RM 233). The impoundment (i.e., Keno reservoir) is generally a broad, shallow body of water. Widths range from several hundred to over 1,000 feet (a range of about 90 to 300 meters), and depths range to a maximum of roughly 20 feet (approximately 6 meters). A total of 18 discharges and 7 withdrawals were represented in the model. This reach is modeled with CE-QUAL-W2.

3.2.2.1 Keno Dam Features

The Keno dam spillway, with an invert elevation of 4,070 feet, contains six Taintor gates. Three additional outlets include a sluice conduit, the fish attraction outlet, and a fish ladder. Details of these outlets are summarized in Table 4.

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Table 4. Keno Dam Outlet Features

Outlet	Invert Elevation	Dimension	Operation
Sluice Conduit	4,073.0 ft	36 inch diameter	Manual gate
Fish Attraction Outlet	4,075.0 ft	30 inch diameter	Manual gate
Fish Ladder	4,078.5 ft	60 inch width	Stop logs
Spillway	4,070.0 ft	6 gates @ 40 ft width each	Remote control on three gates

Sources: PacifiCorp (2002), PacifiCorp (2000)

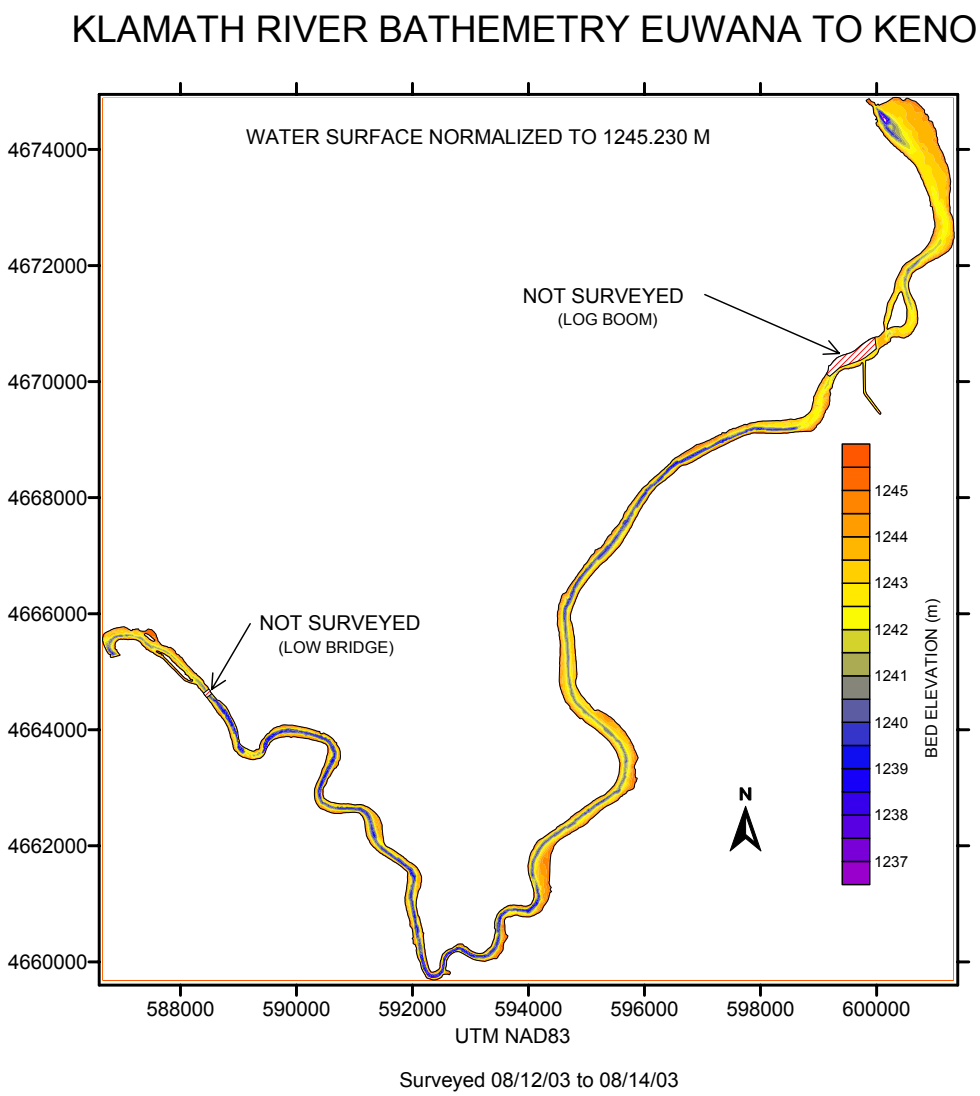

Figure 3. Keno Reservoir Bathymetry (PacifiCorp, 2004a)

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3.2.2.2 Reservoir Bathymetry

The Lake Ewauna to Keno dam model was originally implemented with bathymetry derived from an earlier model of this reach created by Wells (ODEQ, 1995). This original representation was replaced with data from a recent bathymetric survey of the entire reservoir (PacifiCorp, 2004a) (Figure 3).

The number of segments, number of layers, segment lengths, layer widths per segment and water surface elevation were largely retained from the previous CE-QUAL-W2 modeling of the reach by ODEQ (1995), but were supplemented with new segment orientations calculated from x-y coordinates obtained from digitized versions of 1:24,000 USGS topographic quadrangles. River segment orientations were updated because the original orientations (ODEQ 1995) contained discrepancies when applied to the newer versions of CE-QUAL-W2 used in this study. Model representation of this reach is shown in Figure 4.

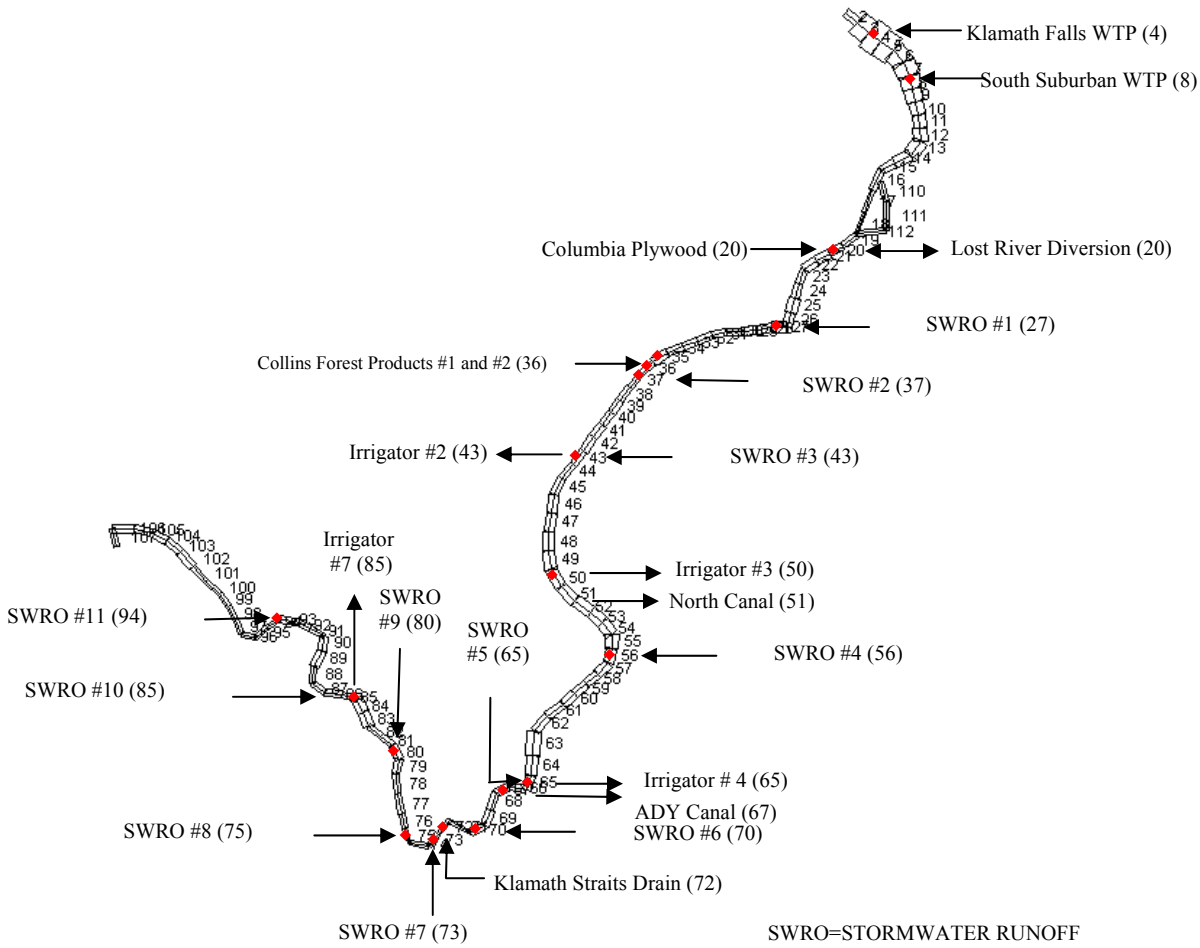

Figure 4. Map of Lake Ewauna to Keno Dam CE-QUAL-W2 Representation, Identifying Inputs and Withdrawals

The CE-QUAL-W2 representation of Lake Ewauna to Keno dam reach consists of two connected reservoir sections, or branches. The main branch, Branch 1, spans the entire length of the reach and is comprised of 106 active segments, all 1,000 ft (304.8 m) in length. A second,

smaller branch, Branch 2, provides an alternate flow path from segment 14 to segment 18 of Branch 1. Branch 2 has no external inflows or outflow and is comprised of three active segments, each 800 ft (243.8 m) in length. A total of 18 discharges and 7 withdrawals were represented in the model (see Table 5). The 15 active layers of this reach are all 2.00 ft (0.61 m) thick. Total volume generated by this model representation was consistent with volume calculated from reservoir bathymetry available from PacifiCorp. Simulated and observed stage-volume curves are shown in Figure 5.

Table 5. Modeled Inflows and Outflows in the Lake Ewauna to Keno Dam Reach

Name	Type	River Bank [a]	Approximate RM [b]	Model Segment
Klamath Falls Wastewater Treatment Plant	Inflow	Left	253	4
South Suburban Sanitation District	Inflow	Left	252	8
Columbia Plywood	Inflow	Right	250	20
Lost River Diversion	Inflow/Outflow	Left	250	20
Collins Forest Products #1	Inflow	Right	247	36
Collins Forest Products #2	Inflow	Right	247	36
Klamath Straits Drain	Inflow	Left	240	72
Stormwater Runoff #1	Inflow	NA	249	27
Stormwater Runoff #2	Inflow	NA	247	37
Stormwater Runoff #3	Inflow	NA	246	43
Stormwater Runoff #4	Inflow	NA	243	56
Stormwater Runoff #5	Inflow	NA	242	65
Stormwater Runoff #6	Inflow	NA	241	70
Stormwater Runoff #7	Inflow	NA	240	73
Stormwater Runoff #8	Inflow	NA	240	75
Stormwater Runoff #9	Inflow	NA	239	80
Stormwater Runoff #10	Inflow	NA	238	85
Stormwater Runoff #11	Inflow	NA	236	94
North Canal	Outflow	Left	247	35
ADY Canal	Outflow	Left	241	67
Irrigator #2 [c]	Inflow/Outflow	NA	246	43
Irrigator #3 [c]	Inflow/Outflow	NA	244	50
Irrigator #4 [c]	Inflow/Outflow	NA	242	65
Irrigator #7 [c]	Inflow/Outflow	NA	238	85

[a] River bank is given for reference only. The model does not discriminate between banks when simulating flows.

[b] River miles are approximate as each model segment is 1000 ft in length.

[c] Nomenclature after Wells (ODEQ, 1995)

Placement of stormwater runoff and irrigator flows is as per ODEQ (1995).

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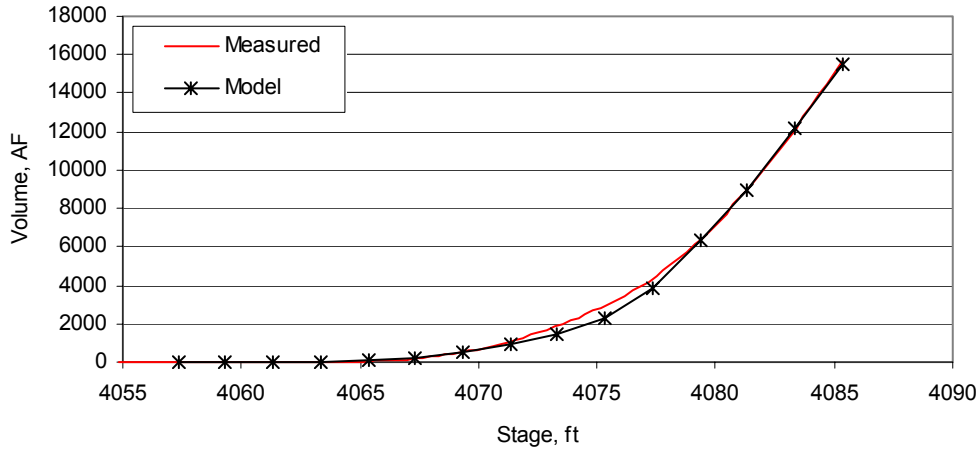

Figure 5. Comparison of Measured and Model Representation of Lake Ewauna Stage-Volume (S-V) Relationships

3.2.3 Klamath River from Keno Dam to J.C. Boyle Reservoir Reach

The Keno reach extends 5.4 miles from Keno dam (RM 233) downstream to the headwaters of J.C. Boyle reservoir (RM 227). No appreciable tributary inflows occur in this reach. Key locations in the Keno reach are presented in Table 6 and a model representation of the reach is shown in Figure 6. This reach is modeled with the RMA models.

Table 6. Klamath River, Keno Reach Geometry Information for the RMA-2 and RMA-11 Models

Location	Node	Element	x-coord	y-coord	Site type
Keno Dam	1	1	186.8	165.4	BC, upper
End Keno R reach	117	58	181.0	166.9	BC, lower
A/D Keno reach	73	37	183.7	167.0	A/D
1/4 mi abv J.C. Boyle	110	56	181.4	166.9	Cal/Val and Reporting

BC – boundary condition (flow, constituent concentration, stage)

A/D – accretion/depletion location

Reporting – model output location

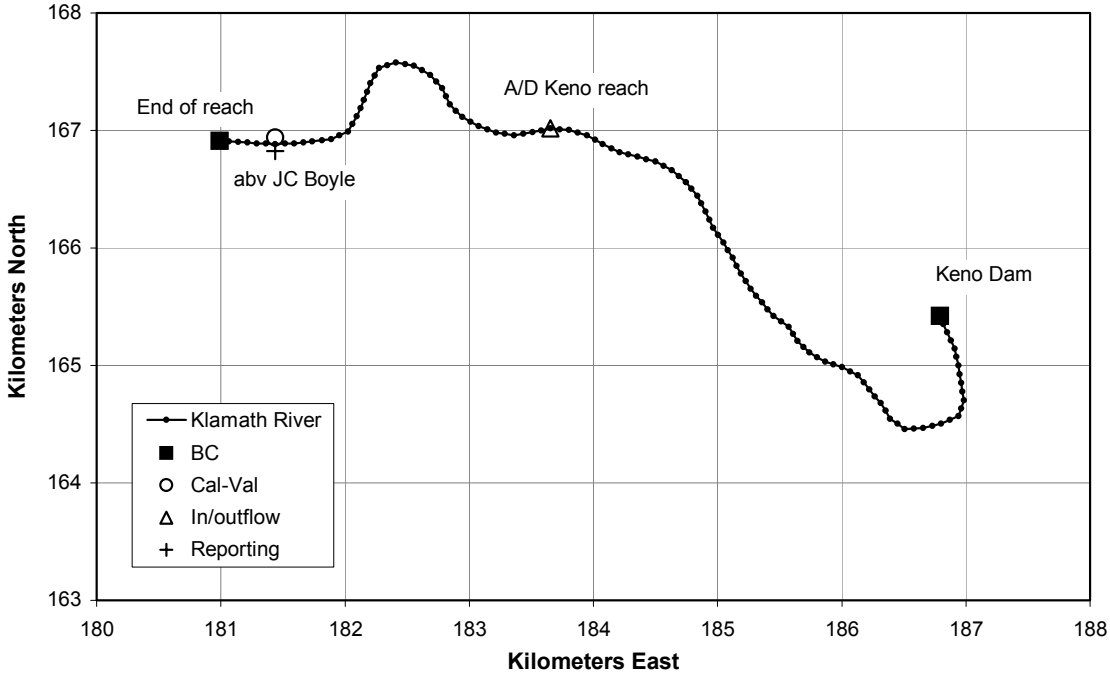

Figure 6. Klamath River, Keno Reach Representation

3.2.3.1 Bed Elevation/Slope

Bed slope for the Keno reach was estimated from USGS topographic maps, known elevations at Keno Dam, and estimated water surface elevations downstream in J.C. Boyle reservoir. Estimated reach elevations range from approximately 3796 ft (1158 m) MSL to 4019 ft (1225 m) MSL.

3.2.3.2 Cross-sections

Keno reach widths were obtained from habitat surveys conducted by Thomas R. Payne and Associates (TRPA) (PacifiCorp, 2004b). Measurements were completed at roughly eight locations per mile. Because measurement locations did not always coincide with the x-y coordinates of the model, field data were linearly interpolated to determine widths for model cross sections. Extreme variations in measured widths were smoothed with a seven-times running average to produce estimates of bottom width. Using these estimates of bottom width, trapezoidal river cross-sections were constructed for each node of the reach at evenly spaced intervals of 75 meters, assuming 1:1 side slopes. A summary of Keno reach geometry is given in Table 7.

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Table 7. Klamath River, Keno Reach Geometry Summary

Node spacing	75 meters
Number of nodes	117 nodes in length
Length	5.37 miles from RM 228.69-234.06
Elevations	Range: 1158-1225 meters
Widths	Range: 28-78 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2M HILL; Elevations estimated from USGS topographic maps
Notes	n/a

3.2.4 J.C. Boyle Reservoir

The J.C. Boyle reservoir reach extends 3.3 miles from the headwaters of J.C. Boyle reservoir (RM 228) to J.C. Boyle dam (RM 224). This reservoir primarily serves to regulate flows for the J.C. Boyle powerhouse located downstream at RM 220. The one significant tributary to this reach, Spencer Creek, is represented in the model as inflow added to Klamath River inflows at the headwater of the reservoir.

3.2.4.1 J.C. Boyle Dam Features

J.C. Boyle dam has four primary outlets: a spillway, a fish ladder, and two outlets into the waterway intake (a fish screen bypass and a waterway pipeline). Details of operational outlets are summarized in Table 8. This reach is modeled with CE-QUAL-W2.

Table 8. J.C. Boyle Dam Outlet Features

Outlet	Invert Elevation	Dimension	Operation
Fish ladder	3780.0 ft	24 inch diameter	Manual
Fish Screen Bypass	3757.0 ft	24 inch diameter	Manual
Waterway pipeline	3775.0 ft	14 foot diameter	**
Spillway	3782.0 ft	3 radial gates @ 35 ft width each	Remote control on one gate

Sources: PacifiCorp (2002), PacifiCorp (2000), PacifiCorp drawing: Exhibit L-4

3.2.4.2 Reservoir Bathymetry

Unlike the Lake Ewauna to Keno dam reach, J.C. Boyle reservoir has never been modeled with CE-QUAL-W2. Reservoir geometry was derived from bathymetric data (PacifiCorp, 2004a) and is presented in Figure 7. Segment length, segment orientation, layer thickness and width were required for the reservoir model. Based on the variation in the reservoir morphology and widths, the reservoir was divided into 20 active segments 887 ft (270m) in length. Segments were chosen to capture both the general shape of J.C. Boyle reservoir and pertinent features (Figure 8).

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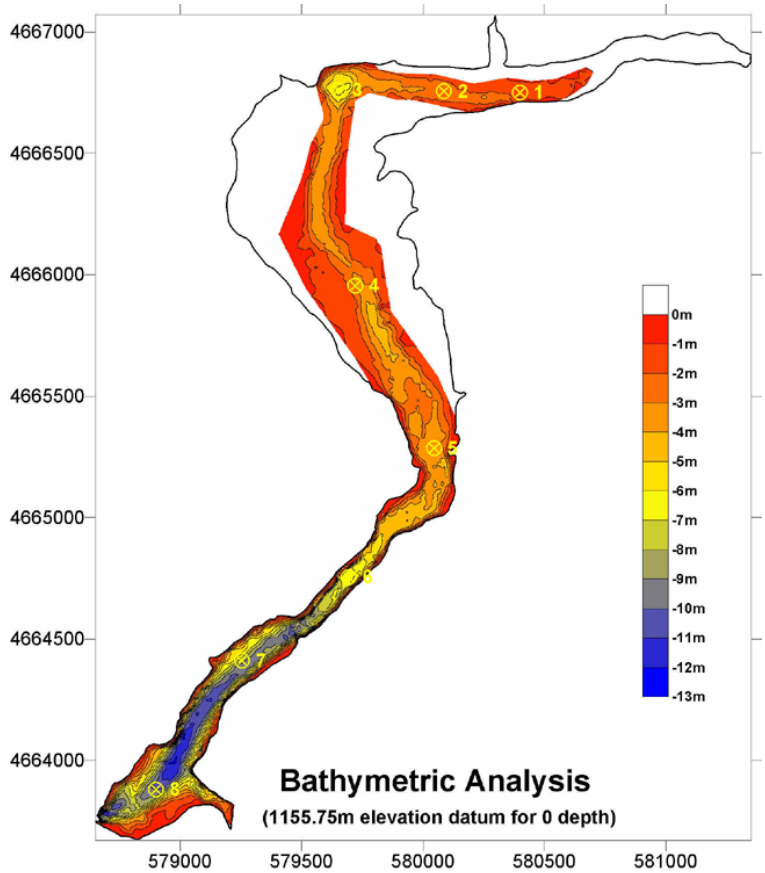

Figure 7. J.C. Boyle Reservoir Bathymetry (PacifiCorp, 2004a)

Layer thickness was set to 3.28 feet (1.0 meter). Layer widths were determined from cross-sectional information taken at the middle of each segment. Twelve active layers of varying widths were determined for each segment from this method. Although a representation using finer resolution (i.e., smaller layer thickness less than 1 meter) was attempted, models using these refined cross-sections took an uncommonly long time (on the order of a day) to run for each one-year simulation period). The model was continually adding and subtracting both layers and segments to account for the dynamic water surface elevations imposed by hydropower operations. A layer thickness of 1 meter produced reasonable results, and one-year simulation times were appreciably reduced to approximately 10 minutes.

A stage-volume curve was generated from the bathymetry data and compared to the measured stage-volume curve of the reservoir. Modeled and measured stage-volume relationships are compared in Figure 9.

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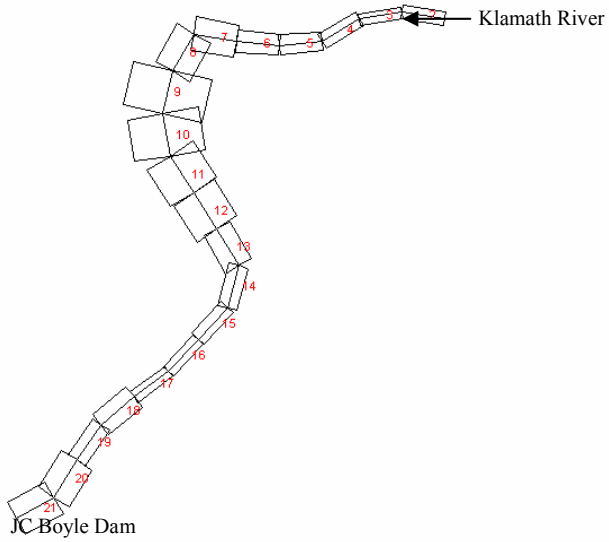

Figure 8. Representation of J.C. Boyle Reservoir in CE-QUAL-W2

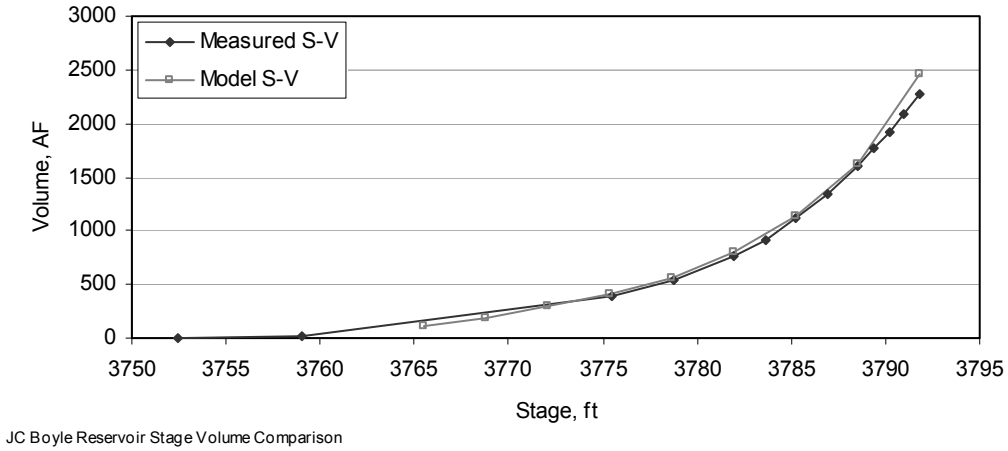

Figure 9. Comparison of Measured and Model Representation of J.C. Boyle Reservoir Stage-Volume (S-V) Relationships

3.2.5 J.C. Boyle Bypass and Peaking Reaches

The J.C. Boyle bypass and peaking reaches extend 20.8 miles from J.C. Boyle dam (RM 224) to the headwaters of Copco reservoir (RM 204). Noteworthy features of the reaches include diversion of mainstem flows at J.C. Boyle dam for hydropower production, the powerhouse penstock return marking the beginning of the peaking reach roughly 4 miles downstream from J.C. Boyle dam (RM 220), a large springs complex in the bypass reach, and hydropower peaking operations downstream of the powerhouse. A few small streams enter the reach, the most significant of which is Shovel Creek. The reaches are shown in Figure 10. Important locations within the bypass and peaking reaches are presented in Table 9. These reaches are modeled with the RMA models.

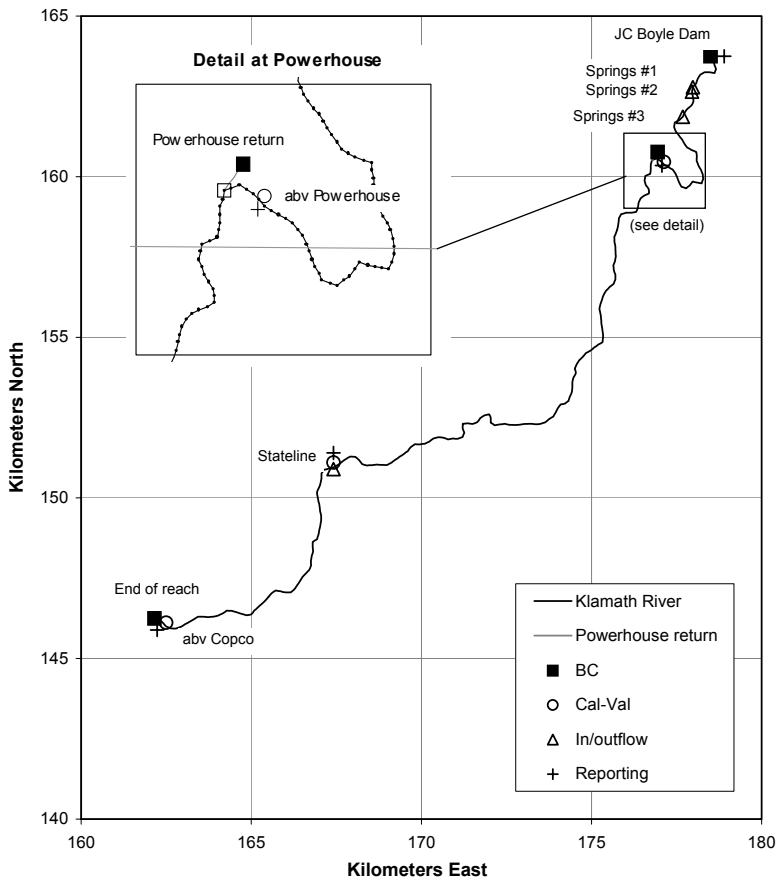

Figure 10. J.C. Boyle Bypass and Peaking Reach Representation

Table 9. Geometry Information for J.C. Boyle Bypass and Peaking Reach EC Simulation

Location	Node	Element	x-coord	y-coord	Site type
J.C. Boyle Dam	1	1	178.7	163.7	BC, upper
End Peaking reach	453	226	162.2	146.2	BC, lower
J.C. Boyle Powerhouse	95	48	176.9	160.8	BC
Simulated Powerhouse Return	97	49	176.8	160.5	Junction, inflow
1/4 mi abv Powerhouse	91	46	177.1	160.4	Cal-Val
1/4 mi abv Shovel Cr	389	195	166.3	147.2	Cal-Val
1/4 mi abv Copco	447	224	162.5	146.00	Cal-Val
CA-OR Stateline	331	166	167.4	151.1	Cal-Val, A/D
Springs #1	21	11	178.0	162.8	A/D
Springs #2	23	12	178.0	162.6	A/D
Springs #4	35	18	177.7	161.9	A/D

BC – boundary condition

A/D – accretion/depletion location

Cal-Val – calibration and validation location

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3.2.5.1 Bed Elevation/Slope

Bed slope for these reaches was estimated from USGS topographic maps and reported elevations at J.C. Boyle dam and Copco reservoir water surface elevations. Reach elevations range from approximately 2592 ft (790 m) MSL to 3760 ft (1146 m) MSL.

3.2.5.2 Cross-sections

J.C. Boyle bypass and peaking reach widths were obtained from habitat surveys completed by TRPA (PacifiCorp, 2004b). Measurements were completed at roughly eight locations per mile. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates of the model, field data were linearly interpolated to provide widths for cross-sections of the model. Extreme variations in measured widths were smoothed with a seven-times running average to produce estimates of bottom width. Using these estimates of bottom width, trapezoidal river cross-sections were constructed for each node of the reach at evenly spaced intervals of 75 meters, assuming 1:1 side slopes. Widths and other geometric characteristics of the bypass and peaking reaches are summarized in Table 10.

Table 10. J.C. Boyle Bypass and Peaking Reach Geometry Summary

Node spacing	75 meters
Number of nodes	459 nodes in length
Length	20.81 miles from RM 204.72-225.53
Elevations	Range: 790-1146 meters
Widths	Range: 12-66 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2M HILL; Elevations estimated from USGS topographic maps
Notes	1 junction: J.C.B Powerhouse; Nodes 97, 458, 459

3.2.6 Copco Reservoir

The Copco reservoir reach extends 5.0 miles from Copco reservoir headwaters (RM 204) downstream to Copco dam (RM 199). No tributaries are represented in this section of the model. Physical data for the Copco reservoir model are outlined below. This reach is modeled with CE-QUAL-W2.

3.2.6.1 Copco Dam Features

Copco dam has three primary outlets: a spillway and two penstocks that provide flows to the Copco No. 1 powerhouse. The two penstocks, fed by three intakes, are treated as a single outlet with an average centerline elevation of 2,581 feet. Details of these outlets are summarized in Table 11. Because of the close proximity and similar invert elevations, the outlet works were represented in the reservoir as a single withdrawal with a midline elevation of 2,581 ft (786.6 m).

Table 11. Copco Dam Outlet Features

Outlet	Invert Elevation	Dimension	Operation
Penstock Intake (Unit 1)	2575 ft	Two intakes @ 10-foot diameter each	Remote Operation
Penstock Intake (Unit 2)	2575 ft	14 foot diameter	Remote Operation
Spillway	2594 ft	3 radial gates @ 35 ft width each	Remote control on one gate, others by motorized hoist

Sources: PacifiCorp (2002), PacifiCorp (2000)

3.2.6.2 Reservoir Bathymetry

Copco reservoir geometry, shown in

Figure 11, was derived from bathymetric data of Copco reservoir (PacifiCorp, 2004a). Segment length, segment orientation, layer thickness and width were required for the reservoir model. Segments were identified based on changes in reservoir morphology and widths. The reservoir was divided into 17 active segments 1,329 ft (405.4 m) in length. Segments were chosen to capture both the general shape of Copco reservoir and pertinent features, such as the submerged features near the dam. Due to the large bedrock outcrop in the vicinity of the Copco dam, a submerged weir was implemented in the model from layer 20 to 32.

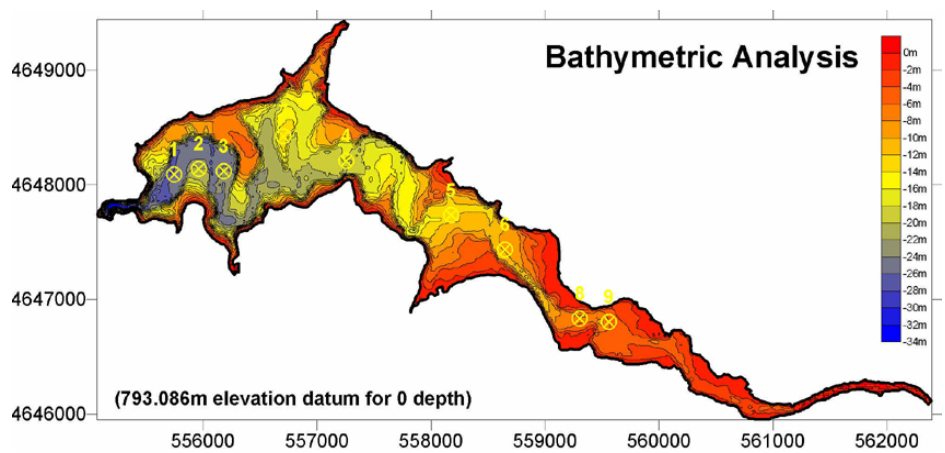

Figure 11. Copco Reservoir Bathymetry (PacifiCorp, 2004a)

Layer thickness was set to 3.28 ft (1.0 m). Layer widths were determined from cross-sectional information taken at the middle of each segment. Thirty-two active layers of varying widths were determined for each segment from this method. The 3.28 ft (1.0 m) layer thickness produced reasonable results and resulted in reasonable execution times. One-year simulation times were approximately 15 minutes. Final CE-QUAL-W2 representation of Copco reservoir is shown in Figure 12.

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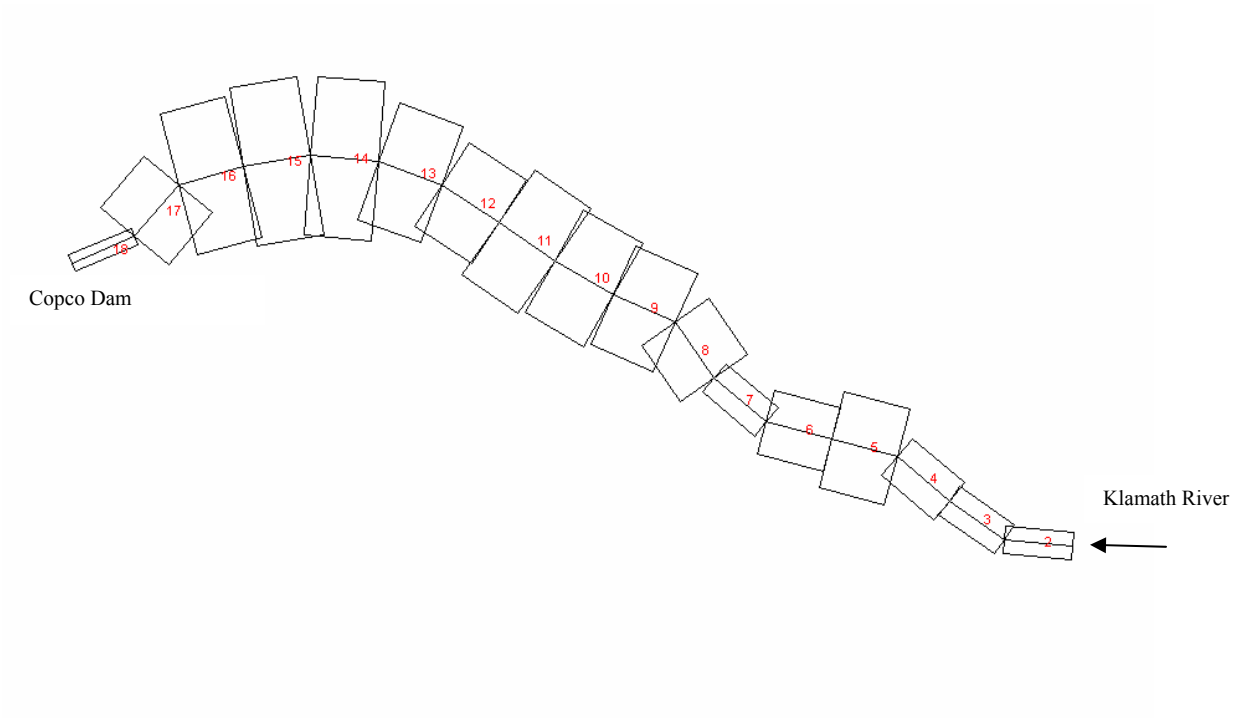

Figure 12. Representation of Copco Reservoir in CE-QUAL-W2

A stage-volume curve was generated by the model and compared to the measured stage-volume curve of the reservoir to ensure proper volume and storage representation. Modeled versus measured stage-volume relationships are compared in Figure 13.

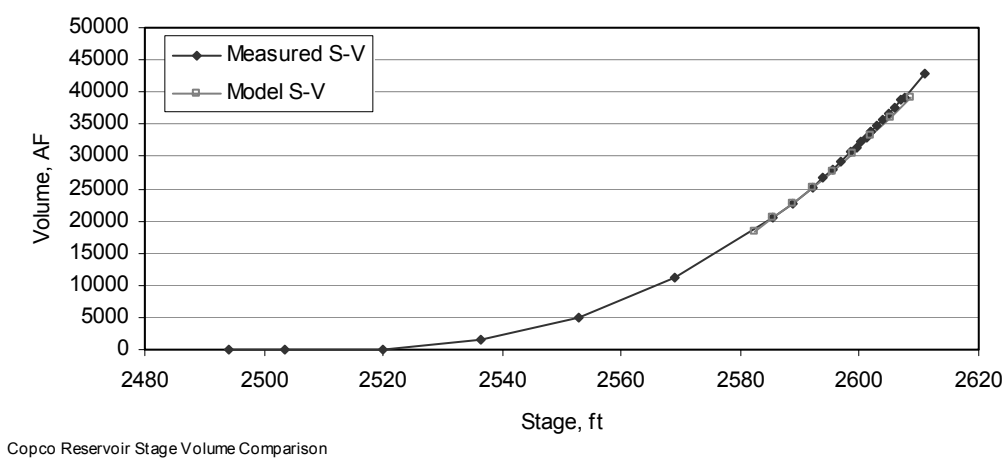

Figure 13. Comparison of Measured and Model Representation of Copco Reservoir Stage-Volume (S-V) Relationships

3.2.7 Iron Gate Reservoir

Iron Gate reservoir extends 6.4 miles from the headwaters of Iron Gate reservoir (RM 197) to Iron Gate dam (RM 190). Except in "Without Project" scenarios, the small Copco #2 Reservoir and short river reach between Copco and Iron Gate reservoirs are not represented in the model.

Instead, Copco reservoir runs directly into Iron Gate reservoir. Three tributaries to Iron Gate reservoir are represented in this CE-QUAL-W2 model: Camp Creek, Jenny Creek, and Fall Creek. The spillway for the dam is modeled as a withdrawal in the last active segment because the spillway structure draws water to the side of the dam, not over or through the dam itself. Due to its dendritic shape, Iron Gate reservoir is represented by two branches, including a main branch that receives water released from Copco Reservoir and a Camp Creek branch that represents a sizeable arm of the reservoir running up to Camp Creek. Geometry of the reservoir is outlined below.

3.2.7.1 Iron Gate Dam Features

Iron Gate dam has four primary outlets: a spillway, a penstock, and two outlets that supply fish hatchery intakes. The details of these outlets are summarized in Table 12.

Table 12. Iron Gate Dam Outlet Features

Outlet	Invert Elevation	Dimension	Operation
Upper Fish Hatchery	2293 ft	24 inch diameter	Manual
Penstock Intake	2309 ft	12 foot diameter	Remote operation
Lower Fish Hatchery	2253 ft	24 inch diameter	Manual
Spillway	2328 ft	Side channel (727 feet in length)	Overflow

Sources: PacifiCorp (2002), PacifiCorp (2000)

3.2.7.2 Reservoir Bathymetry

Reservoir geometry was derived from bathymetric data of Iron Gate reservoir (PacifiCorp, 2004a). Reservoir bathymetry is depicted in Figure 14. Segments were laid out on the basis of changes in reservoir orientation and width. The main branch, Branch 1, has 30 active segments and the Camp Creek Branch, Branch 2, has five active segments. Segment lengths were 1,204 ft (367 m), with the exception of the narrows near the upper end of the reservoir, where half element lengths were used. Branch 2 has an external upstream boundary (Camp Creek) and connects with Branch 1, Segment 23. A schematic of model layout is presented in Figure 15, showing model segments and tributary flows.

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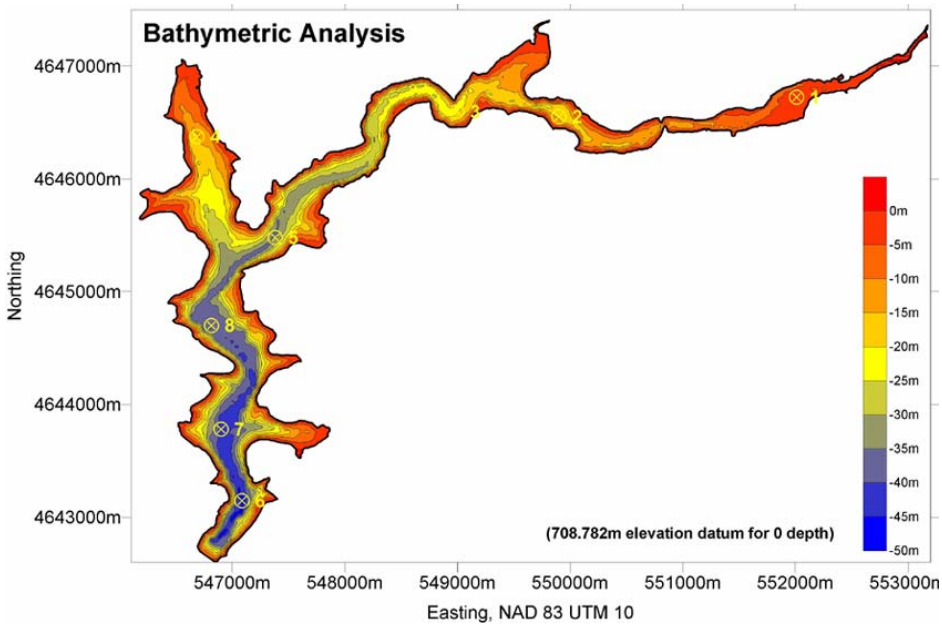

Figure 14. Iron Gate Bathymetry (PacifiCorp, 2004a)

Based on cross-sectional information from the mid-point of each segment, Iron Gate Reservoir is represented by 50 active layers, each 3.28 ft (1 m) in thickness. Modeled and measured stage-volume curves are compared in Figure 16.

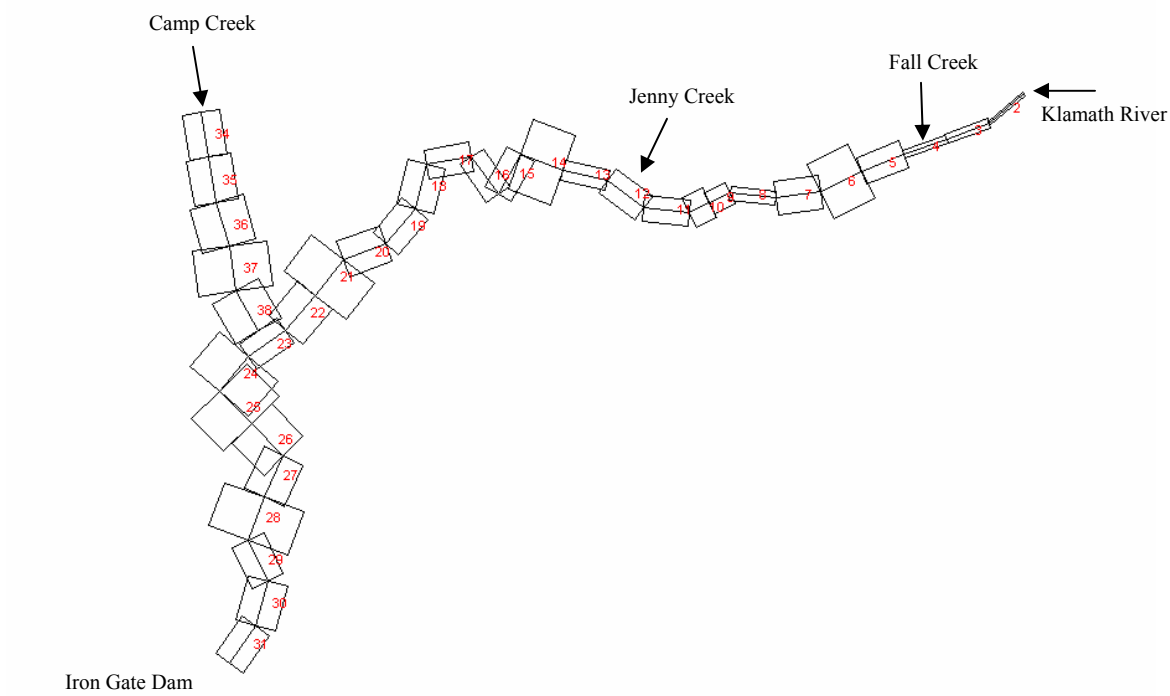

Figure 15. Representation of Iron Gate Reservoir for CE-QUAL-W2

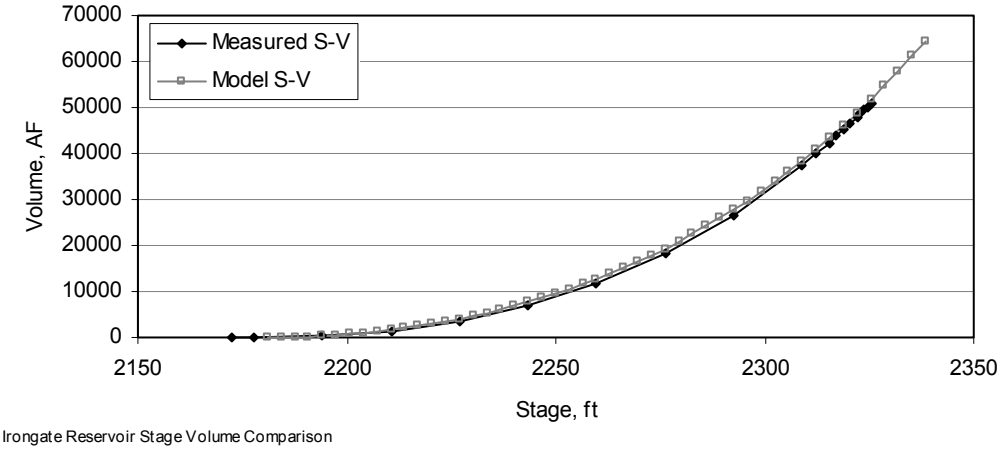

Figure 16. Comparison of Measured and Model Representation of Iron Gate Reservoir Stage-Volume (S-V) Relationships

3.2.8 Iron Gate to Turwar Reach

The Iron Gate dam to Turwar reach extends 185 miles from Iron Gate dam (RM 190) to Turwar near the mouth of the Klamath River (RM 5). Several main tributaries flow into the reach: Shasta River, Scott River, Salmon River, and Trinity River. Many smaller creeks contribute significant flow to the river along this reach and these creeks are also included in the simulation. Geometry of this reach is outlined below.

3.2.8.1 Map Coordinates

X-y coordinates describing the course of the river were taken from a digitized version of the 1:24,000 USGS topographic quadrangles, as discussed in Appendix B. This information was translated into a series of nodes and elements for use by the numerical model. The model network is shown with simulated tributaries in Figure 17. Important locations within the reach, including tributaries and output locations, are presented in Table 13. Nodal spacing for the numerical grid was roughly 490 feet (150 meters). Sensitivity analyses showed model results to be relatively insensitive to a reduction in grid spacing.

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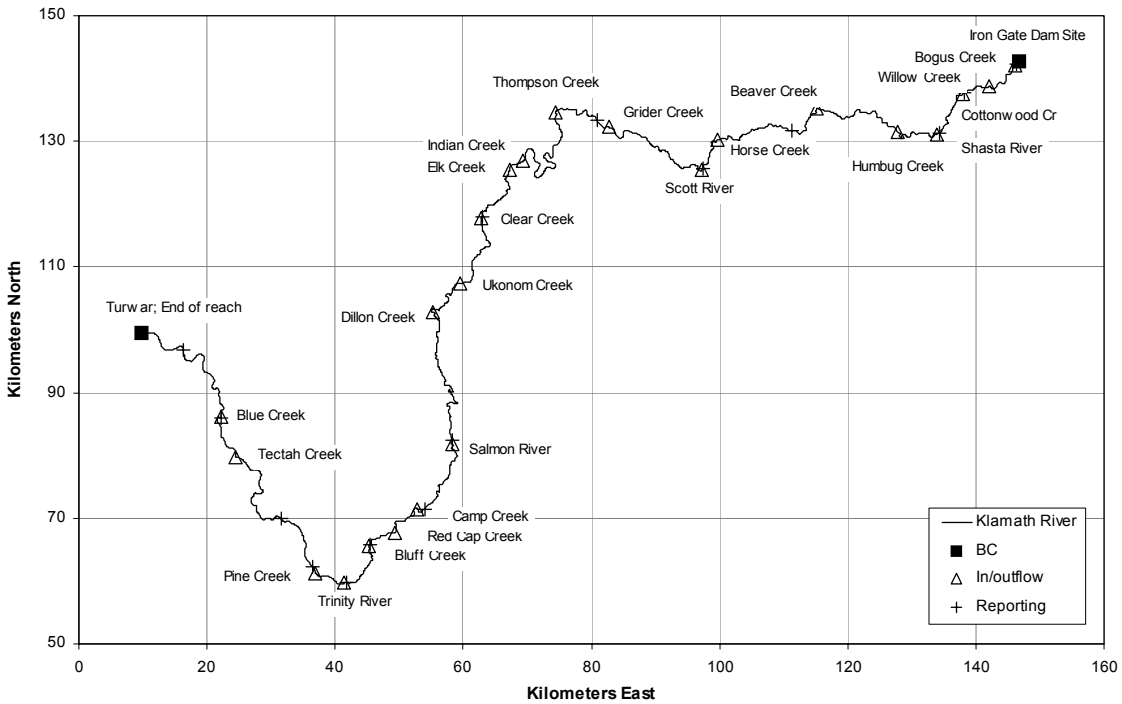

Figure 17. Iron Gate Dam to Turwar Reach Representation Showing Tributary Names

Table 13. Geometry Information for the IG-Turwar reach (150-meter grid)

Location	Node	Element	x-coord	y-coord	Site Type
Iron Gate Dam	1	1	146.747	142.634	BC, upper
End IG-Turwar reach	2081	1040	9.821	99.506	BC, lower
Bogus Creek	7	4	146.141	142.022	A/D
Willow Creek	55	28	142.035	138.739	A/D
Cottonwood Creek	86	43	137.904	137.535	A/D
Shasta River	144	72	133.963	131.178	A/D
Humbug Creek	204	102	127.848	131.402	A/D
Beaver Creek	319	160	115.190	135.232	A/D
Horse Creek	468	234	99.597	130.180	A/D
Scott River	513	257	97.299	125.428	A/D
Grider Creek (A/D Scott to Seiad)	656	328	82.714	132.246	A/D
Thompson Creek	735	368	74.440	134.626	A/D
Indian Creek	906	453	69.371	126.831	A/D
Elk Creek	925	463	67.209	125.507	A/D
Clear Creek	1000	500	62.733	117.818	A/D
Ukonom Creek	1098	549	59.559	107.347	A/D
Dillon Creek	1162	581	55.209	102.905	A/D
Salmon River	1357	679	58.333	81.788	A/D
Camp Creek	1466	733	52.865	71.474	A/D
Red Cap Creek	1511	756	49.403	67.773	A/D
Bluff Creek	1547	774	45.339	65.584	A/D
Trinity River	1609	805	41.415	59.672	A/D

Table 13. Geometry Information for the IG-Turwar reach (150-meter grid)

Location	Node	Element	x-coord	y-coord	Site Type
Pine Creek	1644	822	36.954	61.269	A/D
Tectah Creek	1850	925	24.557	79.833	A/D
Blue Creek	1908	954	22.306	86.220	A/D
1/4 mi bl Iron Gate	4	2	146.419	142.345	reporting
1/4 mi ab Cottonwood	84	42	138.117	137.743	reporting
1/4 mi ab Shasta	142	71	134.262	131.198	reporting
Walker Bridge	369	185	111.329	131.759	reporting
1/4 mi ab Scott	511	256	97.348	125.720	reporting
USGS Gage at Seiad Valley	672	336	80.887	133.289	reporting
1/4 mi ab Clear Cr.	998	499	62.908	118.058	reporting
1/2 mi ab Salmon (Ishi Pishi)	1352	676	58.231	82.372	reporting
USGS Gage at Orleans	1454	727	54.016	71.457	reporting
1/4 mi ab Bluff Cr.	1545	773	45.357	65.876	reporting
1/4 mi ab Trinity	1607	804	41.692	59.692	reporting
Martin's Ferry	1651	826	36.505	62.187	reporting
Young's Bar	1722	861	31.541	69.894	reporting
1/4 mi ab Blue Cr.	1906	953	22.177	85.992	reporting
USGS Gage nr Turwar	2024	1012	16.341	96.868	reporting

3.2.8.2 River Bed Elevation

Bottom elevations along the reach were estimated from USGS topographic maps and reported elevations at Iron Gate dam. These elevations determined bed slope. Reach elevations range from approximately sea level to roughly 2200 ft (671 m) MSL.

3.2.8.3 Cross-sections

Klamath River widths for the Iron Gate dam to Turwar reach were estimated from meso-habitat surveys compiled by US Fish and Wildlife Service (1997). This dataset included a reach-by-reach description of 1,741 units, or sections of the river, by habitat type, width, and maximum depth. Measurements were not uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were linearly interpolated to produce widths for model cross-sections. Large variations in river width were smoothed with a seven-point running average to provide estimates of bottom width for the model. From these estimated bottom widths, trapezoidal cross-sections were constructed at each node assuming 1:1 side slopes. Widths and other geometric characteristics for the Iron Gate to Turwar reach are summarized in Table 14.

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Table 14. Klamath River, Iron Gate Dam to Turwar Reach Geometry Summary

Node spacing	150 meters
Number of nodes	2082 nodes in length
Length	190.54 miles from RM 0.00-190.54
Elevations	Range: 0-671 meters
Widths	Range: 17-340 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2M HILL; Elevations estimated from USGS topographic maps
Notes	n/a

3.3 BOUNDARY CONDITIONS

Boundary conditions, often called "forcing functions," describe the changing state of flow, water quality, and meteorology along the boundaries of a modeling system. These conditions are applied at each time step and along each river and reservoir reach of the model. In the case of the Klamath River model used in this study, most boundary conditions are discrete field observations or values derived directly from discrete observations. To provide a downstream boundary condition, outflow is typically described for each river reach by a stage-flow relationship derived from the Manning's Equation and cross-sectional areas.

To take advantage of the relative strengths of the RMA and CE-QUAL-W2 models, the set of linked river and reservoir models in this study used RMA for river reaches and CE-QUAL-W2 for reservoir reaches. Time-steps through river reaches were constant at 1 hour (except for a 15-minute time-step used in solution of J.C. Boyle bypass and peaking reach hydrodynamics). CE-QUAL-W2 uses a variable time-step solution technique, so time-steps for reservoir reaches varied. Time-steps through reservoirs were typically sub-hourly (e.g., minutes), but simulation results were reported at 1-hour intervals to match the resolution of river reaches. The various reaches of the system are linked by passing flow and water quality downstream from one reach to the next. A reach-by-reach overview of inflows to, and outflows from, the entire Klamath River system is presented in this section. Detailed flow and water quality boundary conditions are presented by location and year in Appendix C.

3.3.1 Flow

Models of each reach, "sub-models" of the Klamath River model, are run separately in series. Beginning at the upstream end of the system, Link River, and progressing downstream to the Iron Gate to Turwar reach, the sub-models are typically run to simulate one year of boundary conditions at a time. A typical simulation begins with the simulation of one year of flow and water quality in the Link River reach. That year's simulated outflow and water quality from the Link River reach is passed as inflow to the Lake Ewauna to Keno reach, which is then run for the same year and produces inflow for the Keno River reach. Flows and water quality are passed so on downstream, until the entire river has been simulated for the year being studied.

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3.3.1.1 Link River Reach

Link River carries water from Upper Klamath Lake to Lake Ewauna, 1.3 miles downstream. Some flow enters Link River as release from the dam, but a significant amount of flow is diverted through two powerhouse diversions and released into the river downstream of the dam. One diversion takes water along the west side of the river through a canal and short penstock to the Westside powerhouse and the other takes water along the east side of the river to the Eastside powerhouse. The Eastside powerhouse delivers water to the river above both USGS Gage 11507500 (Link River at Klamath Falls, OR) and the Westside powerhouse return that enters downstream of the USGS Gage. See Figure 2 for a schematic of the river.

Flow entering the reach at the upstream-most element (Link dam) is called Link Bypass flow and is reported by USBR. Eastside turbine flows were calculated as the difference between the Link River USGS Gage 11507500 and Link Bypass flow. Westside turbine flow is reported by PacifiCorp.

As with all river reaches, a stage-discharge relationship defines the downstream flow boundary condition for Link River. This relationship was derived from application of Manning's Equation and cross-sectional channel geometry at the end of the reach. Stage-discharge at the outflow of this reach is described by the power equation:

$$Q = 22.28y^{2.29} \tag{3.1}$$

3.3.1.2 Lake Ewauna to Keno Dam Reach

Upstream inflow to the Lake Ewauna to Keno dam reach is assumed equal to Link River simulated outflow. Along the course of this reach, there are a number of tributary inflows and withdrawals. To match historic water surface elevations in the reservoir, a mass balance on measured flows and reservoir volume is used to calculate unquantified accretions and depletions. This accretion/depletion flow is distributed among the four irrigation diversion sites in the reach. Each inflow to, and withdrawal from, the reach is discussed below.

<u>Stormwater Runoff</u>

Stormwater runoff inflow to the reach was defined as a function of precipitation based on storm-water flows specified in an earlier simulation of this reach for calendar year 1992 conditions by ODEQ (1995). Stormwater inflow estimated for this simulation was compared to 1992 rainfall data recorded at the nearby KFLO meteorological station. Linear regression describes a strong relationship ($r^2 = 1.0$) between runoff and precipitation:

$$SWRO = 12.129 \times R \tag{3.2}$$

where:

SWRO = total stormwater runoff, cms
R = precipitation, inches

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In the earlier simulation by ODEQ (1995), total runoff was unevenly distributed among 11 locations in the reach and distribution varied with each rainfall event. Using estimates from this earlier study, the fraction of total annual runoff assigned to each site was calculated to produce an annual runoff factor. Total stormwater runoff was calculated daily using local precipitation data and Equation 3.2, and this total was then distributed among the same 11 sites using the annual runoff factors derived from the ODEQ (1995) simulation.

Columbia Plywood

An average monthly flow for Columbia Plywood discharge was estimated from maximum monthly flows reported to ODEQ. Average monthly flow for calendar year 2000-2004 was assumed constant at 0.01 cfs (0.0004 cms) throughout the year.

Klamath Falls Water Treatment Plant

Daily flows for the Klamath Falls Wastewater Treatment Plant (KFWWTP) were reported in monthly monitoring reports submitted to ODEQ. These flows are typically variable, ranging from 4 to 12 cfs, with less variability in the summer months. Flow records were available for 2000 and 2001. Flow data from 2000 were assumed for 2002-2004.

South Suburban Sanitation District

Daily flows from South Suburban Sanitation District were derived from flows reported five times a week in monthly monitoring reports submitted to ODEQ. Because plant discharges varied little from day to day and were relatively small, these data were averaged monthly and these average monthly flows were used as boundary flows to the model. Monthly average flows typically range from a little over 2 cfs to just over 4 cfs. Flow records were available for 2000 and 2001. Flow data from 2000 were assumed for 2002-2004.

Collins Forest Products #1 and #2

Daily inflow from Collins Forest Products discharge #1 and #2 was reported in monthly monitoring reports submitted to ODEQ. These flows, averaging about 1.4 cfs and 0.1 cfs for discharge #1 and #2, respectively, were input directly to the model. Flow records were available for 2000 and 2001. Flow data from 2000 were assumed for 2002-2004.

Lost River Diversion Channel

Daily inflows into Lake Ewauna from the Lost River Diversion Channel are gauged by USBR. USBR records describe both Lost River discharge to, and withdrawal from, Lake Ewauna to Keno Reach. For diversion from Lake Ewauna to Keno reach see the withdrawal section below.

Klamath Straits Drain

Inflow to Lake Ewauna from Klamath Straits Drain is gauged by USBR. Daily flows range from a minimum of 0.0 to a maximum of nearly 350 cfs, depending on season. High monthly variability occurs between February and September. Flows used in the simulations were taken directly from recorded information.

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Klamath Reclamation Project Diversions

There are three withdrawals within Lake Ewauna for the Klamath Reclamation Project: Lost River, North Canal and ADY Canal. All three withdrawals are gauged daily by USBR. Lost River withdrawals range dramatically in summer months to a maximum of over 600 cfs. North Canal withdrawals are less variable and peak in summer and winter months at about 150 to 200 cfs. ADY Canal withdrawals follow the same pattern as those at North Canal but are of greater magnitude, reaching maxima of 400 to 500 cfs.

Non-Reclamation Irrigation Diversions

Due to a lack of available records describing non-USBR irrigation, daily withdrawal rates estimated in the previous simulation (ODEQ 1995) were applied for all simulation years. The irrigation season was assumed to extend from May 30 to September 30 (JD 152-274). Withdrawals peaked at a steady 60 cfs for Irrigator #7 and at a steady 14 cfs for Irrigators #2, #3, and #4. Outside the irrigation season, withdrawals were assumed to be zero for all four irrigators.

Accretion/Depletion

Net ungaged accretions and depletions from the system were determined using a water balance based on measured flows and the change in storage recorded at Keno dam (provided by PacifiCorp). This accretion/depletion was evenly distributed proportionally among the four irrigation withdrawal points.

Keno Dam Outflow

Hourly releases from Keno dam were taken from data recorded at USGS Gage 11509500 (Klamath River near Keno, Oregon). Outflow from the dam ranged from a maximum of over 4,000 cfs in spring to a minimum of under 500 cfs in summer.

3.3.1.3 Keno River Reach

The Keno River reach receives flow directly from Keno dam. No appreciable tributary contributions or diversions have been identified for this relatively short reach and accretions/depletions between Keno dam and J.C. Boyle dam were assigned to the J.C. Boyle reservoir reach.

A stage-discharge relationship defines the downstream flow boundary condition for Keno River reach. This relationship was derived from application of Manning's Equation and cross-sectional channel geometry at the end of the reach. Stage-discharge at the outflow of this reach is described by the power equation:

$$Q = 20.23y^{1.66} \tag{3.3}$$

3.3.1.4 J.C. Boyle Reservoir Reach

J.C. Boyle reservoir receives inflow directly from the Keno River reach. Because tributary flow records are limited, accretion/depletion flows for the reservoir were calculated and located at

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Spencer Creek. Net reservoir accretion/depletion was calculated as the difference between daily average outflow and inflow, assuming constant water surface elevation.

Outflow from J.C. Boyle reservoir was calculated as the sum of recorded releases to the powerhouse canal, spill from the dam, bypass releases, and fish ladder releases. Hourly power canal flows and spill were taken from PacifiCorp records. Fish ladder and bypass releases were assumed constant at 80 cfs and 20 cfs, respectively.

3.3.1.5 J.C. Boyle Bypass and Peaking Reach

The J.C. Boyle bypass reach receives releases directly from J.C. Boyle dam (J.C. Boyle bypass flow), and ungaged inflow from a number of springs upstream of the powerhouse. The peaking reach receives inflow from the bypass reach and the J.C. Boyle powerhouse tailrace (peaking flow). Bypass and peaking flows are derived from measured J.C. Boyle dam releases as reported by PacifiCorp. The springs are represented by three separate inflows, each constant at 75 cfs (2.12 cms). Total spring inflow was 225 cfs (6.36 cms) for the duration of each simulation. Accretion/depletion for the J.C. Boyle bypass reach is accommodated in spring flow. Accretion/depletion for the peaking reach was calculated using a water balance between the USGS gage for the Klamath River below J.C. Boyle powerhouse and outflow from Copco dam, accounting for storage change in Copco reservoir. This accretion/depletion is evenly partitioned to the river and reservoir, with 50 percent applied to the J.C. Boyle peaking reach and 50 percent applied to Copco reservoir. Accretion/depletion for the peaking reach was placed at Stateline, to represent the ungaged inflows and diversions for agriculture that occur in the vicinity.

A stage-discharge relationship defines the downstream flow boundary condition for J.C. Boyle bypass and peaking reach. This relationship was derived from application of Manning's Equation and cross-sectional channel geometry at the end of the reach. Stage-discharge at the outflow of this reach is described by the power equation:

$$Q = 29.27 y^{1.70} \tag{3.4}$$

3.3.1.6 Copco Reservoir Reach

Copco reservoir receives flow directly from the J.C. Boyle bypass and peaking reach. Hourly accretion/depletion for the reach was calculated from a water balance using gauged flows in the peaking reach upstream, Copco dam outflow, and daily change in reservoir storage (as described for the J.C. Boyle peaking reach above) and added to headwater inflow. As with J.C. Boyle reservoir, final accretion/depletion values were determined using the CE-QUAL-W2 water-balance utility "waterbalance.exe."

PacifiCorp reports hourly outflow from the dam to both the Copco powerhouse and spillway. Because intakes to the powerhouses have similar centerline elevations, the two powerhouse units were treated as a single outlet in simulations.

3.3.1.7 Iron Gate Reservoir Reach

Iron Gate reservoir receives flow directly from Copco dam. Sometimes during hydropower operations, release flows are immeasurably small. During these periods, a minimum flow of 0.035 cfs (0.001 cms) was assumed.

Accretion/depletion was calculated to complete a daily water balance as the difference between daily outflow and the sum of inflow and change in reservoir storage.

Records of tributary flow into Iron Gate reservoir (from Camp, Jenny, and Fall Creeks) are limited and insufficient for modeling. Therefore, accretion/depletion was placed at Jenny Creek, the source of greatest actual inflow, and flows for both Camp and Fall Creeks were set to very low values or zero. Camp Creek, represented as a branch of the model, was assigned a flow of 0.0035 cfs (0.0001 cms) for the entire year. Fall Creek inflow was set to zero. As with J.C. Boyle and Copco reservoirs, final accretion/depletion values were determined using the CE-QUAL-W2 water-balance utility "waterbalance.exe."

Powerhouse release and spill from Iron Gate reservoir was determined from PacifiCorp daily flow records. A constant additional flow of 50 cfs (1.42 cms) was assumed for lower fish hatchery releases. Upper fish hatchery releases were assumed zero.

3.3.1.8 Iron Gate to Turwar Reach

The Iron Gate dam to Turwar reach receives inflow directly from Iron Gate dam. Between Iron Gate dam and Turwar, the model accepts inflow from 23 tributary stream and rivers.

Five major tributaries to this reach are actively gauged, including the Shasta, Scott, Salmon, and Trinity Rivers, and Indian Creek. Inflows for minor tributaries were defined and quantified as daily accretion/depletions based on methods described by USGS (1995). Details of USGS methodology are included in Appendix D. The Scott and Trinity Rivers were assigned both USGS gauged flows and daily accretion/depletions. Model node and element numbers, and type of flow record employed for each tributary are summarized in Table 15.

Table 15. Element Flow Information for the IG-Turwar EC Simulation

Location	Node	Element	Flow Type
Bogus Creek	7	4	7 day average
Willow Creek	55	28	7 day average
Cottonwood Creek	86	43	7 day average
Shasta River	144	72	Daily measured
Humbug Creek	204	102	7 day average
Beaver Creek	319	160	7 day average
Horse Creek	468	234	7 day average
Scott River	513	257	Daily measured + A/D Ft. Jones to Klamath
Grider Creek	656	328	7 day average (A/D Scott to Seiad)
Thompson Creek	735	368	7 day average
Indian Creek	906	453	Daily measured
Elk Creek	925	463	7 day average

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Table 15. Element Flow Information for the IG-Turwar EC Simulation

Location	Node	Element	Flow Type
Clear Creek	1000	500	7 day average
Ukonom Creek	1098	549	7 day average
Dillon Creek	1162	581	7 day average
Salmon River	1357	679	Daily measured
Camp Creek	1466	733	7 day average
Red Cap Creek	1511	756	7 day average
Bluff Creek	1547	774	7 day average
Trinity River	1609	805	Daily measured + A/D Hoopa to Klamath
Pine Creek	1644	822	7 day average
Tectah Creek	1850	925	7 day average
Blue Creek	1908	954	7 day average

Shasta River daily flows were taken from USGS Gage 11517500 (Shasta River near Yreka). Scott River daily flows were calculated from USGS Gage 11519500 (Scott River near Ft Jones) and accretion/depletions calculated per USGS (see Appendix D). Daily Indian Creek flows were taken from USGS Gage 11521500 (Indian Creek near Happy Camp). Salmon River daily flows were from USGS Gage 11522500 (Salmon River at Somes Bar). Trinity River daily flows were calculated from USGS Gage 11530000 (Trinity River at Hoopa) and accretion/depletions calculated per USGS (see Appendix D).

A stage-discharge relationship defines the downstream flow boundary condition for the Iron Gate to Turwar reach. This relationship was derived from application of Manning's Equation and cross-sectional channel geometry at the end of the reach. Stage-discharge at the outflow of this reach is described by the power equation:

$$Q = 266.83y^{1.67} \tag{3.5}$$

3.3.2 Water Quality

Water quality boundary conditions required for the Klamath River model include water temperature, dissolved oxygen, organic matter, nutrients, and algae. Others constituents may be simulated by one or the other of the numerical models that comprise the Klamath River model, but these other constituents are not common to the models used and are not discussed in detail here. Each model represents organic matter a little differently, so in passing organic matter from one model to the next a few simplifying assumptions are made. A description of the process used to pass simulation results from one model to the next is included in this section. The remainder of the section presents an overview of water quality boundary conditions for each inflow to the Klamath River model for the five years of simulations (2000–2004).

3.3.2.1 Model Linkage

As described for flow (in section 3.3.1), water quality is passed at each boundary between reaches. Both CE-QUAL-W2 and RMA11 model the same core set of water quality constituents, including water temperature, DO, BOD, NH3, NO3, PO4, and phytoplankton algae. These

constituents are passed directly from one model to the next. Values for other constituents are either assumed or derived.

Organic matter (OM) is an important water quality constituent that is represented by both models, but it is represented a little differently in each. For this application to the Klamath River, Watercourse Engineering modified the RMA-11 code so that OM is analogous to labile organic matter (LDOM and LPOM) in CE-QUAL-W2. The only difference is that both particulate and dissolved forms of labile organic matter are modeled as one in the new RMA-11. In the most current Watercourse version of RMA-11, there is no refractory organic matter (RDOM and RPOM in CE-QUAL-W2) and concentrations of these partitions are assumed to be zero. In transferring results from rivers to reservoirs, riverine OM is assumed to be partitioned 20 percent dissolved and 80 percent particulate, based on the ratio of dissolved and particulate OM that results from algae mortality as reported by Cole and Wells (2002)

The CE-QUAL-W2 reservoir models are set up to simulate residence time (AGE), iron (FE), coliform bacteria (COL1), and suspended solids (ISS1). These constituents are not explicitly simulated in the river reaches. Thus, headwater inflow values of these state variables are set to constants, as presented in Table 16, for all reservoirs. In this fashion AGE provides residence time for each reservoir. Iron, coliform, and suspended solids are not used in these analyses. RMA-11 simulated the entire nitrification process (conversion of ammonia to nitrite to nitrate), while CE-QUAL-W2 combines the two intermediate steps and represents the conversion from ammonia to nitrate. Thus, nitrite is not explicitly included in CE-QUAL-W2, but the oxygen demand of nitrification is effectively represented. Because nitrite levels are very low in the RMA-11 simulations, they are assumed negligible in all cases.

Table 16. Constant Water Quality Concentrations for Headwater Inflow to CE-QUAL-W2 Reservoirs

Variable	Description, units	Inflow value
TDS	Total dissolved solids (mg/L)	100
AGE	Residence time (days)	0
TIC	Total inorganic carbon (mg/L)	0
ALK	Alkalinity (mg/L)	25
FE	Iron (mg/L)	0
COL1	Coliform bacteria (MPN/100 mL)	15
ISS1	Suspended solids (mg/L)	60

3.3.2.2 Link River Reach

Water quality data for the Link River reach was derived from multiple sources. Grab samples collected by the Klamath Tribes at Fremont Bridge from 1994 to 2004 were used to describe seasonal water quality conditions at the upstream boundary of the reach. The Eastside and Westside turbines were assumed to have the same water source as the flows at Link dam (the upstream boundary) because of the short distance of this reach. Therefore, the same water quality was used for all three water sources in the Link River reach. Data sources for Link River water quality boundary conditions are outlined in Table 17.

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Table 17. Data Sources for Boundary Conditions to the Link River Reach

Data	Source	Type
Temperature	U.S. Bureau of Reclamation	Hourly, seasonal estimates
Dissolved Oxygen	U.S. Bureau of Reclamation	Hourly, seasonal estimates
Water quality parameters[1]	Klamath Tribes	Seasonal estimates

[1] Water quality parameters include pH, conductivity, total phosphorus, orthophosphates, total nitrogen, nitrate + nitrite, ammonia, chlorophyll-a and phaeophytin.

Temperature: Records of water temperatures reported from USBR monitoring near Link dam (at A-Canal) during 2000-2004 were used to construct a composite of hourly inflow temperatures for the Link River.

Dissolved Oxygen: Very little field data are available for 2000 and 2001 to describe Link dam DO. Therefore, DO was assumed to be at saturation level, and saturation concentrations were calculated from the composite temperature record. After 2001, data from water quality probes deployed by USBR were used to describe the DO boundary condition.

BOD and Organic Matter (OM): BOD concentrations were estimated for 2000 and 2001 from data collected during a 2002 sampling program completed by USBR. For 2000 and 2001, a baseline BOD concentration of 2 mg/l as background was used from November through April. This level of BOD was ramped up to 10 mg/l for the summer period (June through August). The remaining BOD was assigned to the OM compartment of the model. Available data from 2002-2004 were used to create a boundary condition for BOD and OM; however, in this case, BOD was converted to OM and BOD was not applied. The general outcome among the simulations is similar because BOD and OM are treated similarly.

Nutrients and Algae: Water quality boundary conditions for the Link River were calculated from Upper Klamath Lake grab samples collected by the Klamath Tribes from 1994-2004 at the Fremont Bridge (Kann, 2001). Fremont Bridge was selected because of its proximity to Link dam.

Between 1994 and 2004 over 70 grab samples were taken at multiple depths and analyzed for nutrient concentrations. Because there were insufficient samples in 2000 to identify a boundary condition for the Link River reach, a composite of all data was used to create monthly average concentrations that represented general seasonal conditions. Comparison of field data suggested that conditions in the Fremont Bridge area were generally well mixed (i.e., minimal vertical variation for the selected water quality constituents). Therefore, samples from all depths were used in the determination of monthly average concentrations. For 2001-2004 estimated of nutrient concentrations at Link dam were made based on USBR, PacifiCorp, and Klamath Tribes data.

3.3.2.3 Lake Ewauna to Keno Reach

Inflow locations, data sources, and data and model resolution are summarized in Table 18, followed by descriptions of each data set.

Table 18. Temperature Data for Inflow Locations, Including Data Source, and Data and Model Resolution

Location	Source	Data Resolution	Model Input Resolution
Link River	USBR	Hourly, other	Hourly, other [a]
Distributed tributary	Estimated	n/a	Annual
Stormwater	Estimated	n/a	Annual
Columbia Plywood	ODEQ	Monthly	Monthly
KFWTP	ODEQ/estimated	Daily	Daily
South Suburban Sanitation District	ODEQ	Daily	Monthly
Collins Forest Products #1, 2	ODEQ	Daily	Daily
Lost River	USBR	Semi-monthly	Semi-monthly
Klamath Straits Drain	USBR	Hourly	Daily, other [a]

[a] Hourly data was not available for all periods.

Headwater inflow: Water quality of headwater inflow to the Lake Ewauna to Keno reach is taken directly from output from the Link River reach.

Accretion/Depletion: Accretions and depletions to the Lake Ewauna reach were assumed to represent groundwater exchange within the reach. A constant inflow temperature of 12.0°C was assumed for all simulation years.

Other accretion/depletion constituent concentrations were taken from the 1992 Wells simulation (ODEQ, 1995). Wells' simulation covered only part of the calendar year, from JD 152 to JD 274. Prior to JD 152, concentrations were assumed to be equal to concentrations on JD 152. After JD 274, concentrations were assumed to be equal to those on JD 274.

Stormwater runoff: Stormwater runoff water quality from the previous ODEQ (1995) simulation was used in the simulations for this study. These concentrations were constant for each constituent throughout entire year.

Columbia Plywood: Monthly temperatures reported by Columbia Plywood to ODEQ were used as model input. These temperatures range from 13.3°C in winter to 21.1°C in summer.

Monitoring reports generally provide average monthly pH, biological oxygen demand (BOD) and total suspended solids (TSS). Results for a single sample were reported for 2000 (December) and eight samples were taken in 2001. An average of the nine concentrations reported from December 2000 through December 2001 was used to represent a constant annual input value of 8 mg/L of BOD and 16 mg/L TSS. Values for other water quality parameters were taken from the previous simulation (ODEQ, 1995). ODEQ data from 2000 and 2001 were assumed, with 2000 being applied for 2002-2004.

Klamath Falls Wastewater Treatment Plant (KFWTP): The treatment plant began reporting effluent water temperature in July 2001. To estimate effluent temperatures prior to this date, a

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simple linear regression ($r^2 = 0.89$) was used to describe daily effluent (°C) as a function of daily influent water temperature (°C):

$$T_{effluent} = 0.8952(T_{influent}) + 2.653 \quad (3.6)$$

The regression was based on data from July 2001 through February 2002. Resulting temperatures for 2000 range from a low of about 15°C to a high of about 23°C with a brief spike in late summer of over 25°C.

Constituent concentrations for KFWTP were based on monthly ODEQ reports and the previous ODEQ (1995) simulation. Both dissolved oxygen and suspended solids were reported and showed little day-to-day variation, so monthly average values were calculated for model input. Monthly BOD concentrations were estimated from samples collected at biweekly intervals based on ODEQ reports. All other data are monthly estimates based on the previous ODEQ (1995) simulation. ODEQ data from 2000 and 2001 were assumed, with 2000 being applied for 2002-2004.

South Suburban Sanitation District: Average monthly water temperatures for South Suburban Sanitation District effluent were calculated from data gathered five times a week and reported in monthly monitoring reports submitted to ODEQ. These temperatures range from 2.5°C in winter to below 21°C in summer.

South Suburban Sanitation District also reports DO, BOD, total suspended solids (TSS), total phosphorus, ammonia, nitrate, and pH to ODEQ. The frequency of reporting varied for each parameter, with DO and pH reported five times a week, BOD and TSS reported twice a week, and all nutrients reported once a month. For use in this model, all data were converted to monthly averages. Orthophosphate was estimated as 50 percent of total phosphorous concentrations because no data were available. Temperature and pH were used to estimate monthly average values for alkalinity and total inorganic carbon (Snoeyink and Jenkins, 1980). Total dissolved solids (TDS) were estimated to be 200 mg/L, the same as in the previous ODEQ (1995) simulation. Several parameters were set to zero because there was no available information about their likely concentrations. These parameters included iron, refractory and labile particulate organic matter, and algae concentration. ODEQ data from 2000 and 2001 were assumed, with 2000 being applied for 2002-2004.

Collins Forest Products #1 and #2: Daily measured temperatures for the #1 and #2 discharges from Collins Forest Products were reported in the monthly monitoring reports submitted to ODEQ and were used directly in model input. These temperatures, similar for both discharges, range from about 3°C in winter to over 25°C in summer.

BOD and TSS concentrations, reported twice a week in the ODEQ reports, were combined to produce monthly average values. Other constituent concentrations were estimated from input data for these discharges, called Weyerhaeuser #1 and #3, in the previous ODEQ (1995) simulation. Collins Forest Products is the current owner of the same facilities that Weyerhaeuser owned in 1992. ODEQ data from 2000 and 2001 were assumed, with 2000 being applied for 2002-2004.

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Lost River Diversion: Temperatures for the Lost River Diversion input were estimated from bimonthly measurements taken in the Lost River at Wilson Reservoir by USBR between December 28, 1999, and December 18, 2000. These temperatures range from a low of 2.2°C in winter to a high of 30°C in summer.

Other constituent concentrations were estimated from either the USBR measurements, Klamath Straits data from 2000 (DO), Link dam 2002 grab samples, or from the previous ODEQ (1995) simulation. Wilson Reservoir data were used only during periods when the Lost River diversion channel was flowing into the Klamath River.

Klamath Straits Drain (KSD): The temperature record for Klamath Straits Drain is a composite of hourly measurements by USBR at both KSD near Highway 97 and KSD at Stateline, averaged to daily temperatures. Daily average air temperature, as reported at the KFLO meteorological station, was used as a surrogate for water temperature when no data were available from either site. Sources of data for year 2000 are listed in Table 19.

Table 19. Sources of Temperature Data for KSD in Year 2000

Period:	1/1-1/14/00	1/15-3/16/00	3/20-4/6/00	4/6-5/2/00	5/2-11/22/00	11/23-12/31/00
Source:	KFLO air	Mouth of KSD	KSD at Stateline	Mouth of KSD	Mouth of KSD	KFLO air

If daily average air temperature was less than 0.0ºC, a water temperature of 0.0ºC was used. The composite temperature record for KSD ranges from 0.0ºC in winter to over 25.0ºC in summer.

DO and TDS concentrations were taken from data collected by a USBR datasondes deployed from January through November 2000 in Klamath Straits Drain. Data gaps were filled with linear interpolation. Monthly estimates for ammonia, nitrate, orthophosphate, algae, and alkalinity concentrations were based on USBR grab samples collected in 2000. All other constituent concentrations were estimated from the previous ODEQ (1995) simulation.

3.3.2.4 Keno River Reach

Headwater inflow: Upstream boundary conditions for the Keno River reach are defined by simulated hourly water quality from the Lake Ewauna to Keno reach. There is no other inflow to this reach.

3.3.2.5 J.C. Boyle Water Quality Data

Headwater inflow: Inflow water quality to J.C. Boyle reservoir is taken from simulated hourly water quality from the Keno River reach.

Accretion/Depletion (Spencer Creek): Accretion/depletions, representing Spencer Creek inflow to this reach, were added to Klamath River inflow at the headwaters of the reservoir and were assumed to have ambient river water quality.

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3.3.2.6 J.C. Boyle Bypass-Peaking Reach Water Quality Data

Headwater inflow: The quality of water released to the J.C. Boyle bypass reach and through the J.C. Boyle powerhouse was assumed equal to simulated quality of outflow from J.C. Boyle Dam. Transit time between J.C. Boyle dam and the powerhouse tailrace, a distance of roughly 3 miles, is only about 20 minutes at peaking flows (T. Olson, PacifiCorp, personal communication). Because transit time is so small, water quality concentrations at the tailrace are assumed to immediately reflect concentrations at the dam (i.e. there is no time lag between concentrations at the tailrace and at the dam).

Springs: Water quality of the springs that flow into the J.C. Boyle bypass reach was assumed to be constant throughout the year. Water temperatures of the springs was assumed to be 11.0°C, DO was assumed to be 9.7 mg/L (saturation at 3600 ft elevation), and both nitrate and orthophosphate were assumed to be 0.15 mg/L based on field observations at the top and bottom of the bypass reach. All other constituent concentrations were assumed to be zero.

Accretion/depletions (Stateline): Accretions applied at Stateline were assumed to enter at the ambient water quality of the river. No water quality was assigned to accretions/depletions in this reach.

3.3.2.7 Copco Reservoir

Headwater inflow: Inflow water quality to Copco reservoir is taken from simulated hourly water quality from the J.C. Boyle bypass-peaking reach.

Accretion/depletions: Accretion/depletions for this reach were added to Klamath River inflow at the headwaters of the reservoir and were assumed to have ambient river water quality.

3.3.2.8 Iron Gate Reservoir

Headwater inflow: Inflow water quality to Iron Gate reservoir is assumed equal to simulated quality of outflow from Copco reservoir. During off-peak hours, when simulated outflow from Copco dam is zero, a small nominal inflow is specified and this inflow is assigned water quality from the last time step for which there was a release from Copco dam.

Accretion/depletion and tributary inflow: Because no water quality data are available for these inflows, all tributary water quality (including accretion/depletions applied at Jenny Creek) is assigned the estimated monthly water quality of Shovel Creek, on the Iron Gate to Turwar reach. Shovel Creek, like Jenny Creek, flows out of the Cascades mountain range and is assumed to be representative of water quality conditions in tributaries to Iron Gate reservoir.

3.3.2.9 Iron Gate to Turwar Reach

Headwater inflow: Inflow water quality to the Iron Gate to Turwar reach is assumed equal to the simulated quality of outflow from Iron Gate reservoir.

Tributaries: Major tributaries to this reach include the Shasta, Scott, Salmon, and Trinity rivers. Typically, water temperature has been reported continuously (i.e., every hour) for these major

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tributaries. Although these records are largely intact, data gaps did exist. Generally Scott and Shasta River temperatures were used to fill respective data gaps among the two streams; similarly for the Salmon and Trinity River.

For all simulation years, water temperatures of minor tributaries to this reach, except Blue Creek, were based on data collected by U.S. Forest Service (USFS) between 1994 and 2001 (Appendix E). The Yurok Tribe provided Blue Creek water temperatures data. The USFS temperature database contains all of the stream temperature records available in the Klamath National Forest stream temperature database, as of October 17, 2002. This includes a total of almost 650,000 individual stream records. Generally, USFS monitoring efforts did not provide long-term datasets at any one location, but rather several locations were monitored for intermittent periods. To provide representative temperature for the various minor tributaries, composite hourly temperature traces were constructed for each creek. These composite datasets were used to calculate monthly average temperatures for each tributary. Monthly temperatures are presented in Table 20.

Table 20. Minor Tributary Inflow Temperatures for Iron Gate to Turwar Reach Model

	Temperature, ºC														
JDAY	**1**	**15**	**46**	**75**	**106**	**136**	**167**	**197**	**228**	**259**	**289**	**320**	**350**	**366**	**367**
Bogus Creek	0.13	0.19	0.52	3.39	7.79	12.43	12.76	14.06	14.50	12.43	8.31	2.87	0.06	0.13	0.13
Beaver Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.16	14.03	15.55	14.31	11.09	4.79	4.04	4.00	4.00
Horse Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	13.13	14.08	13.64	11.09	4.79	4.04	4.00	4.00
Grider Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	16.31	16.82	13.95	10.80	4.79	4.04	4.00	4.00
Thompson Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Indian Creek	5.00	5.11	5.55	6.76	7.33	8.74	11.61	16.88	18.41	15.69	12.08	5.74	4.60	5.00	5.00
Elk Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	17.62	18.15	14.95	11.09	4.79	4.04	4.00	4.00
Clear Creek	5.00	5.13	5.50	6.95	7.39	8.76	11.96	15.78	17.29	15.06	11.83	5.45	4.56	5.00	5.00
Ukonom Creek	5.00	5.05	5.26	6.74	7.38	8.17	10.71	13.05	13.95	12.37	10.66	5.52	4.88	5.00	5.00
Dillon Creek	5.00	6.93	6.19	7.67	9.52	12.46	15.49	20.21	18.58	16.92	11.80	7.63	4.93	5.00	5.00
Camp Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Red Cap Creek	6.50	6.93	6.19	7.67	9.52	12.46	15.49	20.30	19.37	16.62	13.06	9.22	6.23	6.50	6.50
Bluff Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Pine Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Tectah Creek	7.90	7.76	8.26	8.18	9.94	10.02	12.51	13.73	14.10	14.48	13.50	9.98	8.03	7.90	7.90
Blue Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89

Other constituent concentrations, in either major or minor tributaries, are not nearly as well documented as water temperature. To create a record of DO concentrations, saturation conditions were assumed everywhere. DO in all tributaries was estimated assuming 100 percent saturated conditions based on observations that most of these rivers and streams reach the Klamath River after flowing through:

- Steep canyon reaches that are several miles long

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- Watersheds that have little or no water resources development
- Watersheds where organic loads and other oxygen-demanding processes are modest

Review of available data (USBR, 2003) indicates that this is a reasonable assumption for modeling applications. Diurnal variations due to primary production are assumed to be small and are not represented in these estimates.

Oxygen saturation concentrations were calculated from water temperature and atmospheric pressure, corrected for elevation. Because atmospheric correction along the reach was small, average elevations for three sub-reaches were used in the calculation. Average elevation from Iron Gate dam to the USGS Gage at Seiad Valley (1759.9 ft (536.4 m)) was used to correct atmospheric pressure for all tributaries within that section of the reach. Likewise, the average elevation for USGS Gage at Seiad Valley to Trinity River reach (810.0 ft (246.9 m)) and from the Trinity River to the end of the IG-Turwar reach (150.0 ft (45.7 m)) were used to correct atmospheric pressure for all tributaries within those sections of the reach. Methodologies for dissolved oxygen saturation calculation and atmospheric pressure correction are included in Appendix F.

Concentrations for all other constituents (e.g., nutrients, BOD, and algae) are estimated seasonally from grab samples taken by EPA (1997), USFWS (1999), and USBR (2003). Overall, there were little data available for most tributaries, and minor tributaries generally had no water quality data of this type available. The Shasta and Scott Rivers had sufficient data from USBR (2003) to represent seasonal variations only. Many of these tributary watersheds are lightly populated, have minimal water resource development and, although active timber management areas reside within several tributary watersheds, water quality out of most tributaries is of good quality. Estimated water quality boundary conditions for all tributaries of the Iron Gate to Turwar reach are summarized in Table 21.

Table 21. Water Quality Boundary Conditions for Constituent Concentrations for Klamath River Tributaries Between Iron Gate Dam and Turwar

Parameter		**Shasta R.**		**Scott R [a]**		**All Other Tributaries [b]**
		1/1-7/15	**7/16-12/31**	**1/1-7/15**	**7/16-12/31**	**1/1-12/31**
Organic N (D [c])	(mg/L)	0.45	0.45	0.20	0.20	0.15
NH_4^+	(mg/L)	0.15	0.05	0.15	0.05	0.05
NO_2^-	(mg/L)	0.00	0.00	0.00	0.00	0.00
NO_3^-	(mg/L)	0.05	0.05	0.15	0.05	0.05
Organic P (D [c])	(mg/L)	0.05	0.05	0.05	0.05	0.05
PO_4^{3-}	(mg/L)	0.45	0.15	0.10	0.05	0.05
BOD	(mg/L)	2.00	2.00	2.00	2.00	2.00
Algae	(mg/L)	1.00	1.00	1.00	1.00	1.00
Dissolved Oxygen	(mg/L)	Based on saturation dissolved oxygen				

[a] based on synoptic at mouth

[b] Including Salmon River, Trinity River and all minor tributaries

[c] D – Dissolved

3.3.3 Meteorology

Meteorological input data, used to calculate heat flux and light intensity in the model, include air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0.0-1.0) and atmospheric pressure (mb). Typically, cloud cover, atmospheric pressure, and wet bulb temperature are derived from observed data.

To best represent meteorological conditions, the 260-mile length of the Klamath River is divided into three climate zones. Zone 1 extends from Upper Klamath Lake (RM 255; 4,135 ft (1,259 m) above MSL) to J.C. Boyle dam (RM 226; 3759.8 ft (1146 m) above MSL) and represents the climate of higher elevations. Zone 2 is a mid-zone extending from J.C. Boyle dam to Seiad (RM 129; 1,318.9 ft (402 m) above MSL). Zone 3 represents the more coastal climate of lower elevations, extending from Seiad to Turwar (RM 5.0; approximately sea level).

Meteorological data for Zone 1 were derived from observations near Klamath Falls, OR. This meteorological station, KFLO (4,100 ft (1,249.7 m) above MSL), is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provided dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed. Atmospheric pressure was calculated based on an assumed elevation of 4100 ft (1250 m) and was assumed constant at the calculated value of 870 mb throughout the simulation period.

Meteorological data for Zone 2 were derived from observations at Brazie Ranch (3,020 ft (920 m) above MSL), near Yreka, CA. This meteorological station is operated by the California Department of Forestry, and provided dry bulb temperature, relative humidity, cumulative solar radiation, and wind speed. Atmospheric pressure was calculated based on an assumed elevation of 3020 ft (920 m) and was assumed constant at the calculated value of 910 mb throughout the simulation period.

Meteorological data for Zone 3 were derived from observations at the Trinity River near Hoopa, CA (375 ft (114 m) above MSL). This meteorological station is operated jointly by USGS and the California Department of Water Resources, and provided dry bulb temperature, relative humidity, cumulative solar radiation, and wind speed. Atmospheric pressure was calculated based on elevation and assumed constant at 992 mb throughout the simulation period.

Cloud cover and wet bulb temperatures for all zones are derived from reported data. Cloud cover is calculated from the daily summation of solar radiation, using an ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Wet bulb temperature is calculated from relative humidity, atmospheric pressure, and air temperature.

3.4 MODEL PARAMETERS

In addition to system geometry and boundary conditions, the numerical models that simulate flow and water quality of the Klamath River depend upon parameters, including coefficients and constants, to describe the many relationships that govern the simulations. These relationships

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describe the effects of system geometry and boundary conditions on state variables (e.g. the effect of surface area and solar radiation on water temperature) and interactions between state variables (e.g. the effect of organic matter decay on DO). Details of all the relationships simulated by the RMA and CE-QUAL-W2 models are presented in model documentation (King, 2002; Cole, 2002).

Typically, model parameters may be grouped as either "reach-dependent" or "global." Global parameters apply to the entire system. Either these parameters are not expected to change throughout the system or there is not enough information available to indicate how they would change throughout the system. Reach-dependent parameters change from reach to reach within the system. These parameters generally reflect special characteristics of particular sections of the system. Depending on the scope of application, values for both global and reach-dependent parameters may be derived from calibration. The Klamath River has been modeled as one system and parameter values have been chosen for consistency throughout the system. But, because the numerical models used in this study are formulated differently, parameter values are not always comparable between the two. Reach-dependent parameters for river and reservoir reaches are presented in Table 22 and Table 23, respectively. Global parameters for river and reservoir reaches are presented in Table 24 and Table 25, respectively.

Most biological and chemical rate reactions are dependent upon temperature. Higher temperatures typically result in faster reaction rates. Reaction rates can respond dramatically to changes in temperature, so temperature correction of rates is an important feature of the numerical models used in these simulations. The RMA models use a van't Hoff-Arrhenius equation (Tchobanoglous and Schroeder, 1985) to correct for temperature changes. Depending on the reaction, CE-QUAL-W2 uses either van't Hoff-Arrhenius or a user-defined correction curve. For reference, temperature-based correction factors used in RMA11 are listed in Table 26.

Table 22. RMA-2 and RMA-11 Reach-Dependent Parameters (River Reaches)

Variable	Model	Description, units	Link River	Keno River	J.C. Boyle Bypass-Peaking	Iron Gate-Turwar
	RMA2	Hydrodynamic time step, hr	1	1	0.25	1
	RMA11	Water quality time step, hr	1	1	1	1
	RMA2, RMA11	Spatial resolution, m	75	75	75	150
	RMA2	Slope factor	0.8	0.9	0.95	0.8/0.5*
EXTINC	RMA11	Light Extinction coefficient, 1/m	1.5	1.5	1.5	0.3
ELEV	RMA11	Elevation of site, m	1255	1192	975	287

* From IG Dam to Orleans SF=0.8; from Orleans to Turwar SF=0.5

Table 23. CE-QUAL-W2 Reach-Dependent Parameters (Reservoirs)

Parameter	Description	LE-Keno	JC Boyle	Copco	Iron Gate
LAT	Latitude, degrees	42.13	42.12	42.12	42.97
LONG	Longitude, degrees	121.95	122.05	122.33	122.42
EBOT	Bottom elevation of waterbody, m	1237.30	1143.75	761.09	663.78
TSED	Sediment (ground) Temperature, C	8.5	12	12	12
AR	Maximum algal respiration rate, 1/day	0.10	0.05	0.05	0.05
SOD	Zero-order sediment oxygen demand, g O2/m2day	3	1	1	1

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Table 24. RMA-2 and RMA-11 Global Parameters

Variable	Description, units	Value
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coeff a, m/mbar-hr	0.000015
EVAPB	Evaporative heat flux coeff b, sec/mbar-hr	0.000010
ALP0	Chl a to algal biomass conversion factor, phytoplankton, mg Chl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.07
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.01
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.10
RESP	Local respiration algae, phytoplankton, 1/d	0.10
RESP	Local mortality rate of algae, phytoplankton, 1/d	1.0
SIG1	Settling rate of algae, phytoplankton, 1/d	0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m-2 s-1	0.01
PREFN	Preference factor for NH3-N, phytoplankton	0.60
ABLP0	Chl a to algal biomass conversion factor, bed algae, mg Chl_a to mg-A	50
BMUMAX	Maximum specific growth rate, bed algae, 1/d	1.15
BRESP	Local respiration rate of algae, bed algae, 1/d	0.20
GRAZE	Local respiration rate of algae, bed algae, 1/d	0.10
BMORT	Local respiration rate of algae, bed algae, 1/d	0.20
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m-2 s-1	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.30
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.50
BET3	Rate constant: hydrolysis organic matter to NH3-N, 1/d	0.20
KNINH	First order nitrification inhibition coefficient, mg-1	0.60
K1	Deoxygenation rate constant: BOD, 1/d	0.20
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	4.0
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.014
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.003
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.014

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Table 24. RMA-2 and RMA-11 Global Parameters

Variable	Description, units	Value
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.003
ALP3	Rate O2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.5
ALP4	Rate O2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.5
ABLP3	Rate O2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.5
ABLP4	Rate O2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.5
ALP5	Rate O2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
SIG6	BOD settling rate constant, 1/d	0.0

Table 25. CE-QUAL-W2 Global Parameters

Parameter	Description	Value
DLT MIN	Minimum time step, sec	5
DLT MAX	Maximum time step, sec	500
SLOPE	Waterbody bottom slope	0
CFW	C coefficient in the wind speed formulation	1
WINDH	Wind speed measurement height, m	2
FI	Interfacial friction factor	0.04
TSEDF	Heat loss added back to water from bed, fraction	0.1
EXH2O	Extinction for pure water, m-1	1.00
ASAT	Light intensity at a max photosynthesis, W/m2	100
AFW	A coefficient in the wind speed formulation	9.2
CBHE	Coefficient of bottom heat exchange, W/m2sec	0.3
AG	Maximum algal mortality rate, 1/day	2
AR	Maximum algal respiration rate, 1/day	0.05
AE	Maximum algal excretion rate, 1/day	0.04
AM	Maximum algal growth rate, 1/day	0.1
EG	Maximum epiphyton mortality rate, 1/day	2
ER	Maximum epiphyton respiration rate, 1/day	0.04
EE	Maximum epiphyton excretion rate, 1/day	0.04
EM	Maximum epiphyton growth rate, 1/day	0.1
O2NH4	Rate O2 uptake per unit Ammonia-N oxidation, mg-O/mg-N	4.57
SEDK	Sediment decay rate, 1/day	0.04
AS	Algal settling rate, m/day	1.0

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Table 25. CE-QUAL-W2 Global Parameters

Parameter	Description	Value
ALGP	Stoichiometric equivalent between algal biomass and phosphorus	0.1
ALGN	Stoichiometric equivalent between algal biomass and nitrogen	0.07
ALGC	Stoichiometric equivalent between algal biomass and carbon	0.45
EP	Stoichiometric equivalent between epiphyton biomass and phosphorus	0.01
EN	Stoichiometric equivalent between epiphyton biomass and nitrogen	0.07
EC	Stoichiometric equivalent between epiphyton biomass and carbon	0.45
LDOMDK	Labile DOM decay rate, 1/day	0.2
RDOMDK	Refractory DOM decay rate, 1/day	0.001
LRDDK	Labile to refractory DOM decay rate, 1/day	0.01
LPOMDK	Labile POM decay rate, 1/day	0.2
RPOMDK	Refractory POM decay rate, 1/day	0.001
LRPDK	Labile to refractory POM decay rate, 1/day	0.01
POMS	POM settling rate, m/day	0.5
ORGP	Stoichiometric equivalent between organic matter and phosphorus	0.01
ORGN	Stoichiometric equivalent between organic matter and nitrogen	0.07
ORGC	Stoichiometric equivalent between organic matter and carbon	0.45
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03
NH4R	Sediment release rate of ammonium, fraction of SOD	0.07
NH4DK	Ammonium decay rate, 1/day	0.1
NO3DK	Nitrate decay rate, 1/day	0.1
NO3S	De-nitrification rate from sediments, m/day	0
CO2R	Sediment carbon dioxide release rate, fraction of SOD	0.01
O2AR	Oxygen stoichiometry for algal respiration	1.5
O2AG	Oxygen stoichiometry for algal primary production	1.5
AHSN	Half-saturation constant: nitrogen, phytoplankton, mg/l	0.014
AHSP	Half-saturation constant: phosphorous, phytoplankton, mg/l	0.003
EHSN	Half-saturation coefficient for nitrogen, epiphyton, mg/l	0.014
EHSP	Half-saturation coefficient for phosphorus, epiphyton, mg/l	0.003

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Table 26. RMA-11 Temperature-Based Rate Correction Factors

Variable	Description, units	Water	Bed
THET1	Algal growth rate temperature factor	1.047	1.047
THET2	Algal respiration rate temperature factor	1.047	1.047
THET3	Algal settling rate temperature factor	1.047	1.000
THET4	Organic nitrogen decay rate temperature factor	1.047	1.000
THET5	Organic nitrogen settling rate temperature factor	1.024	1.000
THET6	Ammonia nitrogen decay rate temperature factor	1.083	1.000
THET7	Ammonia nitrogen benthic sources rate temperature factor	1.074	1.000
THET8	Nitrite nitrogen decay rate temperature factor	1.047	1.000
THET9	Organic phosphorous decay rate temperature factor	1.047	1.000
THET10	Organic phosphorous settling rate temperature factor	1.024	n/a
THET11	Orthophosphate benthic sources rate temperature factor	1.074	n/a
THET12	BOD decay rate temperature factor	1.015	n/a
THET13	BOD settling rate temperature factor	1.024	n/a
THET14	DO benthic demand rate temperature factor	1.000	n/a
THET15	DO reaeration rate temperature factor	1.024	n/a

3.5 CALIBRATION AND VALIDATION

Model calibration and validation are the processes of adjusting parameters to fit model results to field observations (calibration) and testing the model with an independent set of boundary conditions and field observations (often termed validation). These processes provide a means to test the model and quantify its ability to replicate field conditions under different hydrological, meteorological, and water quality conditions. In this section, results of model calibration and validation are presented for each of twenty locations along the river. River reaches were calibrated for flow, and details of that calibration process are given in the Flow Calibration section. Reservoir reaches were not calibrated for flow, but rather stage. Inflows and outflows are specified as input values in CE-QUAL-W2 and these were determined based on changes in observed or assumed storage. Because inflow, outflow, and water surface level are all used to drive the reservoir models, there are no independent data by which to calibrate the hydrology of the reservoirs. Existing data are insufficient to test actual hydrodynamic performance of these models, but simulated reservoir elevation is used as a proxy.

All river and reservoir reaches were calibrated for water temperature and dissolved oxygen. To attain dissolved oxygen calibration, parameters that affect nutrients, phytoplankton, or benthic algae were typically examined. Where data were available for in sufficient quantity and quality, nutrient and algae observations were compared with simulated values to assess model performance. Comparisons of simulated and observed temperature, dissolved oxygen, nutrients, and algae for each of the five simulation years (2000-2004) are presented in this section.

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Although reservoir models were applied over a calendar year during calibration, there were generally little or no data to calibrate during winter months until later years and then, generally, only for temperature. Nonetheless, model results are presented for the entire year. Results of calibration-validation show that the Klamath River model represents the majority of system processes and translates water quality conditions downstream through the system with significant accuracy. Certain components, such as flow and temperature, are well represented throughout the modeling domain. Other components are less certain because the model is limited in its ability to fully characterize the highly dynamic nature of the system, and especially the fate of organic matter, by lack of data. However, the process of developing this model and its components has been instrumental in developing a deeper understanding of water quality within the project and the response of water quality to change in both environmental conditions and management. This modeling tool, as it now stands, is capable of assessing complex questions about how Project operations and various meteorological, hydrological, and water quality conditions influence the environment of the Klamath river from Upper Klamath Lake to Turwar. Examples of the use of this model in assessing complex management options include:

- Characterizing existing water quality conditions in the Klamath River basin;
- Identifying the impacts of system wide steady flow regime (no peaking hydropower) on water quality;
- Assessing water quality conditions under a "without project" scenario, wherein the PacifiCorp hydropower facilities are removed and the system is modeled as a river from Link Dam to Turwar;
- Exploring of temperature management feasibility through selective withdrawal, temperature control curtains, and reservoir reoperation;
- Analysis of the impact of increased flows through the Bypass reach below J.C. Boyle dam on water temperatures associated with groundwater (springs) inflow;
- Exploring System Landscape Operations Management (SLOM) scenarios wherein selective Dams are removed and the impacts on flow and water quality assessed;
- Identifying the extend of Project effects below Iron Gate Dam under variable hydrological and meteorological conditions; and
- Identifying the role of boundary conditions (e.g., tributaries, return flows, diversions) on water quality conditions in the Klamath River basin.

3.5.1 Calibration Measures and Methods

Calibration required application of several alternative parameter sets and comparison of results against reported field conditions. Selection of final parameter values was based on graphical comparisons of simulated and measured data. Graphical comparisons were used to assess general model performance. These graphical comparisons provided significant insight, but could not be used to quantify differences over long time periods and at multiple locations along the river.

Flow calibration, including the technique of "iterative calibration" and the use of slope factors, is described below. Final parameter values from flow and water quality calibration have been included in Table 22 through Table 26.

Model calibration and validation depend upon field data for rigor. But there are inherent problems in using field data with a numerical model. Field data used to calibrate and validate the Klamath River Model, like all field data, describe field conditions with a certain significant amount of uncertainty. Heterogeneity of field conditions is a large factor in this uncertainty. Water quality can vary dramatically both spatially, within a water body, and temporally. Spatially, water quality may be influenced by proximity to shore, atmosphere, the bed, diversions, or to tributary sources and other inflows. Temporally, water quality is influenced by changes in light, temperature, and a range of biogeochemical processes that can range from sub-daily to seasonally or longer. Because sampling is necessarily limited in scope, often taken only periodically and at specific sites, field data provide an approximation of field conditions to guide calibration and validation of detailed numerical models. In this study, graphical analyses to show seasonal trends are the primary method of comparing field data to simulated results.

3.5.2 Flow Calibration

River reaches and reservoirs are calibrated differently for flow. River reaches are generally calibrated using an "iterative calibration" process and adjusting bed roughness and slope factors. Reservoirs are calibrated to reported water surface elevation.

3.5.2.1 River Reaches

Hydrodynamic calibration of river reaches typically requires varying channel roughness (e.g., Manning coefficient, n) through a range of values while comparing simulated transit time and river stage with measured data. Transit time can be estimated from stream velocity measurements or tracking changes in river stage under varying flow conditions. Although USGS gages are located near Seiad Valley (RM 129), Orleans (RM 56), and Turwar (RM5), travel time could only be roughly calibrated due to the long distance between gages and uncertainty in ungaged tributary flows and other accretions.

To calibrate long river reaches more accurately, Deas and Orlob (1997) developed a method for iterative calibration wherein hydrodynamic and water quality models were used jointly. Application of this method requires modeling on a sub-daily time step (e.g., hourly) and availability of associated sub-daily water temperature data. Both criteria were filled for this project. The method is outlined for the Klamath River in Appendix G.

Local bed slope over much of the length of steep rivers is generally significantly less than the overall gross slope of a river reach. This is because steep rivers are typically not uniform in slope, but consist of short cascades, or riffles, combined with intermediate pools and runs. RMA-2 includes a slope factor (SF) and associated logic that is designed to account for these changes in slope. The RMA slope factor reduces effective bed slope and assumes that travel time through the short cascade sections is negligible compared to the transit time through runs or pools. A short description of the slope factor and its application is presented in Appendix H.

Based on typical summer flow rates, slope factor was set at 0.80 for Link River, 0.90 for Keno reach, and 0.95 for the J.C. Boyle bypass-peaking reach. Two different slope factors were assigned to the Iron Gate to Turwar reach, representing significantly different geomorphology in the upper and lower sections of this reach. Slope factor was set at 0.80 for the upper section of

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the reach between Iron Gate dam and Seiad Valley and 0.95 for the lower section of the reach from Seiad Valley to Turwar. Slope factors were modified slightly during calibration. Because slope factors are applied, consideration should be exercised before using this calibrated Manning coefficient in other flow models.

Results of the flow calibration of river reaches consist of comparison of total flow, velocity and stage. Results are compared to six USGS gage locations where stage and velocity data: Link River near Klamath Falls (11507500), Klamath River near Keno (11509500), Klamath River below J.C. Boyle Powerhouse (11510700), Klamath River below Iron Gate Dam (11516530), Klamath River near Seiad Valley (11520500), and Klamath River at Orleans (11523000). The Turwar gage is tidally influenced and not included in this assessment. Flow is effectively represented throughout the system and examining the stations in the Klamath River below Iron Gate dam indicates that travel time is reproduced. Velocity and depth are generally well represented, but there are deviations from measured data. These deviations, resulting from approximation of river geometry based on habitat studies (USWFS, 1997), are not expected to notably affect model results on a reach scale. Results of flow calibration (2000-01) and validation (2002-04) are presented graphically in Appendix I.

3.5.2.2 Reservoirs

As noted above, hydrodynamic calibration of the reservoir components of the Klamath River flow and water quality model was indirectly addressed by using reservoir storage to assess model flow performance. This mode of calibration (2000-01) and validation (2002-04) was completed for Keno, J.C. Boyle, Copco, and Iron Gate reservoirs. Reservoir stage is replicated in all years for all reservoirs. Simulated stage in Keno sometimes deviates from observed values (typically less than 1.5 feet (0.45 m), but these differences are not expected to affect model results. Graphical representation of simulated versus observed stage is included at the end of Appendix I.

3.5.3 Water Quality Calibration

The Klamath River Model has been calibrated against 2000 and 2001 water quality observations, and validated with 2002-2004 observations, at twenty water quality calibration-validation sites along its length. Data may not be available for all parameters at all sites for all years. Likewise, certain data are available for only a day or two over the calibration and validation period. The usefulness of presenting only a few data points over an extended set of modeling simulations such as these is limited when assessing model performance on a basin-wide scale for multiple years. As such, not all plots are presented or plots may show only a few data points or none at all. Calibration-validation sites that were considered throughout the modeling completed to date and their respective reaches are listed in Table 27. Results of calibration and validation are presented below, along with summary statistics. A compilation of summary statistics and a list of calibration parameters are presented at the end of this section. Graphical representations of model results and observed data at each site for each of the five years (2000-2004) simulated for this study are presented in Appendix J.

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Table 27. Calibration and Validation Sites along the Klamath River

RM	Site	Reach	Notes
252.7	Link River at Lake Ewauna	Link River	Time series
244.7	Miller Island	L. Ewauna to Keno	Time series
234.3	Keno Reservoir at the Highway 66 Bridge near Keno	L. Ewauna to Keno	Time series
232.8	Klamath River below Keno Dam	Bypass and Peaking	Time series
227.8	Klamath River above J.C. Boyle Reservoir	Bypass and Peaking	Time series
224.3	J.C. Boyle Reservoir near J.C. Boyle Dam	Bypass and Peaking	Profiles, Time Series
224.2	Klamath River below J.C. Boyle Dam	Bypass and Peaking	Time series
220.2	Klamath River above J.C. Boyle Powerhouse	Bypass and Peaking	Time series
203.8	Klamath River above Copco Reservoir	Bypass and Peaking	Time series
198.6	Copco Reservoir	Copco	Profiles, Time Series
190.5	Iron Gate Reservoir	Iron Gate	Profiles, Time Series
190.4	Below Iron Gate Dam	Iron Gate to Turwar	Time series
177.5	Klamath River above Shasta River	Iron Gate to Turwar	Time series
129.0	Klamath River at Seiad Valley	Iron Gate to Turwar	Time series
57.6	Klamath River at Orleans	Iron Gate to Turwar	Time series
43.6	Klamath River above Trinity River	Iron Gate to Turwar	Time series
5.0	Klamath River at Turwar	Iron Gate to Turwar	Time series

3.5.3.1 Link River Reach

Temperature, dissolved oxygen and nutrient conditions were examined in light of available data. However, calibration and validation of this reach was completed based on available data, but due to the short length and transit time, only modest insight was gained through this exercise. Thus, water quality parameters were set for this reach based on simulation in much longer river reaches: Klamath River in the J.C. Boyle bypass-peaking reach and Iron Gate dam to Turwar reach. Most simulation results at the mouth of Link River mirrored boundary conditions at Link dam, just over one mile upstream.

<u>Discussion</u>

This short river reach is fairly insensitive to model conditions except when Link dam bypass flows are low and most water is passed through the Eastside and Westside powerhouses.

3.5.3.2 Lake Ewauna to Keno Dam Reach

The CE-QUAL-W2 model for Lake Ewauna to Keno Dam reach was calibrated and validated using water temperature, DO, and nutrient (phosphorous and nitrogen) data collected at Miller

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Island and Hwy 66 near Keno. The model was calibrated to data collected during 2000-2001 and validated to data from 2002-04.

Calibration

Calibrated water temperatures generally match observed water temperatures. Observed temperatures sometimes exhibit greater range than simulated temperatures in summer months, but overall, diurnal range, short-term events (e.g., hot spells), and seasonal trends are well represented. Calibrated temperatures are typically higher than observed in summer and lower in winter at Hwy 66 near Keno. An external review of the model (Wells, 2004) provided input on under-prediction of winter temperatures, and several attempts were made to improve representation. Ultimately, the potential cause was estimated to be non-local meteorological data (i.e., not on-river meteorological conditions). A general trend towards low DO concentrations and high diurnal variation in summer is matched by calibration; but overall, simulated DO does not match observed hourly data. The range of simulated values can both under- and overestimate observation.

Observed nutrient concentrations are matched by simulated concentrations with overall range often good but with some elevated observations under-represented by simulation. Some distinct seasonal trends are well matched by simulation. Simulated algal peaks are elevated and timing occasionally off, but simulations match observed algal range and seasonal trend. Pattern of growth beginning in late spring and decline in fall is well represented, but some simulated algal concentrations can be considerably higher than reported values.

Validation

Water temperatures simulated during validation generally match observed water temperatures in value, diurnal range, and trend. Validated temperatures are typically higher than observed in summer and lower in winter at Hwy 66 near Keno. In validation, DO matches reported values much as it did in calibration. A summer pattern of oxygen depletion and re-oxygenation is matched by simulation, but simulated spring DO is considerably lower than reported for 2002.

Observed nutrient concentrations are fairly matched by simulated concentrations with overall range often good and summer rises in nutrient concentrations well represented. Reported concentrations of nitrates (as nitrogen; $N\text{-}NO_3$), typically low in 2002-03, are overestimated, as are orthophosphate (as phosphorus; $P\text{-}PO_4$) concentrations in 2003. A pattern of algae growth beginning in late spring and declining in fall is well represented by simulation. The range of observed values were matched by calibration at Miller Island, but simulated algal concentrations are considerably higher than reported values at Hwy 66 near Keno.

Discussion

The Lake Ewauna to Keno dam reach is a dynamic and complex reach to model for water quality. Water resources, including agricultural, municipal, and industrial activities, are intensively developed and occur adjacent to the river throughout much of this reach. Multiple diversions from the system supply industrial and agricultural use, and much of this flow is returned to the river after use. The Klamath River also receives municipal wastewater discharge.

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Additionally, review of available literature and discussions with stakeholders suggest historical log rafting and timber industry practices have deposited considerable organic matter throughout the upper portion of this reach.

Impoundment of this reach and upstream Upper Klamath Lake has far-reaching consequences on water quality. Active management of storage in Upper Klamath Lake for summer use within the USBR Klamath Irrigation Project has reduced the frequency, and to some degree the magnitude, of winter flows through the Lake Ewauna to Keno dam reach. These reduced winter flows, coupled with impoundment at Keno dam and extensive restoration of local marshlands, have created a slow-moving waterway that encourages primary production of phytoplankton (as opposed to riverine forms of algae) and favors deposition. Upstream inputs from hypereutrophic Upper Klamath Lake, as well as historic and continued inputs from municipal, industrial, agricultural, and non-point discharges lead to significant oxygen demands within this reach.

Contemporary field work and review of data previously collected suggest that daily weak stratification, wind, withdrawals and return flows, a stable water surface (near constant storage), and a perceptible current (on the order of 0.05 to 0.2 feet per second at mid-channel) create complex conditions that directly impact water quality.

With the notable exception of water temperature, water quality in the Lake Ewauna-Keno Reach responds strongly to water quality of releases from Upper Klamath Lake. In fact, all downstream reaches are likewise strongly impacted by water quality conditions at Link dam. Water temperature is only moderately affected in downstream reaches because water in the system tends quickly towards equilibrium temperatures and water temperature in Upper Klamath Lake is generally already near equilibrium with the atmosphere.

Given the level of complexity encountered within this reach, simulation of temperature in this dynamic reach was by-and-large successful. Simulation of dissolved oxygen, nutrients, and algae, was not as successful because concentrations of these constituents depend so heavily on upstream boundary conditions at Link dam that are not well-defined. The model replicates seasonal dissolved oxygen concentrations, but short-term conditions are not always well represented.

Additional model simulations were completed to determine if algal populations, and thus DO and nutrients, would be affected if algal respiratory requirements were not met during anoxic periods and algae populations suffered accordingly. The model was modified to limit algal growth and increase mortality based on respiratory needs of phytoplankton. Specifically, if there was insufficient DO in the water column to support respiration of algae, algal mortality was increased. While there were no field data to test the model logic, sensitivity testing of model parameters while assessing phytoplankton, DO, and nutrient level responses indicated that algal respiratory requirements may not be the only factor behind the persistent anoxia, elevated nutrients and low algal counts that are prone to occur in this reach. Advection from upstream reaches tends to re-colonize downstream reaches on the order of days. Further research into this issue has focused on algal growth inhibition by one of several factors, potentially including impacts of pharmaceutical/human health and personal care products in municipal treated effluent, phenolic compounds associated with organic matter – including that within the

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sediments (source: tannins, humic substances, lignin), production of hydrogen peroxide, other chemical constituents or reactions that may lead to inhibition or toxicity.

Another factor potentially affecting the spatial DO concentrations and distribution of phytoplankton is local meteorological conditions. Local meteorological data suggest that during summer periods afternoon winds are typical, especially in the vicinity of Keno. During the warmer periods of the year, daily afternoon wind events at Keno, located near the Klamath River canyon, are the norm. However, during these same periods, conditions are calm in much of the reservoir that lies east of Keno. Presence or absence of wind-driven mixing most likely has a direct impact on local phytoplankton populations and DO conditions.

Model performance for nutrients varies between year 2000 and 2001 applications. With the more complete data set of 2001, the model replicates observed conditions appreciably better than in 2000, when composite upstream boundary conditions were applied. Model performance during the validation period, when data are available for comparison, suggests results similar to the calibration period. The model has undergone a wide range of testing to assess its response to variable conditions and parameters.

3.5.3.3 Keno Dam to J.C. Boyle Reservoir Reach

The RMA-11 model of Keno River reach was not calibrated with 2000 and 2001 data due to data limitations. Instead, calibration relied largely on parameter values from the Iron Gate to Turwar reach and the J.C. Boyle bypass and peaking reaches. These longer river reaches provided more transit time to assess model performance. Light extinction was set specifically for this reach, based on light extinction measurements completed in 2004. The model was validated with available information from 2002-2003 below Keno dam and above J.C. Boyle reservoir.

<u>Validation</u>

Simulated water temperatures match monthly observations. Simulated summer temperatures tend to be modestly higher than those reported for summer months. The model typically represents a pattern of DO concentrations that begin to decline in spring, reach a low in summer, and climb back up in fall. Simulated DO is consistently lower than observations during spring and summer months below Keno dam and often lower than observations during spring above J.C. Boyle reservoir.

Simulations represent range and trend of observed nutrient concentrations, particularly ammonia (as nitrogen; N-NH3). Simulated N-NO3 and P-PO4 tend to be higher than reported during late summer through fall below Keno dam.

<u>Discussion</u>

Keno Dam to J.C. Boyle reservoir is a fairly short reach, with a transit time of a few hours. The models performed well in this steep river reach, replicating temperature, DO, and nutrient concentrations well. Under-prediction of winter temperatures persists through this river reach as a byproduct of the upstream model representation; but predicted values begin to improve as distance from Keno dam increases. Deviations between measured and observed DO below Keno

dam are probably due to factors associated with predicted DO in Keno reservoir, the effects of reaeration at Keno dam proper, and the dynamics of mechanical and biological reaeration in the river reach between Keno dam and J.C. Boyle reservoir. Reaeration occurs throughout this reach.

3.5.3.4 J.C. Boyle Reservoir

The CE-QUAL-W2 model of J.C. Boyle reservoir was calibrated and validated using water column profiles of water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) reported at J.C. Boyle reservoir near J.C. Boyle dam. The model was calibrated to data collected during 2000-2001 and validated to data from 2002-2004.

Calibration

Calibration simulations reproduce values and trends in reported monthly profiles of water temperature with little deviation. The model simulates a slight seasonal gradient with depth noticeable in reported temperatures. Both simulated and reported temperatures show generally well-mixed, isothermal conditions throughout the year. Simulated DO concentrations generally fit observed data in spring and fall. The model reproduces a pattern of moderate hypolimnetic deoxygenation, observed in reported DO concentrations during summer months. But significant deviations occur in summer months of 2000 when simulated DO concentrations are often greater than observed at all depths. Profiles during periods of stratification can have greater than reported gradients. The model indicates depletion of DO in the hypolimnion in August 2001 that is not reflected in observations.

Although data are limited, simulated nutrient concentrations generally represent observed data fairly. With only a few exceptions, well-mixed, homogeneous conditions are indicated by both observed and simulated values. Simulated N-NO3 concentrations are often lower than reported concentrations. Generally, there is little variation in observed concentration from top to bottom of the reservoir and simulated algae concentrations reflect these well-mixed conditions. Simulations tend to overestimate algae concentrations in summer months.

Validation

Generally, validation simulations reproduce values and trends in reported monthly profiles of water temperature with little deviation. The model simulates generally well-mixed, isothermal conditions with a slight seasonal gradient noticeable in reported temperature profiles. Deviations from observation occur in August 2002 and in April and November of 2003, but these deviations appear to be short-lived. Simulated DO concentrations generally fit observed data in spring and fall. The model reproduces a pattern of moderate hypolimnetic deoxygenation, observed in reported DO concentrations during summer months. Gradients are reproduced, but significant deviations can occur in summer months when simulated DO profiles sometimes show depletion of DO at depth. Significant deviations appear to be short-lived in 2002, but are evident in spring and summer of 2003.

As in calibration, nutrient concentrations simulated in validation generally represent observed data fairly. With only a few exceptions, well-mixed, homogeneous conditions are indicated by both observed and simulated values. Simulated N-NO3 concentrations are often lower than

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reported concentrations. The model reflects both trends and values of algae concentrations, showing well-mixed conditions and population growth in the summer and early fall.

Discussion

Critical factors affecting J.C. Boyle reservoir water quality include a short residence time, weak and intermittent stratification, and a large nutrient and organic matter load from upstream. Although the reach between Keno dam and J.C. Boyle reservoir provides an opportunity for mechanical reaeration, the reach is short and light limitation is appreciable, limiting the ability of the reach to oxidize material and capture nutrients. The short residence time creates a reservoir that is more like a slow, deep stream, suggesting that J.C. Boyle reservoir can be dramatically affected by short-duration events—deviating from a typical condition to an atypical condition and back again over the period of days. Wind mixing is another factor that may not be completely represented due to lack of local meteorological data. Such short-term events could affect stratification, mixing, and DO conditions within the reservoir.

3.5.3.5 J.C. Boyle Bypass-Peaking Reach

The RMA-11 model of J.C. Boyle bypass-peaking reach was calibrated and validated to data collected at Klamath River below J.C. Boyle dam, above the J.C. Boyle powerhouse, and above Copco Reservoir. Limited data were available at these locations in 2000 and 2001. As with the shorter river reaches upstream (Link River and the Klamath River between Keno dam and J.C. Boyle reservoir), insight was gained by examining calibration results from the longer river reach below Iron Gate dam.

Calibration

Water temperatures simulated in calibration match monthly observations in both value and trend. Simulated temperatures tend to be somewhat lower than those reported for winter months. Calibration simulations reproduce observed patterns of declining DO concentrations in spring, lows in summer, and rising concentrations in fall. Simulated concentrations match reported concentrations throughout 2000, but are consistently low in spring and summer of 2001.

Simulated concentrations of N-NH3 are lower than observed, but N-NO3 and P-PO4 are representative of reported values. Seasonal patterns of elevated concentrations in spring and summer are reproduced in simulations. Care must be used when interpreting results because peaking and non-peaking operations dramatically alter water quality below the J.C. Boyle powerhouse.

Validation

In validation years, water temperatures match observed data in both value and trend. Simulated temperatures at all validation sites in 2002 are modestly higher than reported values. DO concentrations simulated in calibration match trends in observed data. Generally, reported values are within the diurnal range of simulated values except in spring when simulated values tend to be low in comparison to reported values. Simulated values in the J.C. Boyle bypass reach approximate observed nutrient concentrations. N-NH3 is over-predicted in 2002. The model

results also indicate more variability in years when field data for nutrients show more variability. Downstream of the J.C. Boyle powerhouse, simulated levels of nutrients are likewise representative of field observations.

Discussion

The J.C. Boyle bypass-peaking reach experiences a highly dynamic flow regime and variable water quality due to peaking operations and the influence of a large springs complex. Modeling this steep reach required representing both physical features and short-duration hydropower operations. The models performed well for all parameters, although some of the peaking operations produced highly variable water-quality conditions. During processing of the 2003 data, numerical instability in some ammonia concentrations was identified. The overall impact was deemed not to adversely affect model results.

3.5.3.6 Copco Reservoir

The CE-QUAL-W2 model of Copco reservoir was calibrated to profiles collected within the reservoir near the dam in 2000-01. The model was validated with profiles from the same site collected in 2002 through 2004. Algae data for 2004 were not available for validation.

Calibration

The calibrated model effectively captures observed season variation in temperature profiles and water temperature gradients with depth. Simulated values are generally consistent with observation, except in the summer of 2001 when the model produces hypolimnetic temperatures that are warmer than observed, failing to capture the extent of summer stratification. The model matches DO concentrations in Copco reservoir when the reservoir is well-mixed in winter and spring. Summer stratification occurs, but simulated profiles during summer stratification in 2001 are more complex than observed profiles. The model captures oxygen depletion in the hypolimnion whenever it occurs and can accurately estimate the depth at which depletion occurs. But the model also produces depletion on both sides of summer, in June and October 2001, when none is observed.

Results from calibration simulations capture the general distribution of observed nutrient concentrations throughout the summer, when observations were made. The model generally reproduces the increase in N-NH3 and P-PO4 with depth. Simulated algae concentrations are representative of observed values. The model reflects reported data showing growth to occur predominantly in the upper layers of the reservoir. Simulated bloom begins in June 2001 when no algae were observed.

Validation

Water temperatures from validation simulations match observed values at all depths for the validation years. The model reproduces Copco reservoir's observed pattern of temperature stratification in the summer and de-stratification in the fall. When the reservoir is mixed, the calibrated model matches observed values at all depths. As stratification occurs, simulated results tend to overestimate DO concentrations in the hypolimnion. By late summer, the model again

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matches observed DO profiles. The model captures oxygen depletion in the hypolimnion whenever it occurs and can accurately estimate the depth at which depletion occurs.

Validation simulations capture the general distribution of observed nutrient concentrations from spring through fall, when observations were made. The model generally reproduces the increase in N-NH3 and P-PO4 with depth during summer stratification and the mixing of the water column in late fall, as reflected in reported data. Simulated algae concentrations are representative of observed values. The model reflects reported data showing growth to occur predominantly in the upper layers of the reservoir. Occasionally, algae were observed at times when no simulated algae appear.

Discussion

Copco reservoir receives peaking flow from the J.C. Boyle bypass-peaking reach and releases peaking flows from Copco Dam for a significant portion of the year. These inflow and outflow operations have a notable affect on the reservoir thermal regime and water quality due to variable inflow temperature, quality, and rate, as well as variable outflow rates.

Although DO concentrations are over-represented in some years during certain periods of the year, these volumes are small and bottom waters do not, by and large, participate in day-to-day releases (or if so, in small quantities). When the reservoir mixes in the fall, its small hypolimnetic volume mixes into a much larger reservoir volume with minimal consequences. Low DO conditions in Copco reservoir probably have some bearing on autochthonous demand (algal mortality), but are most likely directly affected by the influx of organic matter and nutrients from upstream sources, which also serves to increase in-reservoir production. Hypolimnetic anoxia results in sediment release of ammonia and phosphorous. The model replicates this seasonal condition in years when it is present, and replicates the absence of this when it is absent.

3.5.3.7 Iron Gate Reservoir

The CE-QUAL-W2 model of Iron Gate reservoir was calibrated to profiles collected within the reservoir near the dam in 2000 and 2001. The model was validated with profiles from the same site collected in 2002 through 2004.

Calibration

Water temperature profiles from calibration simulations match observed profiles at all depths in all seasons except for consistent overestimation in the area of the thermocline during times of stratification. Observed top and bottom temperatures are closely and consistently matched by simulated values. When Iron Gate reservoir is mixed, in winter and spring, simulated DO concentrations generally reproduce observed concentrations. As the reservoir stratifies, both simulated and observed profiles exhibit similar shapes. However, from June into September, the simulated thermocline can be as much as 15 to 20 ft (4.5 to 6.0 m) lower than measured data for all years. DO in both simulated and observed profiles tend to be depleted in a water layer at, or around, the inflection point of the thermocline. Because simulated and observed thermoclines are different, the locations of these depletion layers are offset. Additionally, simulated DO

concentrations tend to be greater than observed concentrations in the hypolimnion. In fall, simulated DO profiles more closely resemble observed profiles and reproduce oxygen depletion in the hypolimnion.

Nutrient concentrations simulated during calibration generally reproduce observed concentrations and distributions, and are particularly representative of N-NH3 and P-PO4 in summer and fall of 2000. Simulated values reflect an increase in N-NO3 with depth, as reported, but tend to underestimate N-NO3 concentrations in 2001. Simulated algae concentrations are generally representative of observations, but the model tends to overestimate algae concentrations in late summer and underestimate concentrations in fall.

Validation

Water temperature profiles from validation simulations also match observed at all depths in all seasons except for consistent overestimation in the area of the thermocline during times of stratification. Observed top and bottom temperatures are closely and consistently matched by simulated values except in 2003 when simulated temperatures tend to overestimate temperatures observed in the hypolimnion. Validation results for dissolved oxygen are similar to calibration results. When the reservoir is mixed, simulated DO concentrations generally reproduce observed concentrations. As Iron Gate reservoir stratifies, both simulated and observed profiles exhibit similar shapes but the shapes are offset and distorted because simulated DO concentrations tend to be greater than observed concentrations in the hypolimnion. In fall, simulated DO profiles more closely resemble observed profiles and reproduce oxygen depletion in the hypolimnion.

Nutrient concentrations simulated during validation generally reproduce observed concentrations and distributions, and are particularly representative of all nutrients for all three sampling dates in 2003. Observed decreases in surface concentrations of N-NO3 during spring and summer months are reflected in simulation results. Generally, simulated algae concentrations are representative of observed values, but there are several dates in 2002 when observed algae do not show up in simulated results.

Discussion

There are several factors that warrant discussion with regard to Iron Gate Reservoir water quality. One point is the location of the thermocline in simulation results during the summer period. Sensitivity analyses were completed on the both the location of the lower fish hatchery intake and the quantity of water used by the fish hatchery. The simulated location of the thermocline is sensitive to both features. If the intake is raised even modestly (e.g., 10 feet (3m)), the simulated thermocline rises accordingly. Review of construction drawings suggest that the lower fish hatchery intake is properly represented. However, features of the intake may predispose waters to enter from higher in the reservoir (e.g., final constructed configuration). These possible features cannot be assessed because as-built drawings are unavailable. The feature more likely to be affecting simulations is the assumed hatchery intake rate. Based on conversations with hatchery staff, hatchery intake rate is currently assumed to be 50 cfs.

Low DO conditions in Iron Gate reservoir probably have some bearing on autochthonous demand (algal mortality), but are most likely directly affected by the influx of organic matter and

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nutrients from upstream sources, which also serves to increase in-reservoir production. Improvement of the Link dam boundary conditions and accurate assessment of fish hatchery intake quantities would most likely improve simulations in Iron Gate reservoir.

3.5.3.8 Iron Gate to Turwar Reach

Like other reaches, the RMA-11 model for Iron Gate to Turwar was calibrated with 2000 and 2001 data and validated with 2002-2004 data. The discussion is presented generally by constituent and extends downstream to illustrate model performance in determining transport and fate of simulated constituents. Calibration and validation locations presented here include the Klamath River below Iron Gate dam, above the Shasta River, near Seiad Valley, at Orleans, above the Trinity River, and at Turwar. It is important to recall that these results have been passed through three river reaches and four reservoirs en route to Iron Gate dam. Thus, uncertainty in model results for this reach includes the sum of uncertainty introduced in upstream model representations.

Calibration

Water temperature from the CE-QUAL-W2 model of Iron Gate reservoir formed the upstream boundary conditions for the Iron Gate to Turwar Reach. Results from calibration years indicate that the model reproduced field-observed temperatures for sub-daily, short duration, and seasonal conditions. At sites in the upper part of the reach, the simulated diurnal range corresponds to measured data, but in the lower river the simulated diurnal range is suppressed. Overall, mean daily temperatures are similar to field observations at all locations.

DO conditions are underestimated below Iron Gate dam during summer and fall periods for both calibration years. Downstream locations, away from the influence of Iron Gate dam, are representative of field conditions in amplitude and timing.

Nutrients are generally well represented in the calibration period, although some scatter in the data is evident.

Validation

Results from validation years indicate that simulated temperatures match field-observed values for sub-daily, short duration, and seasonal conditions. However, in 2003 and 2004, model results underestimate temperature in the late winter and spring. At sites in the upper part of the reach, simulated diurnal range corresponds to measured data, but in the lower river, simulated diurnal range is suppressed. Overall, mean daily temperatures are similar to field observations at all locations.

DO concentrations are underestimated below Iron Gate dam during summer and fall periods for all three validation years. Downstream locations, away from the Iron Gate dam influence, are representative of field conditions in amplitude and timing but local deviations occur.

As with the calibration period, nutrients are generally well represented in the calibration period. Although there is some scatter in the field data, summer minimums for N-NO3 and seasonal

increases in N-NO3 and P-PO4 in the late summer and fall are clearly represented in simulated values.

Discussion

Water temperature below Iron Gate reservoir is moderated by a relatively deep release from Iron Gate reservoir. The model effectively reproduced this suppressed diurnal variation. It is also pertinent to note that immediately downstream of Iron Gate dam, simulated temperatures were not appreciably affected by the Iron Gate reservoir simulation wherein the thermocline was lower than observed during summer periods. Careful examination of the simulation suggests that much of the water leaving the reservoir is from the top 20 or 30 feet of the water column, where simulated thermal profiles are more similar to observations. In the validation period, simulated location of the Iron Gate reservoir thermocline appeared to have a larger impact than during calibration.

Progressing downstream, water temperatures begin to respond more to local meteorological conditions than to conditions at Iron Gate dam. Seasonal trends and responses to short-duration events are well represented. In some years, simulated diurnal range is more representative of observations than in others. In the lower river, where alluvial processes are dominant and channel form is highly variable, the trapezoidal cross-section may not fully represent actual conditions. Accurate representation of daily mean values indicates that tributary boundary conditions have been effectively specified and/or estimated.

Simulated DO concentrations are lower below Iron Gate dam than observations during summer and fall months. These conditions, largely due to simulated Iron Gate dam outflows are quickly remedied through mechanical reaeration. Model performance is more consistent with field observations at all downriver sites. Variability in diurnal range (both spatially and temporally) in both the simulated output and the prototype is due to complex interactions between nutrient availability, benthic algae growth, stream geometry, and light limitation. Although recent field campaigns have improved characterization of benthic flora, these interactions are incompletely understood. Algal biofouling of water quality probes further confounds efforts to characterize DO conditions by increasing uncertainty in field data. Nonetheless, model simulations show promising results.

Overall, simulated nutrients correspond to field observations along the longitudinal profile of the river, with higher-level and seasonal variations more prominent in the upper river reach and lower, less variable conditions in the lower reach. Reproduction of seasonal trends is evident in the model results. Phytoplankton populations are likewise well represented in all years where data are available.

One of the most critical aspects of the Iron Gate dam to Turwar calibration is the fact that these simulation results represent the end product of all upstream modeling. Results below Iron Gate dam, extending to Turwar, suggest that the model replicates a majority of system processes and effectively reproduces temperature, dissolved oxygen, nutrients, and algae. During processing of the data, numerical instability in some ammonia concentrations was identified. The overall impact was deemed not to adversely affect model results.

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4.0 MODEL SENSITIVITY

Sensitivity analysis is a test of the impact that changes in a single model variable or parameter can have on model results. Such analyses can be used to identify important characteristics of a system. Sensitivity analysis can be used to:

- confirm that model response is consistent with theory,
- quantify the effect of error on state variables,
- identify sensitive parameters or variables that must be reliably estimated,
- indicate the relationship between control variables and decision (or state) variables to help ensure that a change in control variable can have a desirable effect on the decision variables, and
- identify regions of "design invariance" where target levels of decision variables are insensitive to errors of estimation in control variables and parameters.

The amount of sensitivity analysis that has occurred for the Klamath River modeling framework through the implementation, subsequent updates, and extension of the model for additional years is extensive. In this large, multifaceted, complex system a formal sensitivity analysis would be a large effort in itself. For this study, selected model parameters in both the RMA and CE-QUAL-W2 models were varied to determine the model's relative sensitivity to them. In this analysis, one model variable or parameter is changed while all others remain constant, and the impact of this change on a particular model state variable (e.g., temperature) is observed. Neither flow, water quality, nor meteorological boundary conditions were altered; however, during implementation these parameters were varied over a large range and model testing was extensive. Generally, parameters used in calibration were also tested for sensitivity.

This qualitative assessment gives an estimate of the sensitivity of important state variables to particular parameters, and provides insight on model performance (e.g., was model consistent with theory?). All parameter values were changed over representative ranges.

Conditions are highly variable throughout the Klamath River system and sensitivity varied by season and reach. Because reaction rates typically depend upon temperature and residence time, seasonal air temperature, flow, and reach length or volume had noticeable impact on sensitivity. Water quality typically shows less sensitivity to parameter change during cooler seasons, in shorter river reaches, and in reservoirs with less volume. Although presented herein as qualitative results, the actual model simulations were quantitative.

4.1 RMA PARAMETERS STUDIED FOR SENSITIVITY

Water quality in river reaches was tested for sensitivity to ten parameters. These ten parameters included the five variables used in calibration (roughness, slope factor, two evaporation constants, and light extinction) and the five other variables selected for their expected influence (reaeration rate constant, bed algae growth and respiration rate constants, atmospheric pressure,

and algal ammonia preference). Results of sensitivity testing in river reaches are outlined in Table 28. The tested parameters, as identified in model literature, are:

- n – Manning roughness coefficient
- SF – Slope Factor fraction to reduce bed slope of river to approximate water surface slope in solution of flow equations
- EVAPA, EVAPB – Evaporative heat flux constants
- RK2MIN – Minimum reaeration rate
- MUMAX – nominal bed algae growth
- RESP – bed algae respiration rate
- EXTINC – non-algal light extinction
- EA – atmospheric pressure
- PBREFN –algal preference for ammonia

For a full description of model parameters the reader is referred to the user's manual for RMA-2 and RMA-11 (King 2001, 2002).

Generally, water temperature was sensitive to bed roughness and slope factor, both parameters that directly impact travel (or, residence) time through the river reaches. Temperature was also highly sensitive to the evaporative heat flux parameters. In addition, temperature response was tested under different geometric representations of the system. Specifically, temperature output from several reaches was examined while varying river width and side slope. Impacts resulting from moderate geometric changes were generally modest, with the notable exception that marked changes in river width can dramatically impact travel time and thus water temperature. Changing nodal resolution of the models from 75 meters and 150 meters had negligible effect on water quality.

DO was sensitive to minimum reaeration rate and highly sensitive to algal growth and respiration parameters. In particular, if minimum reaeration rate is set too high, an excess of respiration occurs. Nutrients were generally low-to-moderately sensitive to algal growth parameters, but ammonia and nitrate concentrations were sensitive to ammonia preference factor. Nutrients were moderately sensitive to light extinction in certain river reaches because, under high extinction rates, benthic algal growth was light limited and nutrient uptake suppressed. Algal concentrations were very sensitive to growth rate, respiration rate, and light extinction.

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Table 28. RMA-11 Water Quality Constituent Sensitivity to Different Modeling Parameters

Parameter	State variable					
	Temperature	**DO**	**PO4**	**NH4**	**NO3**	**Algae**
Manning n	H	-	-	-	-	-
SF	H	-	-	-	-	-
EVAPA	H	L	-	-	-	-
EVAPB	H	L	-	-	-	-
IREAER*	N	H	N	L	S	-
MUMAX	N	H	N	L	S	H
RESP	N	H	N	-	-	H
PBREFN	N	-	N	M	M	L
EXTINC	N	M	-	L	L	H
EA	N	L	-	-	-	-
Bathymetry	M	L	-	-	-	-

N– no sensitivity
L– low sensitivity
M– moderate sensitivity
H– high sensitivity
If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

4.2 CE-QUAL-W2 PARAMETERS STUDIED FOR SENSITIVITY

4.2.1 Assessment

Twenty parameters were tested for their impact on water quality in reservoir reaches modeled by CE-QUAL-W2. These twenty parameters included a wide range of parameters selected for their demonstrated influence on water quality. The tested parameters, as identified in model literature, are:

- AFW, BFW, and CFW - Evaporative heat flux coefficients
- AG - Algal Growth Rate
- AR - Algal Respiration Rate
- AM - Algal Mortality Rate
- ASAT - Algal light saturation intensity at the maximum photosynthetic rate
- SOD- Sediment Oxygen Demand
- CBHE - Bed heat conduction coefficient
- TSED - Specified bed temperature: TSED

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- EXSS Light Extinction due to inorganic suspended solids:
- EXOM - Light extinction due to organic matter
- EXH20 - Light extinction due to water
- EXA - Light extinction due to algae
- BETA - Solar radiation absorption fraction: the BETA parameter is the fraction of incident solar radiation absorbed at the water surface
- LDOMDK - Labile organic matter decay rate
- POMS - Particulate organic matter settling rate
- NH4DK - Ammonia decay rate
- NO3DK - Nitrate decay rate
- O2LIM - Aerobic/anaerobic oxygen Limit: user defined oxygen limit refers to the concentration below which anaerobic processes begin to be simulated.

Results of sensitivity testing in reservoir reaches are outlined in Table 29. Generally, temperature was sensitive to evaporative heat flux parameters. In the deeper reservoirs (i.e., Copco and Iron Gate), impacts were observed over longer periods than in the shallow reservoirs (i.e., Keno and J.C. Boyle). In deeper reservoirs with longer residence time, bottom water temperature was moderately sensitive to bed heat exchange coefficient.

DO was sensitive to algal growth, respiration, and mortality. Parameters affecting algal growth, such as the various light extinction parameters, also affected dissolved oxygen concentrations. In reservoirs with long residence times, organic matter decay rates noticeably impacted DO concentrations. DO sensitivity to ammonia decay rate was low.

Nutrients were generally low-to-moderately sensitive to algal growth parameters and associated parameters such as extinction, and nitrate was notably more sensitive to these parameters than ammonia. Algal concentrations were very sensitive to growth rate, respiration rate, and light extinction.

Table 29. CE-QUAL-W2 Water Quality Constituent Sensitivity to Different Modeling Parameters

Parameter	State Variable					
	Temperature	**DO**	**PO4**	**NH4**	**NO3**	**Algae**
AFW	M	-	-	-	-	-
BFW	M	-	-	-	-	-
CFW	L	-	-	-	-	-
AG	N	L	L	L	H	H
AR	N	M	L	L	M	H
AM	N	M	L	L	M	H

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Table 29. CE-QUAL-W2 Water Quality Constituent Sensitivity to Different Modeling Parameters

Parameter	State Variable					
	Temperature	**DO**	**PO4**	**NH4**	**NO3**	**Algae**
ASAT	-	-	-	-	-	-
SOD	N	M	M	N	N	L
CBHE	M	-	-	-	-	-
EXSS/EXOM	N	H	L	L	M	H
EXH2O	N	H	M	L	M	H
BETA	N	H	M	L	M	H
EXA	N	H	L	L	H	H
LDOMDK	N	M	L	L	L	N
POMS	N	L	L	L	L	N
NH4DK	N	L	N	L	L	N
NO3DK	N	N	N	N	M	N
O2LIM	N	N	M	N	L	N
Bathymetry	H	H	H	H	H	H

N – not sensitive
L – low sensitivity
M – moderate sensitive
H – high sensitivity
If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

4.3 OTHER CONSIDERATIONS

As noted above, the model was tested widely throughout the implementation and calibration phase, as well as during model modification, update, and application. Outlined below is a brief discussion of selected aspects of the modeling framework that were tested and considered while completing the various simulation and modeling tasks.

4.3.1 System Geometry

A number of modifications to the geometry of river and reservoir reaches were made during model development and implementation. Additional resolution was added to all reservoirs with the exception of Keno reservoir to assess sensitivity to layer thickness. The models in general are sensitive to layer thickness and simulation results improved (as compared to measured data) in all cases with finer layer thickness to a point where further refinement yielded no additional benefit. At this point the balance of computational effort and grid resolution was examined and final layer thickness selected. For example, at J.C Boyle reservoir a 1.6 ft (0.5m) thick layer versus a 3.2 ft (1.0 m) layer made a 20 hour difference in the model's run time because, at the small layer thickness, the model continually added and subtracted segments in response to peaking operations. Additional simulations with different segment lengths and layouts were completed as well. Lake Ewauna-Keno reservoir was tested using three bathymetric

representations: the original bathymetry from ODEQ (1995), a fictitious bathymetry to determine if model results were sensitive to a different geometry, and new bathymetry from a 2003 survey (PacifiCorp, 2004a). Findings suggest that water quality in this reservoir is sensitive to bathymetry and that using the best available data is important in effective representation. The 2003 data (PacifiCorp, 2004a) are currently used in the model.

River reaches were likewise examined in terms of inter-node distance, cross sectional width, and side slope. Both 490 ft (150 m) and 246 ft (75 m) inter-node distances were examined. In most reaches, a 246 ft spacing was selected, but for the longer Iron Gate to Turwar reach a 490 ft spacing was used because the differences in simulated output between the two node spacing were negligible and the run time was reduced by 50 percent. In addition, different river widths were examined in the J.C. Boyle bypass-peaking reach, Keno reach, and Link River reach prior to field data becoming available. These early runs were instrumental in our understanding of the importance of incorporating field data into our geometric representation.

4.3.2 Meteorological Data

Both during implementation and during subsequent updates, various meteorological specifications were attempted and model response assessed. Initially, Klamath Falls data was used for the entire system, with corresponding lapse rates applied to selected parameters. This approach was abandoned in favor of meteorological data from site specific locations along the river. However, there were multiple meteorological stations which required the river to be broken down into discrete reaches where meteorological conditions would be applied. The entire river network was run under various conditions (as well as discussions with local basin residence) to identify which meteorological conditions would apply to which reach. Throughout this process, multiple runs were completed and the model sensitivity assessed. Overall, in the short river reaches, meteorology had a modest impact. The longer river reaches and the long residence time reservoirs responded more strongly.

4.3.3 Flow

Flow conditions were largely taken from field observations and was widely tested during calibration. The river flow model was most sensitivity to the bed roughness and slope factor, as expected. The reservoir models were most sensitive to geometric presentation. Because the inflow and outflow are explicitly specified, there is little to assess beyond stage. Overall, the reservoir applications were insensitive to bed roughness.

4.3.4 Water Quality

The range of water quality parameters used in model testing the various reaches, seasons, and years creates hundreds of possible permutations. As noted above, the reaches were initially modeled independently then combined into the framework. Model parameters were modified and tested over multiple iterations to identify system response and to compare results with field data. Impacts of changes to model parameters and boundary conditions were explored at Link dam and inflows to Keno reservoir to assess their local impacts, as well as translating those impacts through all downstream reaches.

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4.4 SUMMARY

Water quality modeling parameters most influential in prediction of water temperature and DO are similar for both RMA-11 and CE-QUAL-W2:

- Water temperature is most sensitive to evaporative heat flux parameters, and
- DO and algae concentrations are most sensitive to algal growth dynamics and light extinction.

It is useful to note that these are common calibration parameters in water quality modeling. Based on all of these tests, the models were updated or modified to best characterize the Klamath River system.

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5.0 MODEL APPLICATION

The Modeling framework has been applied to several scenarios identified by PacifiCorp and stakeholders. These include but are not limited to:

- Existing Conditions (EC)
- Steady Flow (no hydropower peaking) (SF)
- Without Project facilities (WOP)
- Without Project facilities, smoothed flows from Klamath Irrigation Project (WOP II)
- Without Iron Gate dam (WIG)
- Without Iron Gate, Copco 1, and Copco 2 dams (WIGC)
- Without Iron Gate, Copco1, Copco2, and J.C. Boyle dams (WIGCJCB
- Selective withdrawal at Iron Gate reservoir only
- Selective withdrawal at Copco reservoir only
- Selective withdrawal at both Copco and Iron Gate reservoirs
- Reservoir curtains at Copco and Iron Gate reservoirs
- Flow augmentation via drawdown of Copco and Iron Gate reservoirs
- Variable J.C. Boyle releases to the bypass reach

Results from these scenarios have been produced in tabular form, and in some cases graphical form, for 26 sites identified by Stakeholders (Table 30).

These scenarios have been developed and documented through stakeholder meetings, technical memoranda, and other reports. The individual applications are not detailed herein, but rather the reader is referred to specific documents addressing the scenarios.

Table 30. Modeling Framework Reporting Location (For Existing Conditions)

Location	River Mile	Model Node (Seg)*
Link Dam	253.88	1
Link River at LE	252.67	27 (2)
RM 248	248	(26)
RM 243	243	(53)
RM238	238	(79)
Keno Dam	232.86	1 (107)
Above JC Boyle	227.57	115
JC Boyle Dam	224.32	(21)

Table 30. Modeling Framework Reporting Location (For Existing Conditions)

Location	River Mile	Model Node (Seg)*
bel JC Boyle Dam	224.32	1
Above Powerhouse	220.2	91
Below Powerhouse	220.02	95
Stateline	209.16	331
Above Copco	203.6	451 (18)
Irongate Dam	190.54	1 (31)
Above Shasta River	177.52	142
At Walker Bridge	156.79	369
Above Scott River	143.86	511
At Seiad Valley	129.04	672
Above Clear Creek	99.04	998
Above Salmon River	66.91	1352
At Orleans	57.58	1454
Above Bluff Creek	49.03	1547
Above Trinity River	43.33	1609
At Martins Ferry	39.5	1651
At Blue Creek	15.95	1908
At Turwar	5.28	2024

* Nodes are associated with the river models RMA-2 and RMA-11, while segments are associated with the reservoir model CE-QUAL-W2. Point of common locations are denoted by both a node and segment number.

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6.0 CONCLUSIONS

All system components have been calibrated to available data in spring, summer, and fall. Lack of data precluded formal calibration of the models during winter months. In complex systems like the Klamath River, additional information and model testing are always recommended but, with calibration and validation done to date, the Klamath River modeling framework is considered complete. The Klamath River model and its individual components have been extremely effective at illustrating flow and water quality processes throughout the system. System characterization, model implementation, sensitivity testing, and calibration have resulted in a greatly improved understanding of Klamath River flow and water quality.

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Data Review and Modeling Approach

Klamath and Lost Rivers TMDL Development

April 23, 2004

Prepared for:
U.S. Environmental Protection Agency Region 10
U.S. Environmental Protection Agency Region 9
Oregon Department of Environmental Quality
North Coast Regional Water Quality Control Board

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EXECUTIVE SUMMARY

The Oregon DEQ (ODEQ) and the North Coast RWQCB (NCRWQCB) have both included the Klamath and Lost Rivers on their corresponding 303d Lists as a result of observed water quality criteria exceedances. As such, the states are required to develop TMDLs for applicable water quality parameters. To support the TMDL development effort, data from numerous sources have been compiled and a preliminary data analysis has been performed. In addition to evaluating available data (with a focus on flow and water quality spatial and temporal variability), proposed and alternative modeling approaches for both the Klamath and Lost Rivers have been developed.

Water quality data for the Klamath and Lost Rivers obtained from ODEQ, USBR, NCRWQCB, City of Klamath Falls, USGS, and PacifiCorp Inc. are included in this document. Additional data have been received since the document was produced, including data from USFWS, the Karuk Tribe, the Yurok Tribe, BLM, and KRIS Klamath Trinity Version 3.0. While these critical datasets are not summarized in this document, they have been compiled in the water quality database and will be used to support model and TMDL development. The period of record varied significantly for each data source, but covered the overall period from 1950 to 2003 for both rivers. Temperature, dissolved oxygen, nutrients, chlorophyll a, bacteria, and pH data were evaluated in the most detail. General statistics, such as minimum, maximum, and mean (or median, log mean, or geometric mean) values were calculated for monitoring stations along the lengths of both rivers to better understand spatial variability and extreme conditions. In many cases, water quality data were also compared directly to prescribed water quality criteria to identify the extent of impairment. For temperature and dissolved oxygen, spatial plots for critical summer months were additionally developed to provide insight into problems at specific locations and potential sources contributing to impairments. As data continue to be compiled and included in the master Klamath River and Lost River databases and model preparation begins, additional spatial and temporal data analyses will be performed to ultimately support model calibration.

A proposed modeling approach and an alternative modeling approach were developed for both the Klamath River (from Upper Klamath Lake to the Pacific Ocean) and the Lost River (from Malone Dam through the Klamath Straits Drain) to support TMDL development. These approaches were developed based on a review of available data, reports, and existing models, and they are subject to approval of the TMDL Workgroup.

The proposed approach for the Klamath River is to combine a series of alternating 1-dimensional models for riverine sections and 2-dimensional models for impoundments and tidal regions. Specifically, the RMA-2 and RMA-11 models will be applied for Link River, Keno Dam to J.C. Boyle Reservoir, Bypass Reach, the Full Flow Reach, and Iron Gate Dam to Turwar. RMA-2 simulates hydrodynamics while RMA-11 represents water quality processes. The CE-QUAL-W2 model will be applied for Lake Ewauna-Keno Dam, J.C. Boyle Reservoir, Copco Reservoir, Iron Gate Reservoir, and the Klamath River from Turwar to the Pacific Ocean. Application of the CE-QUAL-W2 model to the Klamath River downstream of Turwar is subject to the availability of bathymetric data and sufficient water quality monitoring data to support model calibration. The alternative approach for Klamath River modeling is to develop a model using only CE-QUAL-W2. This model would also be configured for the length of the Klamath River from Upper Klamath Lake to the Pacific Ocean, however, it would be a single, integrated model.

The proposed approach for Lost River TMDL modeling is to develop a CE-QUAL-W2 model for the entire Lost River system from Malone Dam to the outlet of the Klamath Straits Drain (into the Klamath River). The model will include the Lost River itself, Tule Lake (and Tule Lake Sump), the P Canal, the Lower Klamath Lakes, and the Klamath Straits Drain. All other canals and drains in the Klamath Project will be incorporated into the modeling framework as time-series flow and water quality inputs at discrete

locations (based on available monitoring data and literature, as necessary). These canals and drains will not be explicitly simulated in the modeling framework. The alternative approach is to develop a modeling framework using a 1-dimensional version of EFDC (Environmental Fluid Dynamics Code) for riverine portions of the Lost River (from Malone Diversion Dam to Tule Lake) and WASP/EUTRO box models for Tule Lake/Tule Lake Sump and Lower Klamath Lake.

Based on the review of available data to date, a number of critical data gaps/needs have been identified. It is important to fill these gaps to support the modeling effort, either by accessing the data from appropriate sources (assuming the data already exists in some state) or by targeting these gaps during data collection efforts over the upcoming year. Key data sets that are needed include:

- Cross-section and slope data along the main channel of the Lost River
- Data for all impoundments/reservoirs on the Lost River, including bathymetric data (width, depth, etc.), dam size, dam height (up- and down-stream of the dam), rating curves, and operation data
- Return flow information, including the locations of drains, flow rates, water quality concentrations (temperature, DO, Ortho-P, NH3, NO2/NO3, CBODu [or CBOD5 and CBOD20], Org-N, Org-P, pH, and conductivity), and corresponding sources (i.e., contributing areas, crops, original irrigation water source, etc.)
- Flow and water quality data (temperature, DO, Ortho-P, NH3, NO2/NO3, CBODu [or CBOD5 and CBOD20], Org-N, Org-P, Chl-a [phytoplankton], pH, and conductivity) for:
    - the Lost River downstream of Malone Dam
    - Miller Creek upstream of the confluence with Lost River
    - Bonanza Creek upstream of the confluence with Lost River
    - Buck Creek upstream of the confluence with Lost River
    - “E” canal upstream of the confluence with Lost River
    - “F-1” canal upstream of the confluence with Lost River
    - Lost River diversion channel upstream of the confluence with Lost River
    - “P” canal downstream of Pump “D”
    - “A” canal at its starting point at Link Dam
    - ADY Canal before entering Lower Klamath Lake and at its source on the Klamath River
    - New North canal at its source on the Klamath River and at the point before discharging for irrigation
    - Cottonwood, Sheepy, and Willow Creeks before entering Lower Klamath Lake.
    - From the Lost River to the J Canal
- Pumping (flow) data for:
    - the main pump stations along the Lost River
    - Tule Lake Sump
    - Lower Klamath Lake
- Periphyton, phytoplankton, and macrophyte information to characterize primary productivity and determine species presence and dominance (e.g., information regarding distribution between blue-greens, diatoms, and green algae species)

Once the modeling approaches are finalized and data gaps are filled, the Klamath and Lost River modeling systems will be constructed, calibrated, and validated. Upon completion of model calibration and validation, sensitivity analyses will be conducted to better understand the response of the systems to variations in external loadings and kinetic parameters. Ultimately, the tested models will be run for a series of scenarios aimed at achieving prescribed TMDL targets, based on input from the TMDL Workgroup.

1.0 INTRODUCTION

The Oregon DEQ (ODEQ) and the North Coast RWQCB (NCRWQCB) have both included the Klamath and Lost Rivers on their corresponding 303d Lists as a result of observed water quality criteria exceedances. As such, the states are required to develop TMDLs for applicable water quality parameters. The first steps in the TMDL development process include compilation of available data; evaluation of monitoring data to identify the extent, location, and timing of water quality impairments; and development of a technical approach to analyze the relationship between source pollutant loading contributions and in-stream response. This document addresses these steps for the Klamath and Lost Rivers.

The first sections provide background information for the Klamath River Basin and its impairments and summarize data that are currently available for the Klamath and Lost Rivers, with a focus on the Lost River and data downstream of Upper Klamath Lake for the Klamath River. The summary includes a description of most monitoring data compiled to date (although a number of datasets were not received with enough lead time to include in the analysis) as well as reports and geographic data sets currently available. Water quality data for the Klamath and Lost Rivers obtained from ODEQ, USBR, NCRWQCB, City of Klamath Falls, USGS, and PacifiCorp Inc. are included in this document. Additional data have been received since the document was produced, including data from USFWS, the Karuk Tribe, the Yurok Tribe, BLM, and KRIS Klamath Trinity Version 3.0. While these critical datasets are not summarized in this document, they have been compiled in the water quality database and will be used to support model and TMDL development. Results of a preliminary and ongoing data analysis are then presented. The goal of this analysis is to gain insight into the characteristics of water quality impairments in the Klamath and Lost Rivers, including the timing, locations, and extent of impairment. Therefore the analysis includes temporal and spatial summaries of water quality data and comparisons of historical conditions to state water quality criteria. The primary focus of the analysis is on the Lost River since a number of reports by PacifiCorp and others have served to characterize conditions in the Klamath River. Where data are presented for the Klamath River, the focus is on the river downstream of Iron Gate Dam, since the first phase of the Klamath modeling effort focuses on this region. Data upstream of the dam will continue to be collected and evaluated over the course of this effort. Following the data analysis is a proposed technical approach for linking source contributions to in-stream response for each of the rivers. An alternative approach is also presented for each.

1.2 Data Availability and Data Needs

The following tables outline the key datasets that are needed for the TMDL modeling effort. The information ranges from geographical/political information such as County boundaries and land use to water quality and flow data. The “currently available to Tetra Tech” column identifies the information already obtained. The “Local Data Sources” identifies additional datasets that may be available and would be useful for the analysis. The “Priority” column identifies the highest priority of the outstanding data needed to support the analysis.

Table 1-1. Geographic or Locational Information

Data Type	Currently Available to Tetra Tech	Local Data Sources	Priority
Reservoir boundaries and stream network	EPA BASINS Reach File coverages (RF1, RF3), NHD, USGS 7.5' Quads, USBR drains	ODEQ, NCRWQCB, or other digitized stream network, reservoir boundaries	
County boundaries, cities/towns, populated places	BASINS		
Land use (including % impervious)	USGS Multi-Resolution Land Characteristics (MRLC) - developed early 1990s	Local watershed land use information, e.g. County coverages	
Soils	STATSGO (entire state), SSURGO (select counties)	County soil surveys	
Watershed boundaries	USGS Hydrologic Unit Boundaries (8-digit)	Agency-specific watershed boundaries	
Topographic relief and elevation data	USGS 7.5 minute Topos, Digital Elevation Models		
Water quality and biological monitoring station locations	EPA STORET See section 3.4 – Tables 3-8 and 3-9 for a list of datasets received	Agency-specific monitoring station locations (spatial coverages, if available, or coordinates)	Y
Meteorological station locations	NOAA-NCDC, EarthInfo Data	Local weather stations, e.g. County; The Pacific Northwest Agricultural Weather Network PacifiCorp weather data	Y
Permitted facility locations	EPA's Permit Compliance System (PCS)	ODEQ and NCRWQCB discharge locations (spatial coverages, if available, or coordinates)	Y
Hazardous waste sites	BASINS - CERCLIS and TRI data		
CAFOs	Not yet obtained		
Active and abandoned mine locations	Not yet obtained		
Dam locations	BASINS	Dam size, type, difference in up- and downstream of dam elevation, rating curve	
Water intakes/withdrawals/diversions	USBR, PacifiCorp Klamath Model		Y
CSO and storm water inflows	No data for Lost River PacifiCorp Klamath Model	County outfall locations	Y
Septic/Sewer spatial coverages	Not yet obtained	County surveys and coverages	

Table 1-2. Monitoring Data

Data Type	Currently Available to Tetra Tech	Local Data Sources	Priority
Flow data	USGS historical streamflow data, see section 2.1.3 Report: Klamath Project Historical Water Use Analysis, Davids Engineering 1998	Agency-specific continuous and instantaneous flow data in Lost River system, especially at each major tributary (and canal) influence, upstream boundary, return flow, and pumping flow	Y
Meteorological data	NOAA-NCDC, EarthInfo, see section 2.1.2	Local weather data, e.g. County; precipitation, temperature, solar radiation, dew point, wind speed, humidity, cloud cover, etc.	Y
Water quality data (including ambient, lake monitoring, sediment, fish tissue, and special study data)	STORET, see section 3.4 – Tables 3-8 and 3-9	Agency-specific: Historical and current water quality monitoring data for the reservoirs, main-stem rivers and upstream tributary stations, upstream tributaries (canals) and return flows. Preferred all the WQ data stations to be associated with the flow data. Include temperature, diel D.O. data, chlorophyll a, limiting nutrients, and other data (sediment, fish tissue, conductivity, etc.)	Y
Biomonitoring and habitat data	Data obtained not yet reviewed	Agency-specific: Historical and current biomonitoring data (benthic macroinvertebrate data, fish community data, periphyton, etc.) Also habitat data, including aquatic vegetation biomass, algal data, primary production rates, habitat surveys, riparian vegetation buffer widths, sediment characteristics, etc.	Periphyton and other macrophyte data are of priority
Reservoir, Canals, etc. physical data		Volume, surface area, discharge characteristics, water balance, bathymetry, other information	Y
Stream channel data (for rivers and upstream tributaries)	Some cross section data obtained, not yet reviewed	Rating curves, cross sectional data, slope, other physical characteristics	Y
Permitted facilities	PCS, see previous page	ODEQ, NCRWQCB: permit limits, design flow, DMR data, information other discharges	Y

Table 1-3. Land Practices and Activities

Data Type	Currently Available to Tetra Tech	Local Data Sources	Priority
Septic systems and illicit discharges	U.S. Census (county information available)	Public health agency: septic population, failure rates, short-circuited systems, illicit discharge data, etc.	
Livestock and wildlife	USDS-NRCS Agricultural Census	Livestock population estimates, livestock management (confinement, grazing, stream access), wildlife population estimates & habitat information	
Major crops, rotation, management	USDA-NRCS Agricultural Census, Report: Farming Practices and Water Quality in the Upper Klamath Basin, Kaffka et al., 2002	Cropping practices, major crops, tillage	
Manure application, fertilizer, pesticide use, biosolids	USDS-NRCS Agricultural Census	Public health agency: manure application rates and lands applied to, fertilizer use information, pesticide use, biosolids	
Timber practices	Not yet obtained	U.S. Forest Service, State Forest Services: timber harvest activities	
Mining activities, reservoir dredging	Not yet obtained	Surface mining information, reservoir dredging history, etc.	

2.0 WATERSHED CHARACTERIZATION

The intent of this section of the document is to put the subject water bodies into context with the watershed in which they occur. This section provides the reader with a general understanding of the environmental characteristics of the watershed that may have relevance to the 303(d) listed water quality impairments. This section also provides some detail regarding those characteristics of the watershed that may play a significant role in driving pollutant loading (e.g., geographical distribution of soil types, vegetative cover, land use, etc.). The information provided in this section is provided for context. A more detailed consideration of some of this information, at a finer scale, will be included in the subsequent documents.

2.1 Physical Characteristics of the Klamath River Watershed

2.1.1 Location

The Klamath River watershed traverses the states of Oregon and California, encompassing an area of approximately 15,722 square miles. The headwaters of the Klamath River originate in the Cascade Mountains and the river flows to the southwest from Oregon into northern California toward its confluence with the Pacific Ocean as shown in Figure 2-1. Major tributaries to the Klamath River include the Shasta River, the Scott River, the Salmon River, and the Trinity River.

The watershed includes portions of Jackson, Josephine, Klamath, and Lake Counties in Oregon, and Del Norte, Humboldt, Modoc, Siskiyou, and Trinity Counties in California. Nearly 63 percent of the watershed (roughly 9,933 square miles) lies in California, while 37 percent (5,727 square miles) is located in Oregon. The Klamath River watershed includes twelve U.S. Geological Survey (USGS) 8-digit hydrologic cataloging units, numbers 18010201 through 18010212.

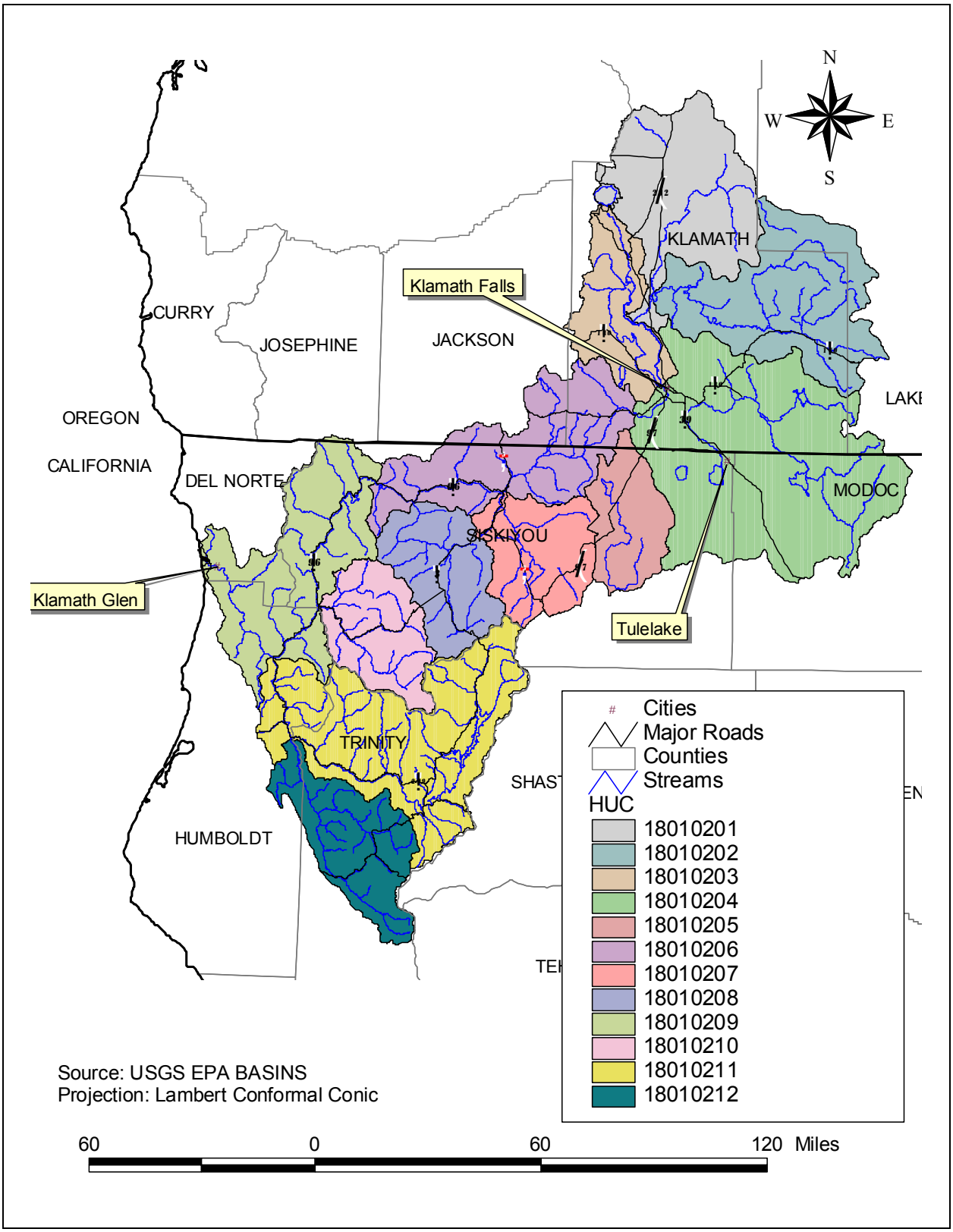

Figure 2-1. Location of the Klamath River watershed.

2.1.2 Climate

Climate in the Klamath River watershed is distinctly different in the upper and lower portions of the basin. The upper portion of the watershed, located in the rain shadow of the Cascade Mountains, has a relatively low mean annual precipitation, approximately 27 inches, about half falling as snow. Mean annual precipitation in the lower portion of the watershed is much more variable and can be as high as 100 inches per year near the Pacific coast. Subtropical storms can also strike the Klamath Watershed from December to early March (NRC, 2003).

The National Oceanic and Atmospheric Administration (NOAA) collects data from many climate stations located within the Klamath River watershed as shown in Figure 2-2 and listed in Table 2-1. Data for these stations include precipitation and minimum and maximum temperature. A graphical summary of the average climatic characteristics at a station is called a climagraph. The climagraphs in Figures 2-3 and 2-4 illustrate the climatological differences between the northern portion of the watershed, located in the rain shadow of the Cascade Mountains, and the southern portion of the watershed, located in the coastal mountains. Station CA9053, located in the northern portion of the watershed, has a semi-arid climate with an average of less than 2 inches of rainfall per month with the majority of the winter precipitation falling as snow. Station CA4577, located in the southern portion of the watershed, has a much wetter climate with a widely variable monthly rainfall average with only a small fraction of the winter precipitation falling as snow.

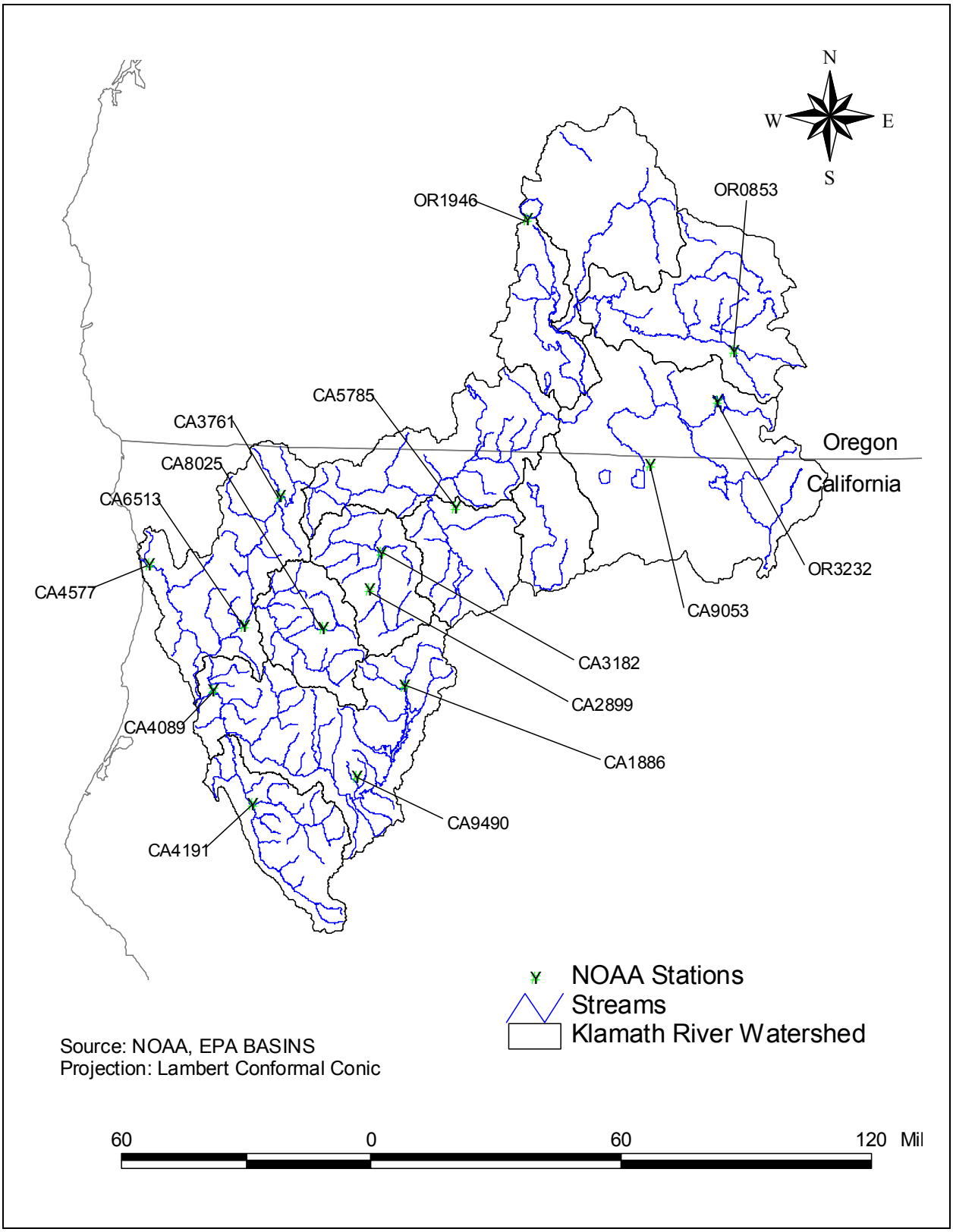

Figure 2-2. Distribution of NOAA climate stations in the Klamath River watershed.

Table 2-1. NOAA climate stations located within the Klamath River watershed.

California			
Station Name	**Coop-ID**	**Period of Record**	**Elevation (ft)**
COFFEE CREEK R S	CA1886	1960-2000	2500.0
ETNA	CA2899	1948-2000	2950.0
FORT JONES 6 ESE	CA3176	1948-1976	3323.0
FORT JONES RANGER STN	CA3182	1976-2000	2725.0
HAPPY CAMP RANGER STN	CA3761	1848-2000	1120.0
HOOPA	CA4082	1948-1974	361.0
HOOPA	CA4089	1971-2000	333.0
HYAMPOM	CA4191	1948-2000	1275.0
KLAMATH	CA4577	1948-2000	25.0
MONTAGUE 5 NE	CA5785	1948-2001	2635.0
OREGON MOUNTAIN	CA6495	1973-1974	3832.0
ORLEANS RS	CA6513	1971-2000	430.0
SAWYERS BAR RS	CA8025	1971-2000	2169.0
TRINITY CENTER RANGER S	CA9023	1948-1960	2303.0
TULELAKE	CA9053	1948-2000	4035.0
WEAVERVILLE	CA9490	1948-2000	2040.0
Oregon			
Station Name	**Coop-ID**	**Period of Record**	**Elevation (ft)**
BLY RANGER STN	OR0853	1948-2000	4390.0
BLY 3 NW	OR0854	1950-1950	4378.0
CRATER LAKE NATL PARK H	OR1946	1949-2000	6475.0
GERBER DAM	OR3232	1958-2000	4850.0
KLAMATH FALLS AG STA	OR4511	1948-1951	4092.0

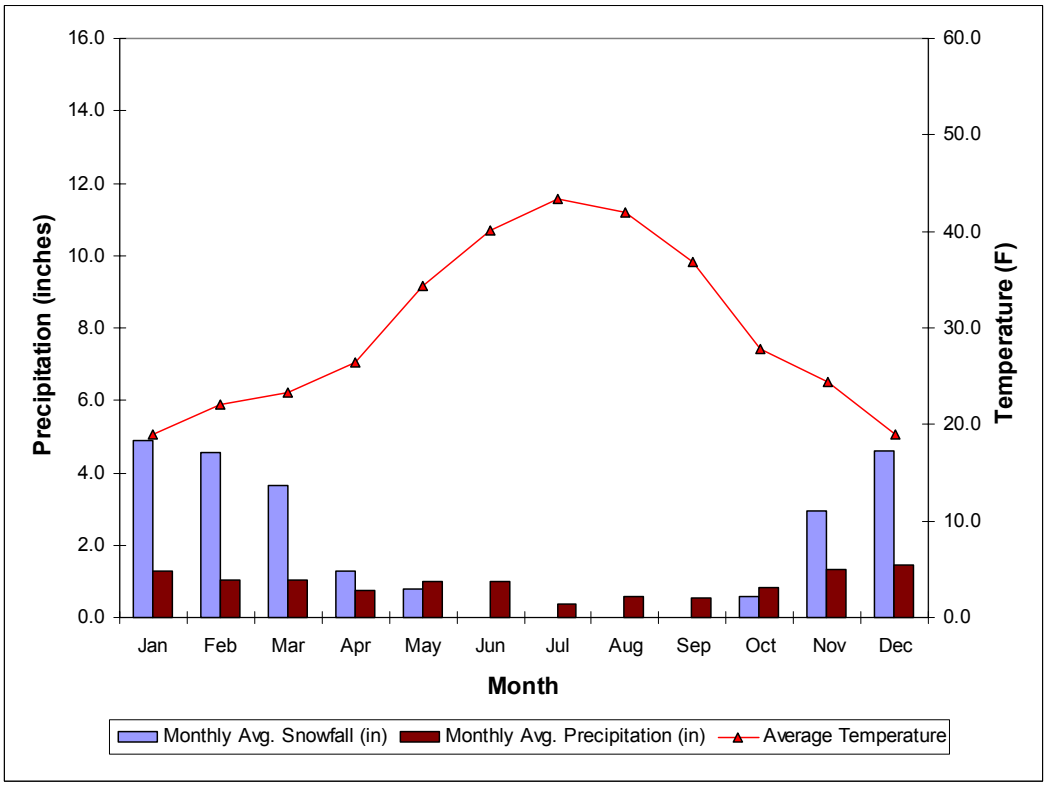

Figure 2-3. Climagraph for CA9053 (Tule Lake).

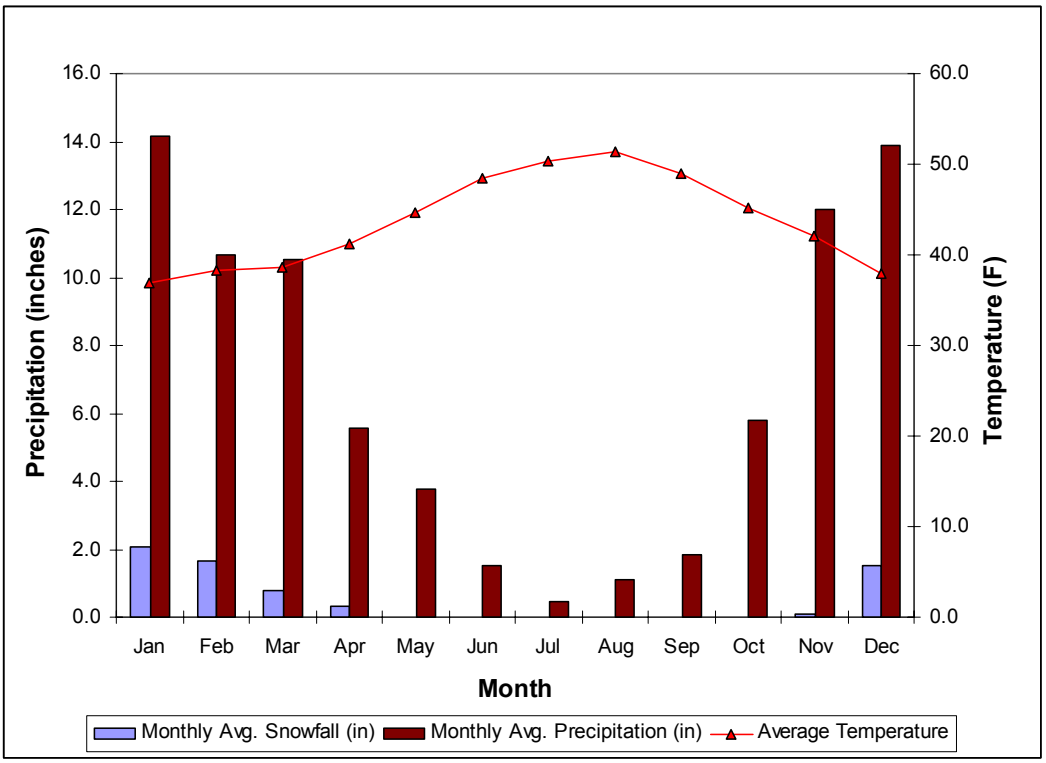

Figure 2-4. Climagraph for CA4577 (Klamath River Mouth).

2.1.3 Hydrology

2.1.3.1 Klamath River Flow Data - Main Stem

The USGS National Water Information System (NWIS) online database lists 22 flow gages with current and historic flow data in the Klamath River watershed. Four of the stations on the main stem of the Klamath River below Iron Gate Dam were analyzed to obtain a general understanding of flow from the dam to the confluence with the Pacific Ocean. These stations were the Klamath River below Iron Gate Dam, CA; Klamath River near Seiad Valley, CA; Klamath River at Orleans; and the Klamath River near Klamath, CA. These stations are shown in Figure 2-5 and described in Table 2-2.

The flow patterns at the four main stem stations are very similar. Figure 2-6 shows that there is an increase in flow in February and March that can be attributed to snowmelt. Flows then decrease gradually between April and June and decrease dramatically between June and August due to evaporation, reduced precipitation, and withdrawals. The low flow rates continue through August, September and early October. Flow rates begin to increase in mid-October (coinciding with the end of the growing season) through to February. The flow magnitude decreases substantially from upstream to downstream stations.

Table 2-2. Selected USGS stream gages on the main stem of the Klamath River.

Station ID	Gage Name	Drainage Area (mi^2)	Period of Record	
			Start Date[a]	End Date[b]
11516530	Klamath River below Iron Gate Dam, CA	4,630	1961	2002
11520500	Klamath River near Seiad Valley, CA	6,940	1952	2002
11523000	Klamath River at Orleans	8,475	1928	2002
11530500	Klamath River near Klamath, CA	12,100	1951[c]	2002

[a]The first year in which continuous flow data to 2002 are available.
[b]The last year in which continuous flow data are available.
[c]Data incomplete from 1995-1997.

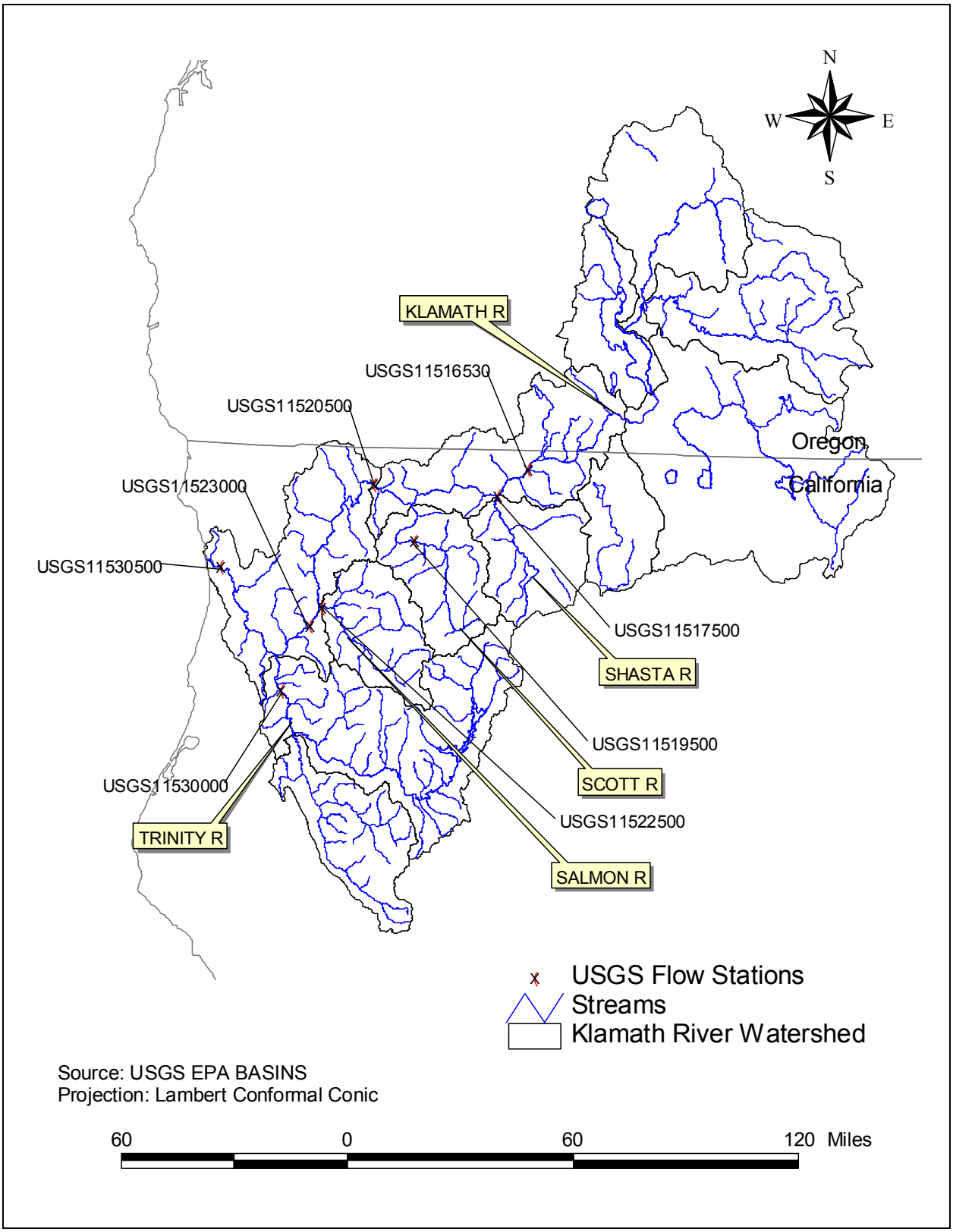

Figure 2-5. USGS Stations on the Klamath River and tributaries downstream of Iron Gate Dam.

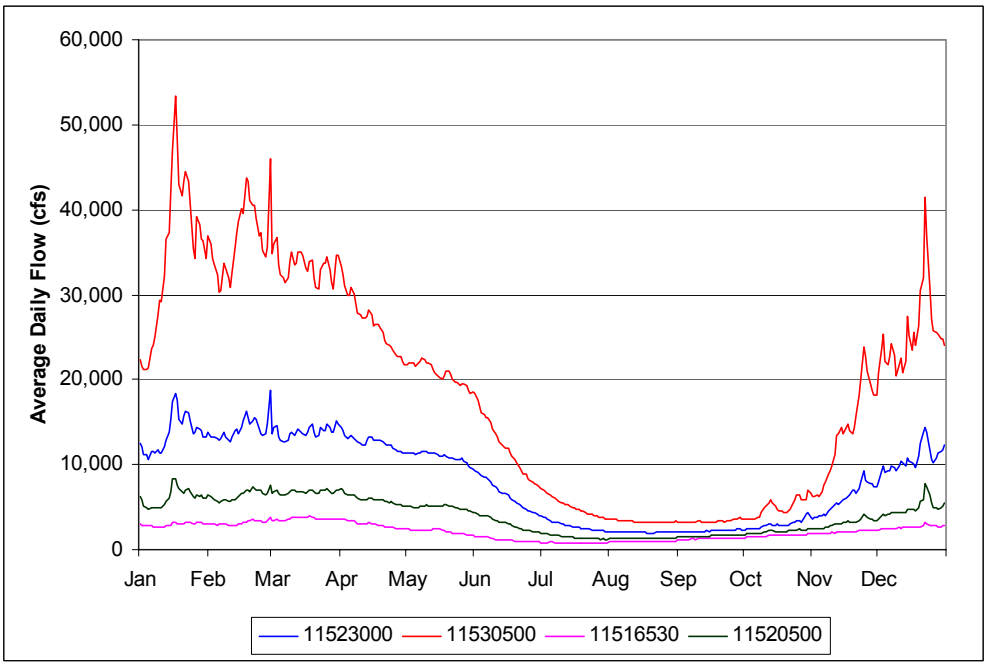

Figure 2-6. Average daily flows at four USGS gages on the main stem of the Klamath River (below Iron Gate Dam).

2.1.3.2 Klamath River Flow Data - Tributaries

The USGS National Water Information System (NWIS) online database lists 4 flow gages with current and historic flow data for the four major tributaries of the Klamath River below Iron Gate Dam. These were analyzed to obtain a general understanding of flow contributions to be expected from these tributaries. These stations were the Shasta River near Yreka, CA; Scott River near Fort Jones, CA; Salmon River at Somes Bar, CA; and Trinity River near Hoopa, CA. These stations are shown in Figure 2-5 and described in Table 2-3.

The average monthly flow at these stations is shown in Figure 2-7 through 2-10. The flow patterns at the four stations are very similar. The Shasta River and Trinity River had their highest monthly flows in February while the Scott River and Salmon had their highest monthly flows in May. The Salmon, Scott and Trinity Rivers all experiences a sharp decrease in flow rate between May and July due to evaporation, reduced precipitation, and withdrawals.

Table 2-3. Selected USGS gages on tributary streams in the Klamath River watershed.

Station ID	Gage Name	Drainage Area (mi^2)	Period of Record	
			Start Date[a]	End Date[b]
11517500	Shasta River near Yreka, CA	793	1933	2002
11519500	Scott River near Fort Jones, CA	653	1941	2002
11522500	Salmon River at Somes Bar, CA	751	1911	2002
11530000	Trinity River near Hoopa, CA	2,853	1911	2002

[a]The first year in which continuous flow data are available.
[b]The last year in which continuous flow data are available.

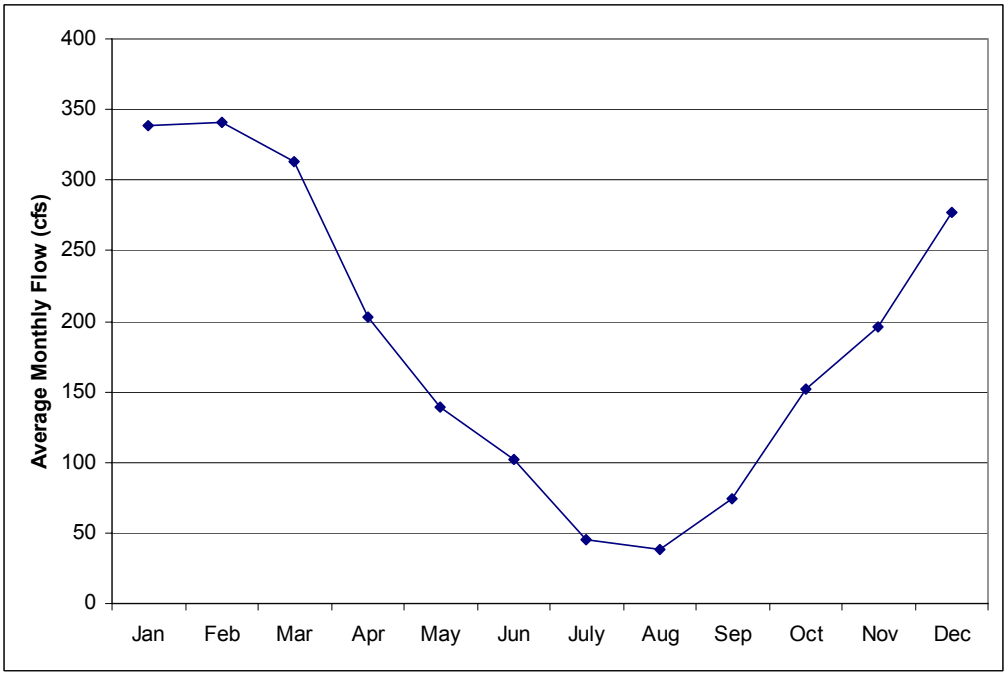

Figure 2-7. Average Monthly Flow, USGS11517500 Shasta River near Yreka, CA (1911-1992).

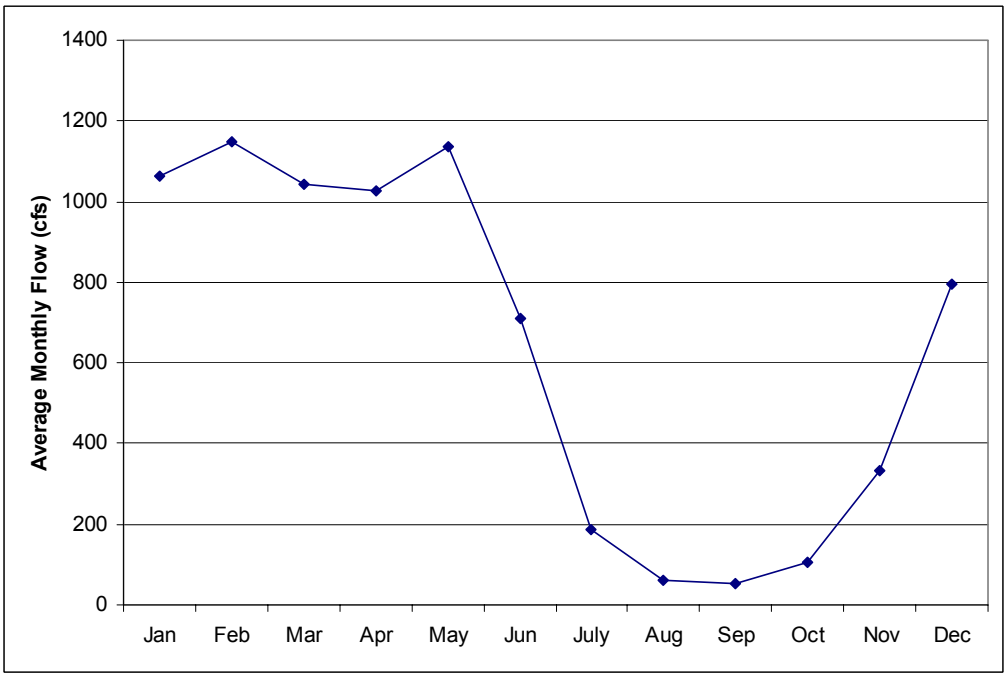

Figure 2-8. Average Monthly Flow, USGS11519500 Scott River near Fort Jones, CA (1941-2002).

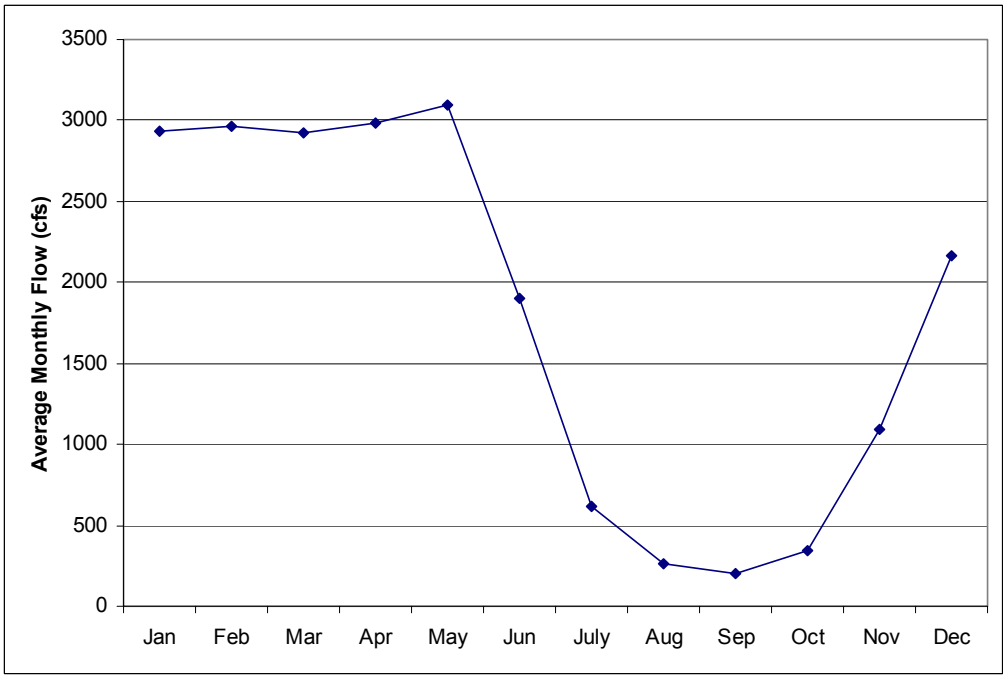

Figure 2-9. Average Monthly Flow, USGS11522500 Salmon River at Somes Bar, CA (1911-2002).

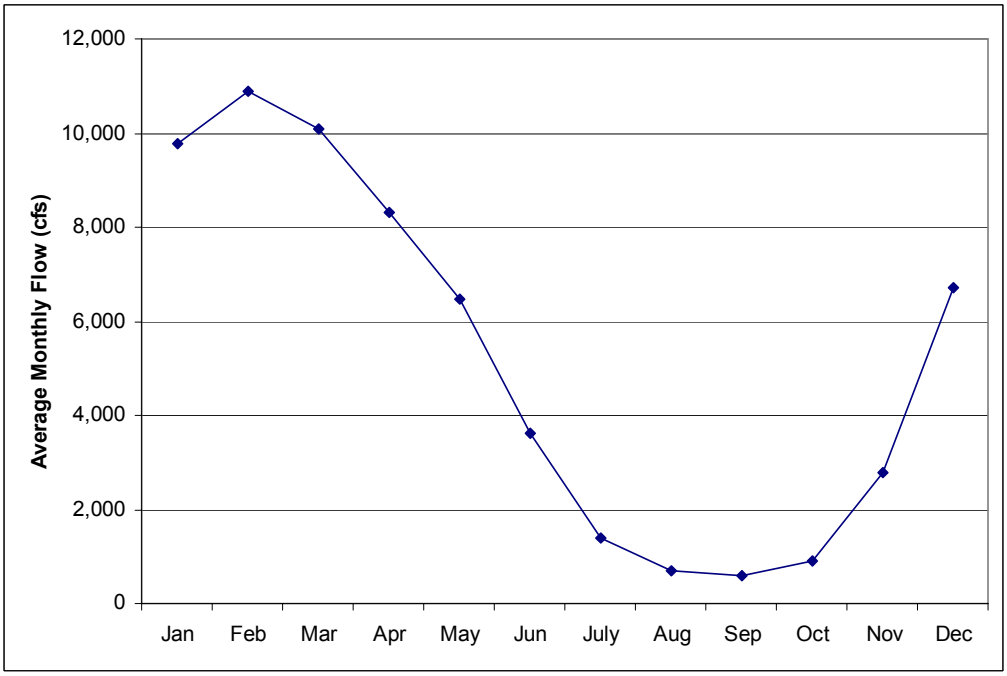

Figure 2-10 Average Monthly Flow, USGS1153000 Trinity River near Hoopa, CA (1911-2002).

2.1.6 Major Land Resource Areas

The USDA has identified major land resource areas (MLRAs) within the United States (USDA, 1965). The MLRAs are large area land resource units geographically associated according to the dominant physical characteristics of topography, climate, hydrology, soils, land use, and potential natural vegetation. MLRAs have been used in statewide agricultural planning and have value in interstate, regional, and national planning. A complete listing and definition of the MLRAs located in the Klamath River watershed is given in Appendix A. The distribution of MLRAs in the Klamath River watershed is shown in Figure 2-11, and is summarized in Table 2-4. Figure 2-11 and Table 2-4 show that 45 percent of the Klamath River watershed is classified as Klamath and Shasta Valleys and Basins. About 23 percent of the Klamath watershed is classified as Sierra Nevada Range while a smaller area is classified as Malheur High Plateau. All other MLRAs constitute less than 10 percent of the watershed.

Table 2-4. MLRAs of the Klamath River watershed.

MLRA Classification	Area (acres)	Area (miles^2)	Percentage
Olympic and Cascade Mountains	501,028	786.8	5.0%
Cascade Mountains, Eastern Slope	1,157,724	1,818.1	11.5%
Siskiyou-Trinity Area	4,236,957	6,653.9	42.2%
Klamath and Shasta Valleys and Basins	3,168,872	4,976.5	31.6%
California Coastal Redwood Belt	210,364	330.4	2.1%
Sierra Nevada Range	489,328	768.5	4.9%
Klamath and Shasta Valleys and Basins	277,210	435.3	2.8%
Central California Coast Range	1,709	2.7	<0.1%
Total Area	10,043,192	15,722.1	100.0%

2.1.7 Land Use and Land Cover

General land use and land cover data for the Klamath River watershed was extracted from the Multi-Resolution Land Characterization (MRLC) database for the states of Oregon and California (MRLC, 1992) and is shown in Figure 2-12. This database was derived from satellite imagery taken during the early 1990s and is the most current detailed land use data known to be available. Each 100-foot by 100-foot pixel contained within the satellite image is classified according to its reflective characteristics. A complete listing and definition of the MRLC land cover categories is given in Appendix B. Table 2-5 summarizes land cover in the Klamath River watershed and shows that evergreen forest is the dominant land cover, comprising approximately 58.9 percent of the total land cover. Shrubland and grasslands/herbaceous comprise 14.0 percent and 8.3 percent, respectively. Other important cover types include mixed forest (3.2 percent), pasture/hay (2.8 percent), small grains (2.5 percent), emergent herbaceous wetlands (2.2 percent), open water (1.6 percent), and deciduous forest (1.2 percent). All other individual land cover types comprise less than one percent of the total watershed area.

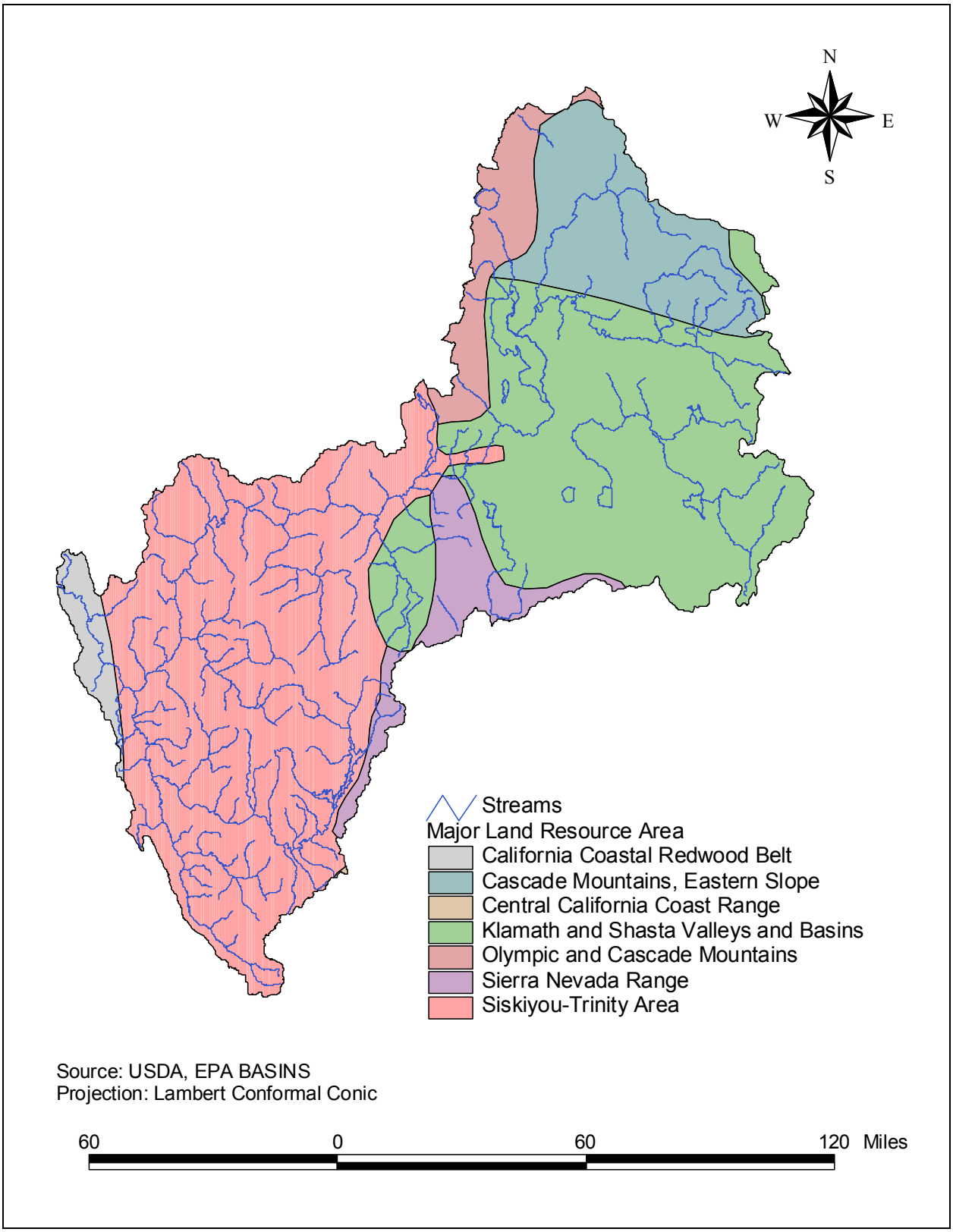

Figure 2-11. MLRAs in the Klamath River watershed.

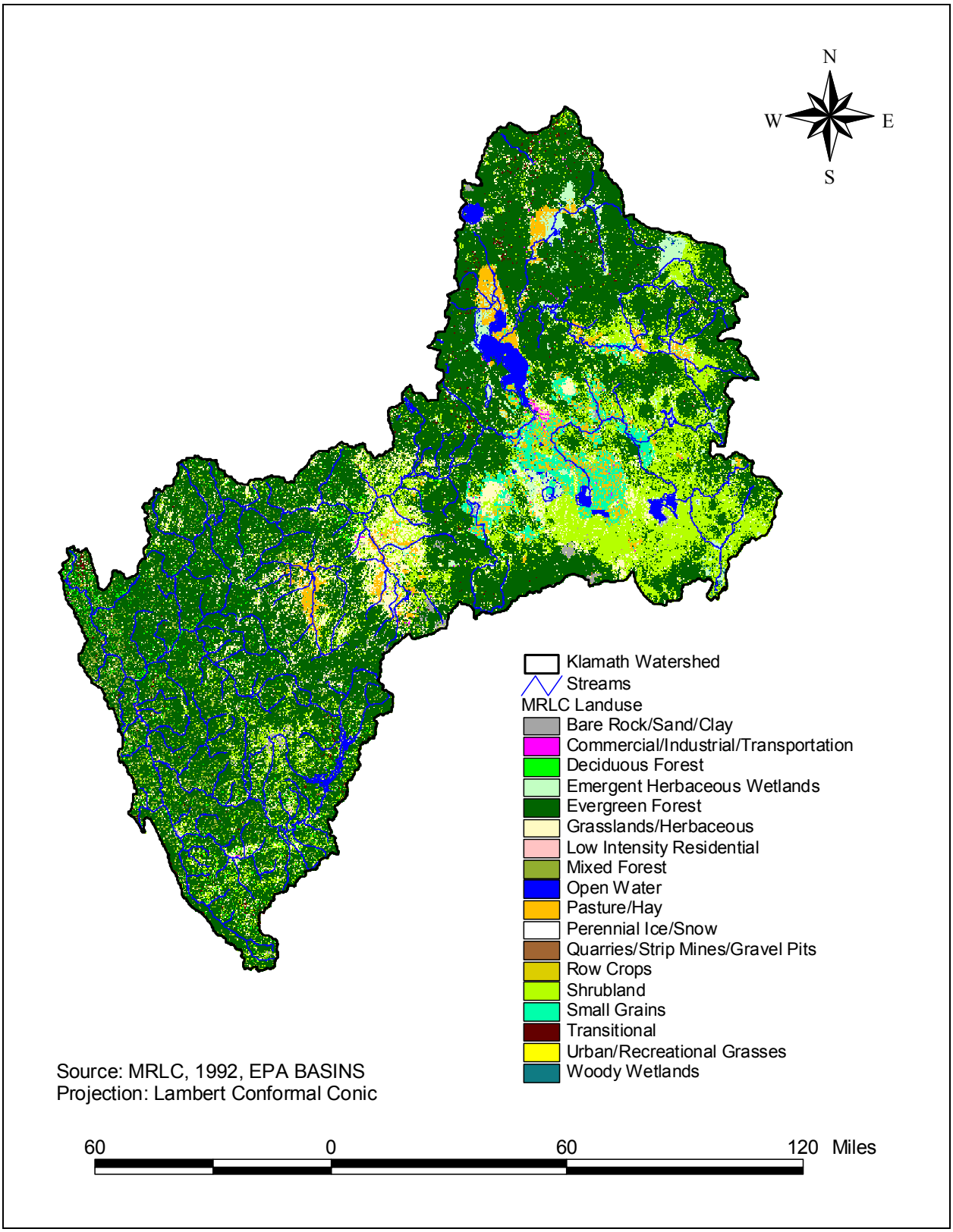

Figure 2-12. Land Use and Land Cover in the Klamath River watershed.

Table 2-5. Land use and land cover in the Klamath River watershed.

Land Use/Land Cover	Area		Percent of Watershed
	Acres	Square Miles	
Evergreen Forest	6,228,663	9,750.7	62.0%
Shrubland	1410,263	2,207.7	14.0%
Grasslands/Herbaceous	834,866	1,306.9	8.3%
Mixed Forest	315,894	494.5	3.2%
Pasture/Hay	285,668	447.2	2.8%
Small Grains	253,466	396.8	2.5%
Emergent Herbaceous Wetlands	217,219	340.0	2.2%
Open Water	157,451	246.5	1.6%
Deciduous Forest	121,454	190.1	1.2%
Bare Rock/Sand/Clay	73,010	114.3	0.7%
Transitional	56,921	89.1	0.6%
Row Crops	50,734	79.4	0.5%
Commercial/Industrial/Transportation	16,503	25.8	0.2%
Woody Wetlands	11,088	17.4	0.1%
Low Intensity Residential	7,363	11.5	0.1%
Quarries/Strip Mines/Gravel Pits	1,241	1.9	<0.1%
Urban Recreational Grasses	849	1.3	<0.1%
Perennial Ice/Snow	539	0.8	<0.1%
Total	10,043,192	15,722.1	100.0%

2.2 Physical Characteristics of the Lost River Watershed

2.2.1 Location

The Lost River watershed traverses the states of Oregon and California, encompassing an area of approximately 2,996 square miles. The headwaters of the Lost River originate from the tributaries leading into Clear Lake in California (including Willow Creek, Fletcher Creek, Boles Creek and Mowitz Creek). The river flows north into Oregon until it reaches the town of Bonanza where it turns and flows west until it reaches the Wilson Reservoir, where it turns south and flows into Tule Lake in California (as shown in Figure 2-13). Major natural tributaries to the Lost River include Miller Creek, Big Springs, and Buck Creek.

The watershed includes portions of Klamath and Lake Counties in Oregon, and Modoc and Siskiyou in California. Approximately 56 percent of the watershed (roughly 1,667 square miles) lies in California, while 46 percent (roughly 1,328 square miles) is located in Oregon. The Lost River watershed includes one U.S. Geological Survey (USGS) 8-digit hydrologic cataloging unit, 18010204.

2.2.2 Major Land Resource Areas

A complete listing and definition of the MLRAs located in the Lost River watershed is given in Appendix A. The distribution of MLRAs in the Lost River watershed is shown in Figure 2-14, and is summarized in Table 2-6. Figure 2-14 and Table 2-6 show that about 92 percent of the Lost River watershed is classified as Klamath and Shasta Valleys and Basins. All other MLRA constitute less than 10 percent of the watershed.

Table 2-6. MLRAs of the Lost River watershed.

MLRA Classification	Area (acres)	Area (miles^2)	Percentage
Klamath and Shasta Valleys and Basins	1,888,608	2,951.0	98.5%
Sierra Nevada Range	28,597	44.7	1.5%
Total Area	1,917,205	2,995.6	100.0%

2.2.3 Land Use and Land Cover

Figure 2-15 shows the land cover in the Lost River watershed, based on MRLC, while Table 2-7 summarizes the various land covers. Table 2-7 shows that shrubland is the dominant land cover, comprising approximately 37.0 percent of the total land cover. Evergreen forest and small grains comprise 31.9 percent and 10.3 percent, respectively. Other important cover types include grasslands/herbaceous (7.8 percent), pasture/hay (4.1 percent), emergent herbaceous wetlands (3.1 percent), open water (2.0 percent) and row crops (2.0 percent). All other individual land cover types comprise less than one percent of the total watershed area.

Table 2-7. Land use and land cover in the Lost River watershed.

Land Use/Land Cover	Area		Percent of Watershed
	Acres	Square Miles	
Shrubland	709,618	1,108.8	37.0%
Evergreen Forest	611,049	954.8	31.9%
Small Grains	196,917	307.7	10.3%
Grasslands/Herbaceous	149,488	233.6	7.8%
Pasture/Hay	78,515	122.7	4.1%
Emergent Herbaceous Wetlands	59,163	92.4	3.1%
Open Water	38,691	60.5	2.0%
Row Crops	37,784	59.0	2.0%
Bare Rock/Sand/Clay	15,436	24.1	0.8%
Commercial/Industrial/Transportation	7,607	11.9	0.4%
Low Intensity Residential	3,807	5.9	0.2%
Woody Wetlands	3,800	5.9	0.2%
Transitional	2,305	3.6	0.1%
Mixed Forest	1,291	2.0	0.1%
Quarries/Strip Mines/Gravel Pits	662	1.0	<0.1%
Urban Recreational Grasses	600	0.9	<0.1%
Deciduous Forest	465	0.7	<0.1%
Perennial Ice/Snow	5	0.0	<0.1%
Total	1,917,205	2,995.6	100.00%

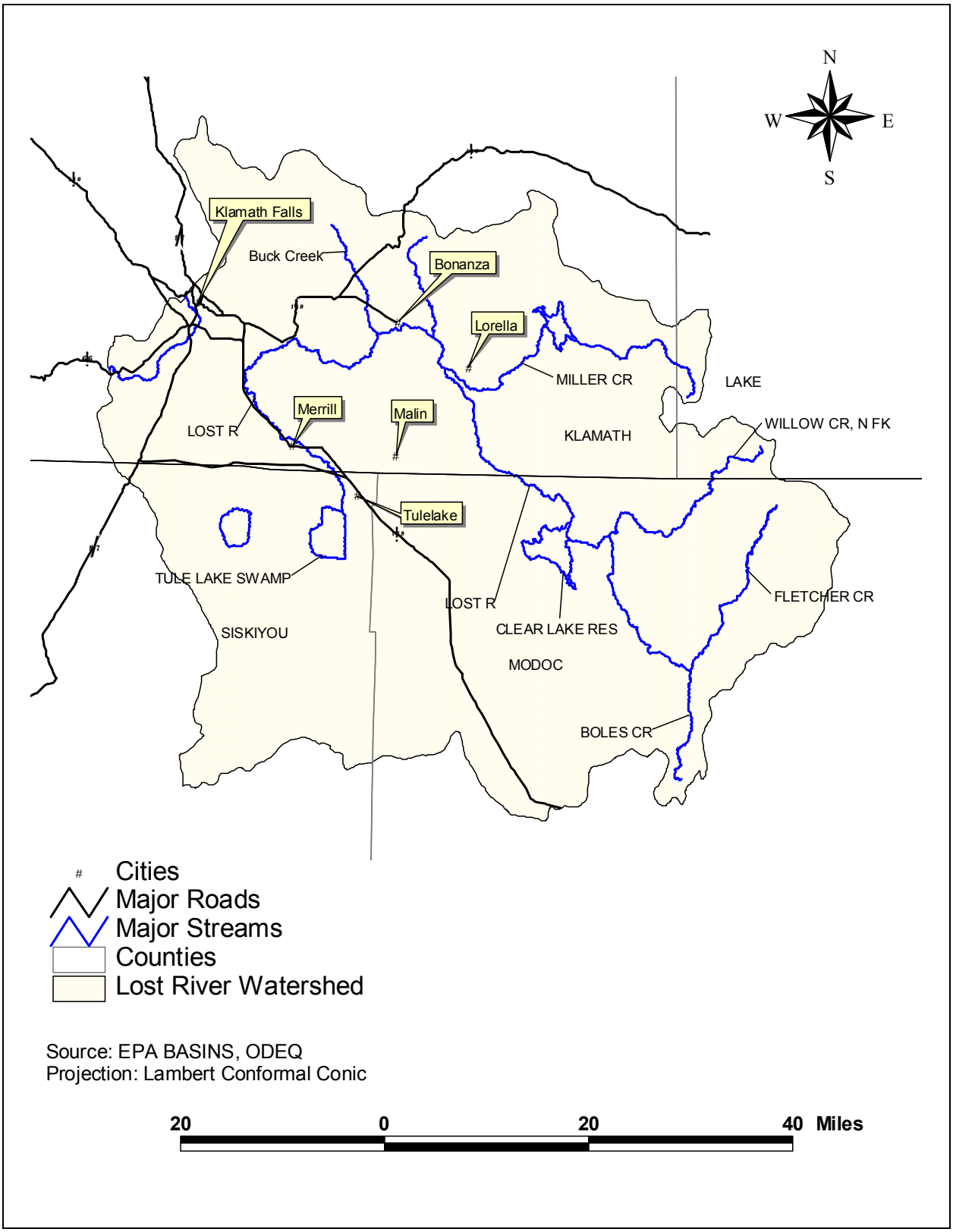

Figure 2-13. Location of the Lost River watershed.

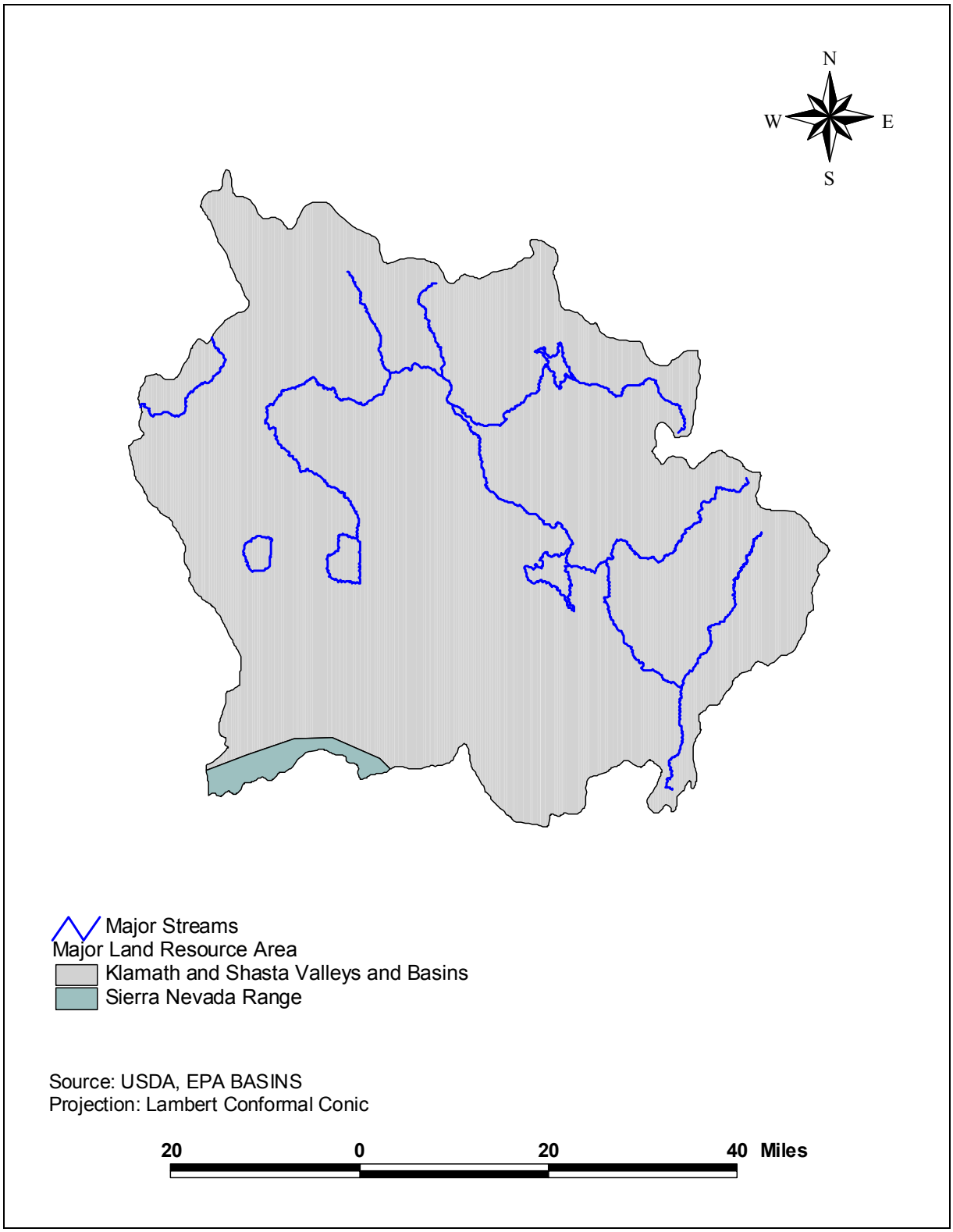

Figure 2-14. MLRAs in the Lost River watershed.

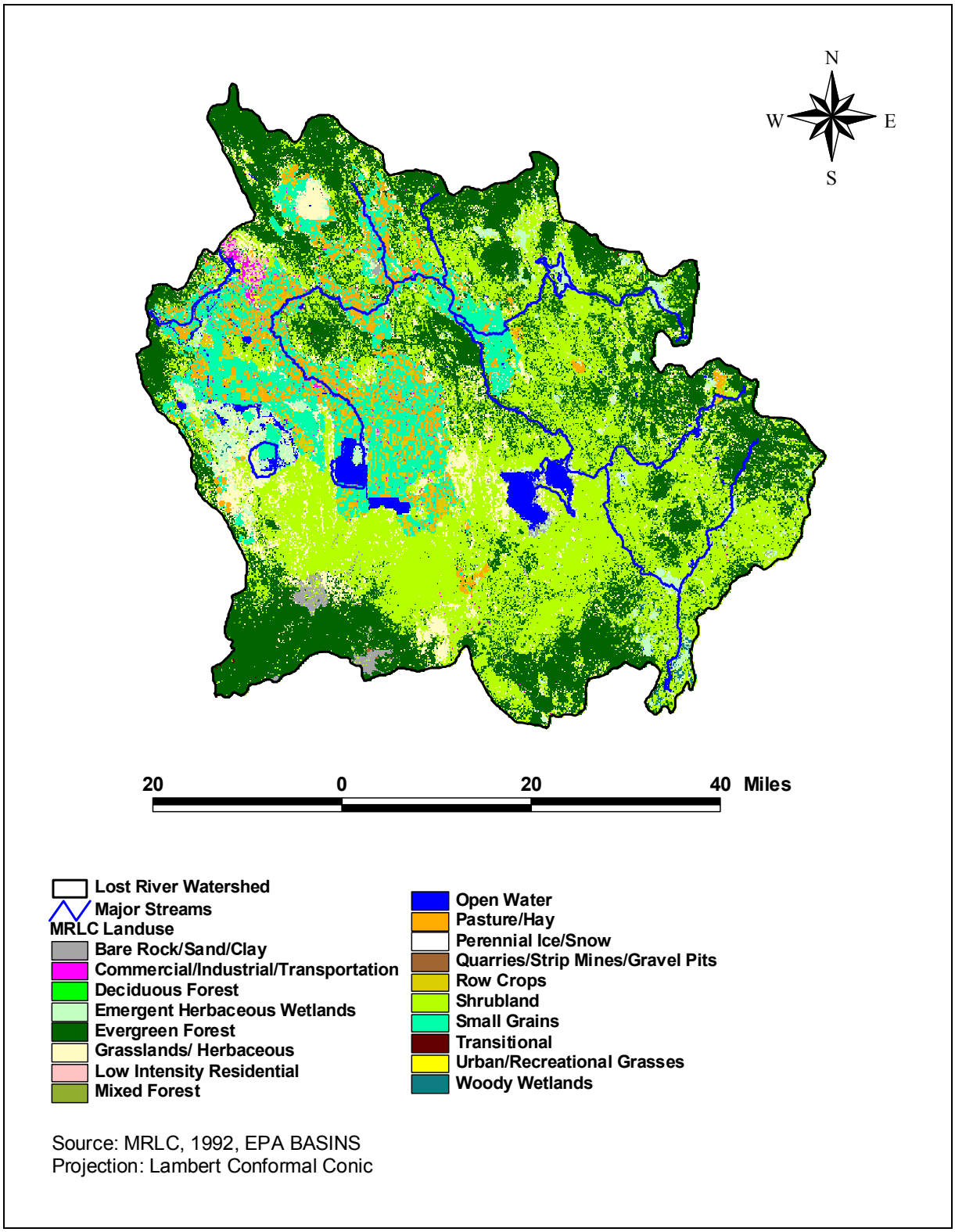

Figure 2-15. Land Use and Land Cover in the Lost River watershed.

3.0 WATER QUALITY CONCERNS AND STATUS

This section of the document first presents the 303(d) list status of all listed water bodies (i.e., which water bodies are listed as impaired or threatened and for which pollutants). This is followed by a description of the parameters of concern, the applicable water quality standards, and a water body by water body review of available water quality data.

3.1 Oregon 303(d) List Status

The Oregon 2002 303(d) list reported that beneficial uses in the Klamath and Lost Rivers were impaired for a variety of reasons (Table 3-1). Figure 3-1 shows the location of the Klamath River watershed, major streams, and the impaired river segments from the 2002 303(d) list. Figure 3-2 shows the Lost River watershed, major streams and the impaired river segments from the 2002 303(d) list.

Table 3-1. Oregon 2002 303(d) for the Klamath River watershed.

Waterbody Name	River Mile	Parameter	Season	List Date	Listing Status
Klamath River	231 to 250	pH	Summer	1998	303(d) List
Klamath River	250 to 251	pH	Summer	1998	303(d) List
Klamath River	231 to 250	Ammonia	Winter/Summer	1998	303(d) List
Klamath River	207 to 231	Temperature	Summer	1998	303(d) List
Klamath River	231 to 250	Temperature	Summer	1998	303(d) List
Klamath River	250 to 251	Temperature	Summer	1998	303(d) List
Klamath River	231 to 250	Dissolved Oxygen	Spring/Summer/Fall	1998	303(d) List
Klamath River	231 to 250	Chlorophyll a	Summer	1998	303(d) List
Klamath River	250 to 251	Chlorophyll a	Summer	1998	303(d) List
Klamath Straits Drain	0 to 0	Temperature	Summer	1998	303(d)
Klamath Straits Drain	0 to 0	Fecal Coliform	Summer	1998	303(d)
Klamath Straits Drain	0 to 0	Dissolved Oxygen	Year Around	1998	303(d)
Klamath Straits Drain	0 to 0	Chlorophyll a	Summer	1998	303(d)
Klamath Straits Drain	0 to 0	pH	Summer	1998	303(d)
Klamath Straits Drain	0 to 0	Ammonia	Summer	1998	303(d)
Lost River	0 to 59.7	Temperature	Summer	1998	303(d)
Lost River	0 to 59.7	Fecal Coliform	Winter/Spring/Fall	1998	303(d)
Lost River	0 to 59.7	Dissolved Oxgyen	Summer	1998	303(d)
Lost River	0 to 59.7	Chlorophyll a	Summer	1998	303(d)
Lost River	0 to 59.7	Fecal Coliform	Summer	1998	303(d)

Source: ODEQ, 2002.

3.2 California 303(d) List Status

The California 2002 303(d) list also reported that beneficial uses in the Klamath and Lost Rivers were impaired for a variety of reasons. The listing information from the report is shown in Table 3-2. Figure 3-1 shows the location of the Klamath River watershed, major streams, and the impaired river segments from the 2002 303(d) list. Figure 3-2 shows the location of the Lost River watershed, major streams and the impaired river segments from the 2002 303(d) list.

Table 3-2. California 2002 303(d) list for the Klamath River watershed.

Name	Calwater Watershed	Pollutant/ Stressor	Potential Sources	TMDL Priority	Estimated Size Affected
Klamath River, Klamath River HU, Lost River HA, Clear Lake, Boles HSAs	10593011	Nutrients	Hydromodification Nonpoint Source	Medium	601 Miles
		Temperature	Hydromodification Dam Construction Upstream Impoundment Flow Regulation/Modification Water Diversions Agricultural Water Diversion Nonpoint Source	Medium	601 Miles
Klamath River, Klamath River HU, Lost River HA, Tule Lake and Mt Dome HSAs	10591063	Nutrients	Agriculture Specialty Crop Production Agriculture-subsurface drainage Agriculture-irrigation tailwater Water Diversions Agricultural Water Diversion Habitat Modification Removal of Riparian Vegetation Drainage/Filling of Wetlands Natural Sources Nonpoint Sources	Medium	612 Miles
		Temperature	Hydromodifcation Channelization Flow Regulation/Modification Water Diversions Agricultural Water Diversion Habitat Modification Removal of Riparian Vegetation Drainage/Filling of Wetlands Nonpoint Source	Medium	612 Miles

Name	Calwater Watershed	Pollutant/ Stressor	Potential Sources	TMDL Priority	Estimated Size Affected
Klamath River, Klamath River HU, Lower HA, Klamath Glen HAS	10511086	Nutrients	Industrial Point Sources Major Industrial Point Source Minor Industrial Point Sources Major Municipal Point Source-dry and/or wet Weather discharge Minor Municipal Point Source-dry and/or wet weather discharge Agriculture Irrigated Crop Production Specialty Crop Production Pasture Grazing-Riparian and/or Upland Range Grazing-Riparian Intensive Animal Feeding Operations Agriculture-storm runoff Agriculture-subsurface drainage Agriculture-irrigation tailwater	Medium	609 Miles
		Organic Enrichment/ Low Dissolved Oxygen	Industrial Point Sources Municipal Point Sources Agriculture Irrigated Crop Practices Specialty Crop Production Range Grazing-Riparian Agriculture-storm runoff Agricutlure-subsurface drainage Agriculture-irrigation tailwater Agriculture-animal Upstream Impoundment Flow Regulation/Modification Out-of-State source	Medium	609 Miles
		Temperature	Hydromodification Dam Construction Upstream Impoundment Flow Regulation/Modification Habitat Modification Removal of Riparian Vegetation Channel Erosion	Medium	609 Miles

Name	Calwater Watershed	Pollutant/ Stressor	Potential Sources	TMDL Priority	Estimated Size Affected
Klamath River, Klamath River HU, Middle HA, Iron Gate Dam to Scott River	10535053	Nutrients	Out-of-state source Nonpoint/Point source	Medium	548 Miles
		Organic Enrichment/ Low Dissolved Oxygen	Out-of-state source Nonpoint/Point source	Medium	548 Miles
		Temperature	Hydromodification Upstream Impoundment Flow Regulation/Modification Habitat Modification Removal of Riparian Vegetation Nonpoint source	Medium	548 Miles
Klamath River, Klamath River HU, Middle HA, Oregon to Iron Gate	10537022	Nutrients	Industrial Point Sources Municipal Point Sources Agriculture Specialty Crop Production Agricultural Return Flows Internal Nutrient Cycling (primarily lakes) Natural Sources Nonpoint Sources	Medium	129 Miles
		Organic Enrichment/ Low Dissolved Oxygen	Industrial Point Sources Municipal Point Sources Combined Sewer Overflow Agriculture Agriculture-storm runoff Agriculture-irrigation tailwater Upstream Impoundment Flow Regulation/Modification Out-of-state source	Medium	129 miles
		Temperature	Hydromodification Channelization Dam Construction Upstream Impoundment Flow Regulation/Modification Nonpoint Sources	Medium	129 Miles

Name	Calwater Watershed	Pollutant/ Stressor	Potential Sources	TMDL Priority	Estimated Size Affected
Klamath River, Klamath River HU, Middle HA, Scott River to Trinity River	10512050	Nutrients	Industrial Point Sources Municipal Point Sources Agriculture Agriculture-storm runoff Agriculture-irrigation tailwater Wastewater-land disposal Upstream Impoundment Natural Sources Nonpoint Sources Out-of-state source	Medium	1389 Miles
		Organic Enrichment/ Low Dissolved Oxygen	Industrial Point Sources Municipal Point Sources Combined Sewer Overflows Agriculture Agriculture-storm runoff Agriculture-irrigation tailwater Upstream Impoundment Flow Regulation/Modification Out-of-state source	Medium	1389 Miles
		Temperature	Hydromodification Channelization Dam Construction Upstream Impoundment Flow Regulation/Modification Water Diversions Habitat Modification Removal of Riparian Vegetation Streambank Modification/Destabilization Drainage/Filling of Wetlands Natural Sources Nonpoint Sources	Medium	1389 Miles
Tule Lake and Lower Klamath Lake National Wildlife Refuge	10591020	pH (high)	Internal Nutrient Cycling (primarily lakes) Nonpoint Sources	Low	26998 acres

Source: NCRWQCB, 2002.

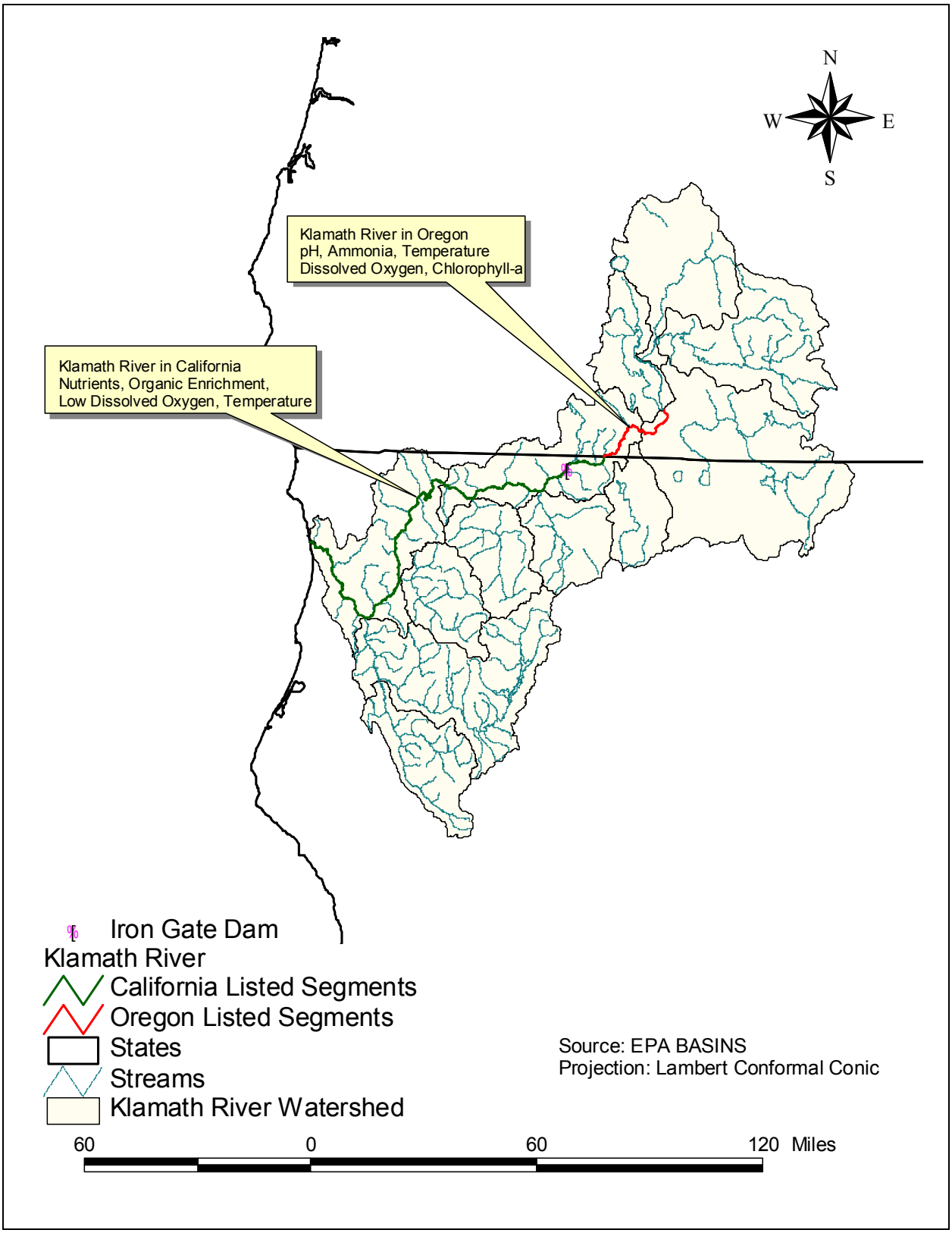

Figure 3-1. Location of the Oregon and California impaired segments for the Klamath River.

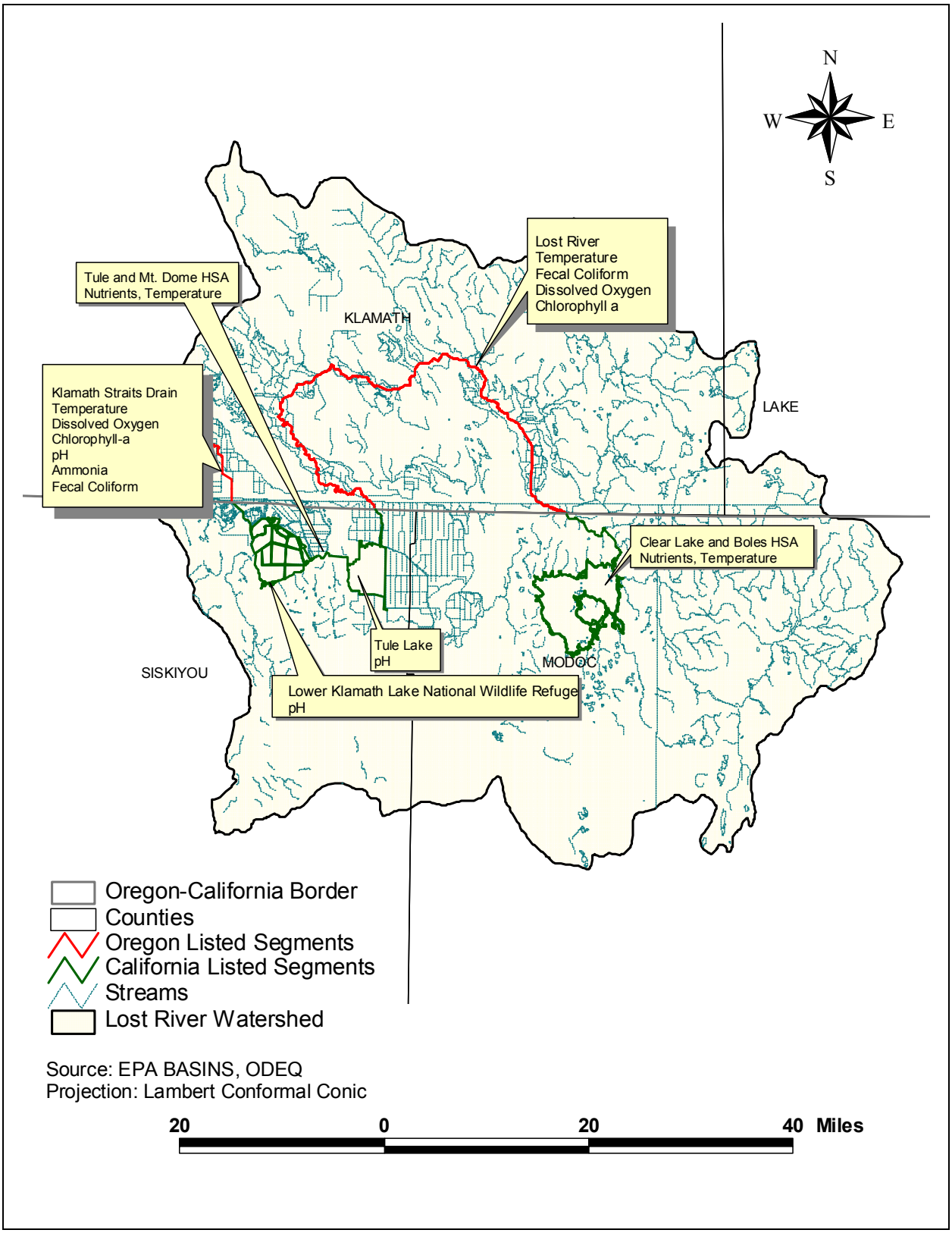

Figure 3-2. Location of Oregon and California impaired segments for the Lost River, Lower Klamath Lake National Wildlife Refuge and the Klamath Straits Drain.

3.3 Applicable Water Quality Standards

The Klamath and Lost River watersheds are regulated by two jurisdictional entities that have applicable water quality standards – the State of Oregon and the State of California. This section presents the current applicable water quality standards. The following sections are taken from "Comparison and Analysis of Oregon and California Beneficial Uses, Water Quality Standards, and Water Quality Objectives as Applied to the Klamath and Lost Rivers." This document was supplied by the NCRWQCB and the ODEQ and is dated January 12, 2004.

3.3.1 Oregon Standards

The following sections present the relevant state standards and beneficial uses for Oregon. The Oregon standards are found in the Oregon Administrative Rules (OAR Chapter 340, Division 41, Section 0962, Table 19).

Table 3-3 provides the beneficial use designation for the Klamath Basin in Oregon.

Table 3-3. Beneficial uses designated for the Klamath Basin, Oregon

Beneficial Uses	Klamath River (Klamath Lake to Keno Dam)	Lost River and Lost River Diversion	All Other Basin Waters
Public Domestic Water Supply[1]	X	X	X
Private Domestic Water Supply[1]	X	X	X
Industrial Water Supply	X	X	X
Irrigation	X	X	X
Livestock Watering	X	X	X
Salmonid Fish Rearing[2]			X
Salmonid Fish Spawning[2]			X
Resident Fish & Aquatic Life	X	X	X
Wildlife & Hunting	X	X	X
Fishing	X	X	X
Boating	X	X	X
Water Contact Recreation	X	X	X
Aesthetic Quality	X	X	X
Hydro Power	X		
Commercial Navigation & Transportation	X		

1. With adequate pretreatment and natural quality to meet drinking water standards
2. Where natural conditions are suitable for Salmonid fish use

3.3.1.1 Temperature

Oregon's temperature standard has recently been revised as a result of a recent court ruling (*Northwest Environmental Advocates v. U.S. EPA*, U.S. District Court for the District of Oregon, No. CV-01-510-HA). The temperature standard is located at: http://www.deq.state.or.us/wq/standards/wqstdshome.htm. DEQ assumes that USEPA will promulgate the revised temperature standard by March 2004. The new temperature standard is excerpted below, in part, from Oregon's Administrative Rules 340-041-0028.

(1) Background. Water temperatures affect the biological cycles of aquatic species and are a critical factor in maintaining and restoring healthy salmonid populations throughout the State. Water temperatures are

influenced by solar radiation, stream shade, ambient air temperatures, channel morphology, groundwater inflows, and stream velocity, volume, and flow. Surface water temperatures may also be warmed by anthropogenic activities such as discharging heated water, changing stream width or depth, reducing stream shading, and water withdrawals.

(2) Policy. It is the policy of the Commission to protect aquatic ecosystems from adverse warming and cooling caused by anthropogenic activities. The Commission intends to minimize the risk to cold-water aquatic ecosystems from anthropogenic warming, to encourage the restoration and protection of critical aquatic habitat, and to control extremes in temperature fluctuations due to anthropogenic activities. The Commission recognizes that some of the State's waters will, in their natural condition, not provide optimal thermal conditions at all places and at all times that salmonid use occurs. Therefore, it is especially important to minimize additional warming due to anthropogenic sources. In addition, the Commission acknowledges that control technologies, best management practices and other measures to reduce anthropogenic warming are evolving and that the implementation to meet these criteria will be an iterative process. Finally, the Commission notes that it will reconsider beneficial use designations in the event that man-made obstructions or barriers to anadromous fish passage are removed and may justify a change to the beneficial use for that water body.

(3) Purpose. The purpose of the temperature criteria in this rule is to protect designated temperature-sensitive, beneficial uses, including specific salmonid life cycle stages in waters of the State.

(4) Biologically Based Numeric Criteria. Unless superseded by the natural conditions criteria described in section (8) of this rule, or by subsequently adopted site-specific criteria approved by EPA, the temperature criteria for State waters supporting salmonid fishes are as follows:
(4)(e) The seven-day-average maximum temperature of a stream identified as having Lahontan cutthroat trout or redband trout use on subbasin maps and tables set out in OAR 340-041-0101 to OAR 340-041-0340: Tables 120B, 140B, 190B, and 250B, and figures 180A, 201A, and 260A may not exceed 20.0 degrees Celsius (68.0 degrees Fahrenheit);

(5) Unidentified Tributaries. For waters that are not identified on the fish use maps and tables referenced in section (4) of this rule, the applicable criteria for these waters are the same criteria as is applicable to the nearest downstream water body depicted on the applicable map.

(8) Natural Conditions Criteria. Where the department determines that the natural thermal potential of all or a portion of a water body exceeds the biologically-based criteria in section (4) of this rule, the natural thermal potential temperatures supersede the biologically-based criteria, and are deemed to be the applicable temperature criteria for that water body.

(9) Cool Water Species. Waters that support cool water species may not be warmed by more than 0.3 degrees Celsius (0.5 degrees Fahrenheit) above the ambient condition unless a greater increase would not reasonably be expected to adversely affect fish or other aquatic life. Cool waters of the State are described on subbasin tables set out in OAR 340-041-0101 to OAR 340-041-0340: Tables 140B, 180B, 201B, and 250B.

Oregon administrative rule, OAR 340-04l-0002(12), defines "Cool-Water Aquatic Life" as aquatic organisms that are physiologically restricted to cool waters, including but not limited to native sturgeon, pacific lamprey, suckers, chub, sculpins and certain species of cyprinids (minnows). Figure 180A indicates that the mainstem of the Lost River, the Klamath River from Upper Klamath Lake to Keno Dam and the Klamath Straits Drain are designated for the protection of cool water species. The mainstem of the Klamath River from Keno Dam to the state line is designated as redband trout.

3.3.1.2 Dissolved Oxygen

The dissolved oxygen standard is excerpted below, in part, from Oregon's Administrative Rules 340-041-0965(2)(a).

(a) For waterbodies identified by ODEQ as providing salmonid spawning, during the periods from spawning until fry emergence from the gravels, the following criteria apply:

(A) The dissolved oxygen shall not be less than 11.0 mg/L. However, if the minimum intergravel dissolved oxygen, measured as a spatial median, is 8.0 mg/l or greater, then the DO criterion is 9.0 mg/l;

(b) For waterbodies identified by ODEQ as providing cold-water aquatic life, the dissolved oxygen shall not be less than 8.0 mg/l as an absolute minimum. Where conditions of barometric pressure, altitude, and temperature preclude attainment of the 8.0 mg/l, dissolved oxygen shall not be less than 90 percent of saturation. At the discretion of ODEQ, when it is determined that adequate information exists, the dissolved oxygen shall not fall below 8.0 mg/l as a 30-day mean minimum, 6.5 mg/l as a seven-day minimum mean, and shall not fall below 6.0 mg/l as an absolute minimum;

(c) For waterbodies identified by ODEQ as providing cool-water aquatic life, the dissolved oxygen shall not be less than 6.5 mg/l as an absolute minimum. At the discretion of ODEQ, when it is determined that adequate information exists, the dissolved oxygen shall not fall below 6.5 mg/l as a 30-day mean minimum, 5.0 mg/l as a seven-day minimum mean, and shall not fall below 4.0 mg/l as an absolute minimum;

(d) For waterbodies identified by ODEQ as providing warm-water aquatic life, the dissolved oxygen shall not be less than 5.5 mg/l as an absolute minimum. At the discretion of ODEQ, when it is determined that adequate information exists, the dissolved oxygen shall not fall below 5.5 mg/l as a 30-day mean minimum, and shall not fall below 4.0 mg/l as an absolute minimum.

3.3.1.3 pH

The pH standard is excerpted below, in part, from Oregon's Administrative Rules 340-041-0965(2)(d).

Fresh waters (except Cascade lakes): pH values shall not fall outside the range of 6.5 to 9.0.

3.3.1.4 Bacteria (Fecal Coliform)

The bacteria standard is excerpted below, in part, from Oregon's Administrative Rules 340-041-0965(2)(e)(A).

Numeric Criteria: Organisms of the coliform group commonly associated with fecal sources (MPN or equivalent membrane filtration using a representative number of samples) shall not exceed the criteria described in subparagraphs (i) and (ii) of this paragraph. Freshwaters:

(i) A 30-day log mean of 126 E. coli organisms per 100 ml.

(ii) No single sample shall exceed 406 E. coli organisms per 100 ml.

3.3.1.5 Chlorophyll a

The chlorophyll a standard is excerpted below, in part, from Oregon's Administrative Rules 340-041-0150(1)(b).

The following values and implementation program shall be applied to lakes, reservoirs, estuaries and streams, except for ponds and reservoirs less than ten acres in surface area, marshes and saline lakes:

(1) (b) Nuisance Phytoplankton Growth; Natural lakes that do not stratify, reservoirs, rivers and estuaries: 0.015 mg/l.

3.3.1.6 Ammonia

Oregon's updated ammonia toxicity standard (Table 20, OAR 340-041 located at http://www.deq.state.or.us/wq/wqrules/wqrules.htm**)** for freshwater criteria is pH and temperature dependent. The criteria is calculated using the formulae specified in *1999 Update of Ambient Water Quality Criteria for Ammonia* (EPA-822-R-99-014; http://www.epa.gov/ost/standards/ammonia/99update.pdf

3.3.2 California Standards

The following sections present the relevant state standards and beneficial uses for California. The standards for the Klamath and Lost River Basins in California are found in the North Coast Regional Water Quality Control Board Water Quality Control Plan (the Basin Plan).

Table 3-4 provides the beneficial use designation for the Klamath Basin in Oregon.

Table 3-4. Existing and Potential Beneficial Uses Designated for the Klamath River and Lost River Basins in California

Beneficial Uses	Upper Lost River & Clear Lake Reservoir	Lower Lost River, Tule Lake & Lower Klamath Lake	Middle Klamath River	Iron Gate & Copco Reservoir	Lower Klamath River
Municipal & Domestic Water Supply	X		X	X	X
Agricultural Supply	X	X	X	X	X
Industrial Service Supply	X	X	X	X	X
Industrial Process Supply	X	X	X	X	X
Groundwater Recharge	X	X	X		X
Freshwater Replenishment	X	X	X	X	X
Navigation					X
Hydropower Generation	X		X	X	
Water Contact Recreation	X	X	X	X	X
Non-Contact Water Recreation	X	X	X	X	X
Commercial & Sport Fishing	X	X	X	X	X
Warm Freshwater Habitat	X	X	X	X	X
Cold Freshwater Habitat	X		X	X	X
Estuarine Habitat					X
Wildlife Habitat	X	X	X	X	X
Rare, Threatened, or Endangered Species	X	X	X	X	
Migration of Aquatic Organisms			X	X	X
Spawning, Reproduction and/or Early Development	X		X	X	X
Aquaculture	X	X	X	X	X

3.3.2.1 Temperature

The natural receiving water of intrastate waters shall not be altered unless it can be demonstrated that such alteration does not adversely affect beneficial uses. At no time or place shall the temperature of any COLD water be increased by more than 5ºF above the natural receiving water temperature. At no time or place shall the temperature of any WARM intrastate water be increased by more than 5ºF above the natural receiving water temperature.

Lost River
Elevated temperature wastes shall not cause the temperature of the river to increase >2ºF when the receiving water is <62ºF, and 0ºF when the receiving water is ≥62ºF

Klamath River (Cold Interstate Water)
Elevated temperature waste discharges into cold interstate waters are prohibited.

3.3.2.2 Dissolved Oxygen

The dissolved oxygen standard for specific waterbodies is provided below.

Clear Lake, Upper & Lower Lost River, Tule Lake, Lower Klamath Lake > 5.0 mg/l minimum

Other Streams in Upper Lost River HA: ≥ 7.0 mg/l minimum

Middle Klamath River above Iron Gate Dam and Other Streams in the Middle Klamath River HA: ≥ 7.0 mg/l minimum

Middle Klamath River below Iron Gate Dam: > 8.0 mg/l minimum

Lower Klamath River: ≥ 8.0 mg/l minimum

3.3.2.3 pH

The pH standard for specific waterbodies is provided below.

Clear Lake Reservoir & Upper Lost River, Tule Lake, Lower Klamath Lake: 7.0 - 9.0

Other Streams in Upper Lost River HA: 7.0 - 8.4

Middle Klamath River: 7.0 – 8.5

Lower Klamath River: 7.0 – 8.5

3.3.3 Comparison of Oregon and California Standards for the Klamath River

Table 3-5 compares the Oregon and California Standards for the Klamath River.

Table 3-5. Comparison of Oregon Water Quality Standards and California Water Quality Objectives for the Klamath River

Parameter	California	Oregon
Temperature	No alteration that adversely affects beneficial uses. Max increase COLD <5F. Prohibition on discharge into interstate waters.	The seven-day-average maximum temperature of a stream identified redband trout use may not exceed 20.0 degrees Celsius (68.0 degrees Fahrenheit)
Dissolved Oxygen	Above Iron Gate Dam: >7.0 mg/L. Below Iron Gate Dam: >8.0 mg/L	Cool water: 6.5 mg/l as a 30-day mean minimum, 5.0 mg/l as a seven-day minimum mean, and shall not fall below 4.0 mg/l as an absolute minimum
pH	7.0-8.5	6.5-9.0
Nutrients	Not in amounts that promote aquatic growths that cause nuisance or affect beneficial uses.	No objective.
Ammonia	NA	pH and temperature dependent criteria using formula in EPA-822-R-99-014
chlorophyll-a	No objective.	Nuisance criteria: <0.015 mg/L

3.3.3.1 Temperature

The Klamath river from RM 231 to 250, the Lost River and Klamath Straits Drain in Oregon were 303(d) listed in 2002 for temperature via a provision in Oregon's old temperature standard which stated: "There shall be no measurable increase in temperature in Oregon waters when dissolved oxygen (DO) levels are within 0.5 mg/l or 10 percent of the water column or intergravel DO criterion for a given stream reach or subbasin." This provision is no longer included in the revised temperature standard. However, temperature modeling will be required to meet California's water quality standards and objectives for the Lost River. Temperature modeling will also be required for the Klamath River upstream of Keno Dam (RM 231) to support temperature TMDLs in the remaining segments (RM 207 to 231) of the Klamath River that are listed for redband trout rearing criteria of 20°C.

California's narrative objective calls for no alteration of natural receiving water temperatures. Application of this objective requires interpretation to characterize natural receiving water temperatures to assess the status of a water body with respect to the objective. Modeling results would likely play an important role in characterizing natural conditions and in assessing the potential for change. California also has a prohibition on thermal discharges to COLD interstate waters, including the Klamath mainstem.

Oregon rules (OAR 340-04l-0002) adopt the term "Natural Thermal Potential" which means the determination of the thermal profile of a water body using best available methods of analysis and the best available information on the site potential riparian vegetation, stream geomorphology, stream flows and other measures to reflect natural conditions.

In the case of temperature criteria, the natural condition of a subbasin or stream reach is the anticipated thermal potential of the subbasin or stream reach.

Further, it is the policy of Oregon DEQ to protect aquatic ecosystems from adverse warming and cooling caused by anthropogenic activities. The Department recognizes that some of the State's waters will, in their natural condition, not provide optimal thermal conditions at all places and at all times that salmonid use occurs. Therefore, it is especially important to minimize additional warming due to anthropogenic sources.

While Oregon's standard and California's objective differ in detail, this analysis suggests that a waterbody that was not experiencing any measurable increases from anthropogenic activities as defined by thermal potential would be achieving natural receiving water temperatures. Consequently although there are apparent differences between California's narrative temperature standard and Oregon's temperature criteria, both States appear to be in agreement with the policy of minimizing adverse warming of waters from anthropogenic sources.

3.3.3.2 Dissolved Oxygen

Oregon has designated the mainstem Klamath River from Upper Klamath Lake to Keno Dam as cool water species habitat and the Klamath River from Keno Dam to the state line as redband trout habitat. The instantaneous absolute minimum DO value of 4.0 mg/L that applies in Oregon is less than the 7.0 mg/L California objective that applies at the Oregon border. Oregon would be required to meet the California DO objective of 7.0 mg/L for Klamath River water at the border. In addition, assuming that upstream inputs in Oregon were a contributing factor to downstream exceedances in California, water delivered across the border would need to be of suitable quality to meet California water quality standards.

3.3.3.3 pH

Oregon's pH range standard of 6.5-9.0 exceeds California's range objective of 7.0-9.0. At the Lower Lost River crossing, Lost River waters would need to meet the more restrictive California objective. However, since waters in this drainage tend to be basic, and the pH values at the upper end of the range are the same, the Oregon standard and the California objective are functionally the same.

3.3.3.4 Nutrients

Oregon does not have standards for nutrients. Because the listings in Oregon are for dissolved oxygen, and not nutrients, Oregon's approach in similar situations has been to use nutrients as a surrogate for developing loading calculations that would lead to compliance with the DO standards. In California, the narrative objective for biostimulatory substances would require interpretation, and could be included in the TMDL as numeric targets for nutrients. Oregon and California are in general agreement that developing nutrient targets *a priori* is difficult, and that the water quality modeling results would be used as the basis for setting nutrient loading values. These values in turn could be used to set numeric targets that could vary by source and season, if appropriate.

Assuming that upstream inputs in Oregon were a contributing factor to downstream exceedances in California, water delivered across the border would need to be of suitable quality to meet California water quality objectives, including avoiding nuisance aquatic growth, at the border and downstream.

3.3.3.5 Ammonia

Oregon's updated ammonia toxicity standard (Table 20, OAR 340-041, http://www.deq.state.or.us/wq/wqrules/wqrules.htm**)** for freshwater criteria is pH and temperature dependent. The criteria is calculated using the formulae specified in *1999 Update of Ambient Water Quality Criteria for Ammonia* (EPA-822-R-99-014; http://www.epa.gov/ost/standards/ammonia/99update.pdf).

3.3.4 Comparison of Oregon and California Standards for the Lost River

Table 3-6 compares the Oregon and California Standards for the Lost River.

Table 3-6. Comparison of Oregon Water Quality Standards and California Water Quality Objectives for the Lost River

Parameter	California	Oregon
Temperature	No alteration that adversely affects BU. Max increase COLD <5F. Prohibition on discharge into interstate waters.	Streams designated as cool-water may not be warmed by more than 0.3° C (0.5° F) above the ambient condition unless a greater increase would not reasonably be expected to adversely affect fish or other aquatic life.
Dissolved Oxygen	5.0 mg/L in Upper and Lower Lost, Clear Lake, Tule Lake and Lower Klamath Lake. 7.0 mg/L elsewhere.	Cool water: 6.5 mg/l as a 30-day mean minimum, 5.0 mg/l as a seven-day minimum mean, and shall not fall below 4.0 mg/l as an absolute minimum; proposed provision for stratified lakes and reservoirs.
pH	7.0-9.0	6.5-9.0
Bacteria	30-day median fecal coliform <50/100 ml, and <10% samples in 30 days >400/100 ml.	30-day log mean <126 E. coli organisms/100 ml, and no single sample > 406 organisms/100 ml.
Nutrients	Not in amounts that promote aquatic growths that cause nuisance or affect beneficial uses.	No standard.
Ammonia	No objective.	See Table 20, OAR 340-41-0965 (2)(p)(B)
chlorophyll-a	No objective.	<0.015 mg/L

3.3.4.1 Temperature

Oregon's fish distributions map (Figure 180A) identifies cool water species as designated beneficial uses of the Lost River and Klamath Straits Drain. The Lost River and Klamath Straits Drain were 303(d) listed in 2002 for temperature based on the following criterion which is not part of the new temperature standard: "There shall be no measurable increase in temperature in Oregon waters when dissolved oxygen (DO) levels are within 0.5 mg/l or 10 percent of the water column or intergravel DO criterion for a given stream reach or subbasin.."

California has a numeric objective for the Lost River that prohibits elevated thermal waste discharges if the receiving water temperature is above 62°F. It is likely that temperatures in the Lost River regularly exceed 62°F at some time during each day of the summer months and possibly other months as well.

California's narrative objective calls for no alteration of natural receiving water temperatures. Application of this objective requires interpretation to characterize natural receiving water temperatures to assess the status of a water body with respect to the objective. Modeling results would likely play an important role in characterizing natural conditions and in assessing the potential for change.

While Oregon's standard and California's objective differ in detail, this analysis suggests that a waterbody that was not experiencing any measurable increases from anthropogenic activities would be achieving natural receiving water temperatures.

3.3.4.2 Dissolved Oxygen

Oregon designated fish distribution for the mainstem Lost River as cool-water habitat, to which an absolute minimum of 6.5 mg/L DO would apply. California's DO objective for both the Clear Lake Reservoir area and the Lower Lost River is a minimum value of 5.0 mg/L. California would be required to meet the Oregon DO objectives where the Lost crosses into Oregon above Malone Reservoir, and where the Klamath Straits Drain crosses out of California. Oregon's standard exceeds California's objective for the Lower Lost River, so water meeting Oregon's standard would meet California's objective. However, for either state, assuming that upstream inputs were a contributing factor to downstream exceedances, water delivered across the border would need to be of suitable quality to meet the other state's water quality standards or objectives as appropriate.

3.3.4.3 pH

Oregon's pH range standard of 6.5-9.0 exceeds California's range objective of 7.0-9.0. For the purpose of TMDL development, the Lost River at the OR/CA border, upstream of Tule Lake would need to meet the more restrictive California objective.

3.3.4.4 Bacteria

The Lost River carries a listing for impairments related to bacteria. The Lost River in California is not listed as impaired for bacteria. Oregon's standard is based on a 30-day log mean value, while California's objective is based on a 30-day median value. It is not clear how these compare, and it may only be possible to make such a comparison on a case-by-case basis. In any case, the TMDL analysis would need to address the requirement that water crossing the border from Lower Klamath Lake and the Straits Drain into Oregon meet Oregon's standard. Water crossing the border in the Lost River upstream of Tule Lake would need to meet California's objective; this is a water quality compliance issue, however, and not a TMDL issue.

3.3.4.5 Nutrients

Oregon does not have standards for nutrients. Because the listings in Oregon are for dissolved oxygen, and not nutrients, Oregon's approach in similar situations has been to use nutrients as a surrogate for developing loading calculations that would lead to compliance with the DO standards. In California, the narrative objective for biostimulatory substances would require interpretation, and could be included in the TMDL as numeric targets for nutrients. Oregon and California are in general agreement that developing nutrient targets *a priori* is not appropriate and that the water quality modeling results will be used as the basis for setting nutrient loading capacity and load allocations. These values in turn could be used to set numeric targets that could vary by source and season, if appropriate.

Assuming that upstream inputs in Oregon were a contributing factor to downstream exceedances in California, water delivered across the border just upstream of Tule Lake would need to be of suitable quality to meet California water quality objectives, including avoiding nuisance aquatic growth, at the border and downstream.

3.3.4.6 Ammonia

Oregon's ammonia toxicity standard would need to be met in water crossing the border above Malone Reservoir, and from Lower Klamath Lake into the Straits Drain. As part of the TMDL development, upstream anthropogenic impacts in California related to ammonia toxicity inputs in California would need to be addressed in order to meet Oregon's ammonia standard at the OR/CA border.

3.3.4.7 Chlorophyll a

Oregon's chlorophyll-a standard would need to be met in water crossing the border above Malone Reservoir, and from Lower Klamath Lake into the Straits Drain. Assuming that upstream inputs in California were a contributing factor to downstream exceedances in Oregon, water delivered across the border would need to be of suitable quality to meet Oregon water quality standards.

3.4 Water Quality Impairment Status

This section presents separate summaries and evaluations of currently available water quality data for the Klamath and Lost Rivers (with the exception of data received with the last two months). Water quality impairments were determined using the standards and data available at the time that this report was written. Water chemistry data presented in the following sections were obtained from numerous sources including the ODEQ, USBR, NCRWQCB, City of Klamath Falls, USGS, and PacifiCorp Inc. Tables 3-7 and 3-8 below provide summaries of the datasets obtained including the source of the data, the dataset name (if applicable), the types of parameters sampled and the period of record. The database provided by PacifiCorp contains most of the readily available public water quality sampling data (including STORET) up to 1998. After 1998, the data is noted by PacifiCorp to be incomplete. The water quality database provided by PacifiCorp was used as a template to create a database for the Lost River data. Additional data obtained for the Klamath River will be added to the PacifiCorp database to provide a comprehensive database of samples collected on the Klamath River. Some datasets are listed in both tables as the dataset contained data for stations on both the Klamath and Lost Rivers.

Table 3-7. Datasets containing water quality observations on the Klamath River and tributaries.

Source	Dataset	Parameters Sampled*	Period of Record
NCRWQCB	104b Sampling Data	DO, nutrients, pH, temperature, TDS, TSS, conductivity, BOD, COD	1996-1998
USBR	Klamath Project Sampling	DO, nutrients, pH, temperature, TDS, conductivity, BOD, metals, turbidity, chlorophyll a, alkalinity	1972-2003
USGS		DO, nutrients, pH, temperature, conductivity, metals, chlorophyll a, alkalinity, pheophytin a	2002-2003
ODEQ		DO, nutrients, pH, temperature, conductivity, BOD, COD, metals, turbidity, chlorophyll a, alkalinity, pheophytin a, E. coli, fecal coliforms, total solids, TSS	1967-2003
SWAMP		DO, nutrients, pH, temperature, conductivity, metals, alkalinity, chlorophyll a	2002-2003
PacifiCorp	PacifiCorp Klamath Water Quality Database	DO, nutrients, pH, temperature, conductivity, BOD, COD, metals, turbidity, chlorophyll a, alkalinity, pheophytin a, E. coli, fecal coliforms, total solids, TSS	1950-2001

* list of parameters is not exhaustive

Table 3-8. Datasets containing water quality observations on the Lost River and tributaries (including the Klamath Straits Drain).

Source	Dataset	Parameters Sampled*	Period of Record
NCRWQCB	104b Sampling Data	DO, nutrients, pH, temperature, TDS, TSS, conductivity, BOD, COD	1996-1998, 2003
USBR	Klamath Project Sampling	DO, nutrients, pH, temperature, TDS, conductivity, BOD, metals, turbidity, chlorophyll a, alkalinity	1972-2003
USGS		DO, nutrients, pH, temperature, conductivity, metals, chlorophyll a, alkalinity, pheophytin a	2002
ODEQ		DO, nutrients, pH, temperature, conductivity, BOD, COD, metals, turbidity, chlorophyll a, alkalinity, pheophytin a, E. coli, fecal coliforms, total solids, TSS,	1967-2003
UC – Davis		nutrients, pH, temperature, conductivity,	1999-2000
PacifiCorp	PacifiCorp Klamath Water Quality Database	DO, nutrients, pH, temperature, conductivity, BOD, COD, metals, turbidity, chlorophyll a, alkalinity, pheophytin a, E. coli, fecal coliforms, total solids, TSS	1950-2001

* list of parameters is not exhaustive

3.4.1 Klamath River

The sections below describe the available water quality data for segments of the Klamath River. The Oregon 2002 303(d) list reported that the Klamath River from Upper Klamath Lake to the stateline was impaired because of pH, ammonia, nutrients, temperature, low dissolved oxygen and chlorophyll a (ODEQ, 2002). The California 2002 303(d) list reported that the entire length of the Klamath River was impaired from stateline to the river's confluence with the Pacific Ocean because of nutrients, organic enrichment/low dissolved oxygen, and temperature.

These causes of impairment were impairing agricultural, aquatic life, hydropower generation, industrial supply, wildlife habitat, aquaculture, drinking water, fishery, recreation, and swimmable uses.

3.4.1.1 Klamath River above Iron Gate Dam

The focus of the current document is the Klamath River below Iron Gate Dam. As the river above Iron Gate Dam will be addressed in the near future, the data from the PacifiCorp database for stations above Iron Gate is summarized in Tables C-1 through C-14 in Appendix C. The new data for stations above Iron Gate Dam has not yet been analyzed. The tables provide summaries of the available data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record.

3.4.1.2 Klamath River below Iron Gate Dam

Data for stations below Iron Gate Dam was obtained from PacifiCorp's database and from new data provided by ODEQ, NCRWQCB, and USBR. The different agencies often assigned different station names to similar sites. In the PacifiCorp database all data sampled at similar sites were analyzed together and only one Site ID is reported. Site IDs were also created for the new data that has been provided. As this new data has not yet been incorporated into the PacifiCorp database there are instances where two Site IDs exist for the same station, one in the PacifiCorp database and one in the new dataset. Due to time constraints, the datasets were analyzed separately and the tables below list both stations separately. Stations at the same location will have the same Site Name but different Site IDs. When all the data is received and incorporated into the database a set of unique Site IDs will be created for all future data

analysis. The discussion below provides a review of available data to evaluate the water quality impairment status.

3.4.1.2.1 Temperature

Temperature data for the Klamath River are available from 11 monitoring stations in California (Figure 3-3). Table 3-9 below provides a summary of the available temperature data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The following table only includes stations with at least 10 temperature observations and includes only instantaneous temperature measurements not continuous observations from a data logger.

Table 3-9. Summary of temperature data, Klamath River (°C).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KR18973	Iron Gate Dam Outflow	34	17.10	7.1	22.6	4/5/1996	10/8/1997
KRBIGD	Klamath River below Iron Gate Dam	217	19.18	7.11	39.0	3/17/1998	6/18/2003
KR18238	Klamath River u/s of Cottonwood Creek	33	17.59	9.2	25.7	4/5/1996	10/8/1997
KRUSHR	Klamath River u/s of Shasta River	19	22.27	19.0	24.8	8/7/2000	6/12/2003
KR17607	Klamath River d/s of Shasta River	33	17.24	9.9	24.7	4/5/1996	10/8/1997
KR16075	Klamath River d/s of Beaver Creek	33	16.61	5.4	23.4	4/3/1996	10/24/1997
KRDEVC	Klamath River d/s of Everill Creek	10	19.95	12.50	34.0	2/27/2002	6/17/2003
KRUSCR	Klamath River u/s of Scott River	16	22.03	17.50	26.26	6/5/2000	6/12/2003
KR14260	Klamath River d/s of Scott River	33	17.14	9.3	23.4	4/3/1996	10/24/1997
KRSV	Klamath River at Seiad Valley	218	18.31	6.86	43	3/18/1998	6/17/2003
KRWE	Klamath River at Weithpec	20	17.70	9.5	26	2/25/2002	6/11/2003

Seven of the stations had temperature data for the critical summer months of June, July and August. Figure 3-4 through 3-6 show the average and maximum temperatures at these stations moving downstream along the Klamath River. In June the average temperatures are close together, ranging from about 17°C to about 21°C. In July the average temperatures ranged between 20°C and 25°C and that pattern continued into August.

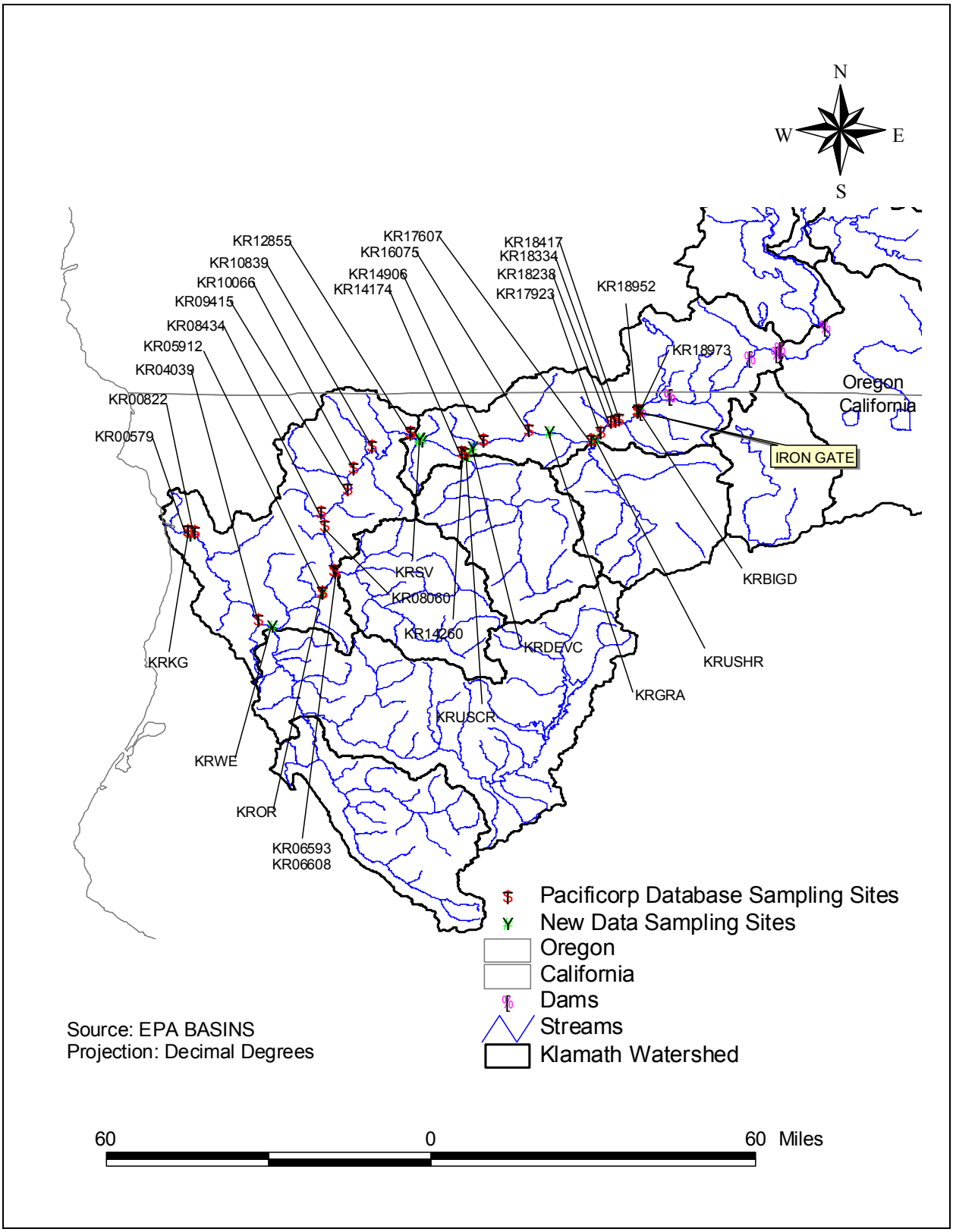

Figure 3-3. Sampling sites along the Klamath River.

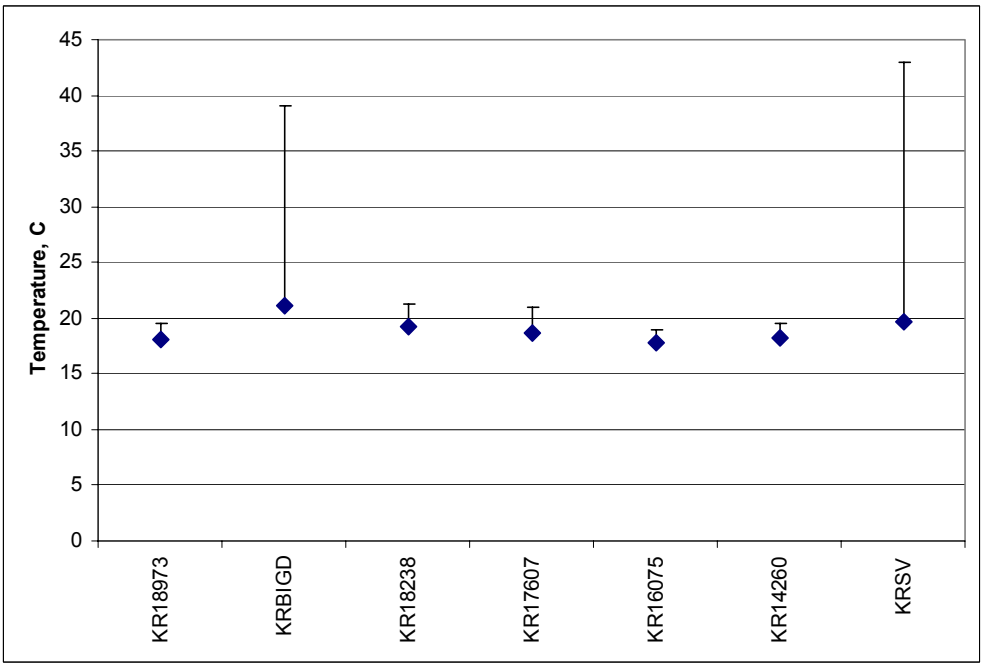

Figure 3-4. June average and maximum temperature along the Klamath River.

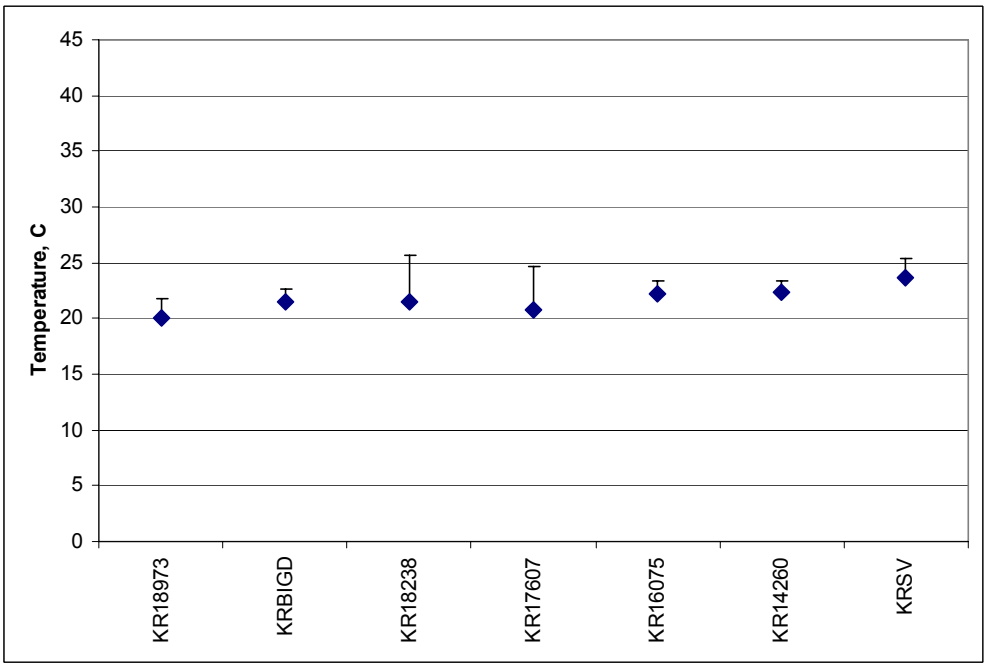

Figure 3-5. July average and maximum temperature along the Klamath River.

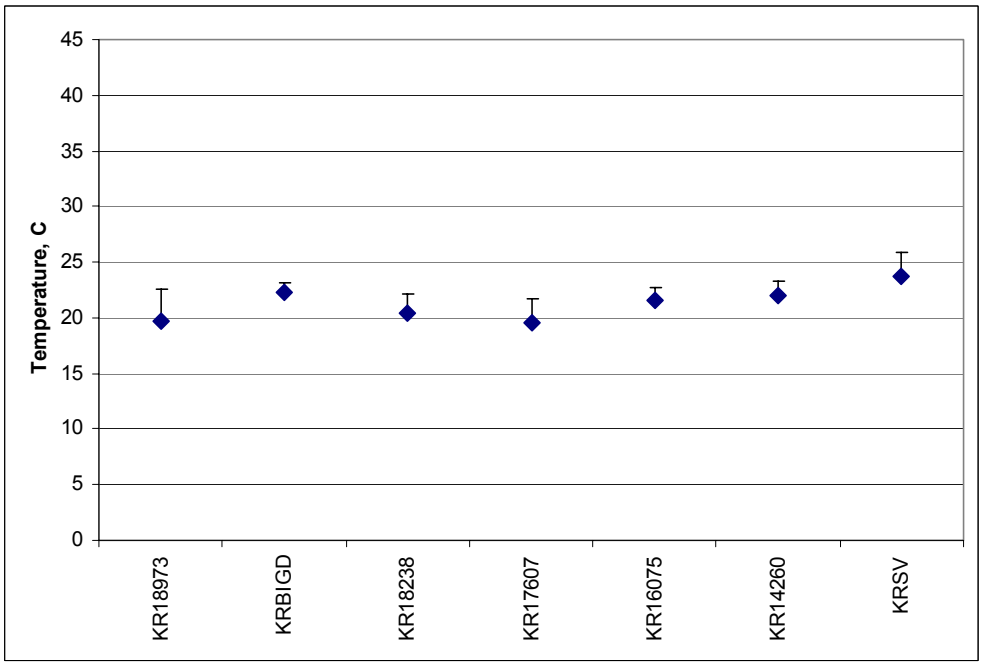

Figure 3-6. August average and maximum temperature along the Klamath River.

3.4.1.2.2 Nutrients

Few states, including Oregon and California, have numeric nutrient standards. This is because natural concentrations of nutrients vary among streams. Also, aquatic life and stream response to nutrient concentrations vary with different systems.

A summary of nutrient data in the Klamath River is presented in Tables 3-10 through 3-13. Sampling data was available for total phosphorous, dissolved orthophosphate and total ammonia and dissolved ammonia.

Dissolved oxygen data can be used to help identify nutrient impairments in the Klamath River. Excess nutrients in a waterbody can lead to nuisance algal blooms and low DO concentrations. DO data for the Klamath River are summarized in the next section.

Table 3-10. Summary of total phosphorous, Klamath River (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KR18973	Iron Gate Dam Outflow	8	0.236	0.025	0.440	4/24/1996	10/8/1997
KRIBGD	Klamath River below Iron Gate Dam	131	0.156	0.076	0.440	3/17/1998	6/18/2003
KR18952	Klamath River below Iron Gate Dam	184	0.151	0	0.380	9/13/1962	12/15/1988
KR18238	Klamath River u/s Cottonwood Creek	7	0.259	0.053	0.400	4/24/1996	10/8/1997
KR17923	Klamath River at R Collier Rest Stop	4	0.16	0.08	0.230	12/28/1977	4/25/1983
KRUSHR	Klamath River u/s of Shasta River	23	0.541	0.110	0.120	6/5/2000	6/12/2002
KR17607	Klamath River d/s Shasta River	8	0.246	0.052	0.380	4/24/1996	10/8/1997
KRGRA	Klamath River at Gottsville Road Access	5	0.136	0.095	0.191	10/8/2002	6/17/2003
KR16075	Klamath River d/s Beaver Creek	8	0.315	0.053	0.710	4/24/1996	10/8/1997
KR14906	Klamath River above Hamburg Res Site	56	0.135	0.03	0.280	1/3/1963	12/15/1988
KRDEVC	Klamath River d/s of Everill Creek	5	0.125	0.066	0.208	10/8/2002	6/17/2003
KRUSCR	Klamath River u/s of Scott River	22	0.195	0.110	0.380	6/5/2000	6/12/2003
KR14260	Klamath River d/s Scott River	8	0.301	0.058	0.930	4/24/1996	10/8/1997
KRSV	Klamath River at Seiad Valley	142	0.126	0.050	0.370	3/18/1998	6/17/2003
KR12855	Klamath River near Seiad Valley	69	0.118	0.000	0.400	9/13/1962	12/15/1988
KR06593	Klamath River below Salmon River	1	0	0	0	5/9/1955	5/9/1955
KR05912	Klamath River at Orleans	27	0.108	0.02	0.670	11/10/1971	12/5/1988
KROR	Klamath River at Orleans	4	0.065	0.032	0.122	10/16/2002	6/11/2003
KRWE	Klamath River at Weitchpec	10	0.063	0.031	0.114	4/24/1996	6/11/2003
KR04039	Klamath River below Trinity River	1	0.06	0.06	0.060	8/4/1972	8/4/1972
KR00822	Klamath River south of Hoopa	21	0.122	0.02	0.830	1/6/1971	1/2/1979
KR00579	Klamath River at Klamath Glen	264	0.104	0.01	1.2	4/14/1966	9/26/1995
KRKG	Klamath River at Klamath Glen	5	0.063	0.035	0.079	10/15/2002	6/10/2003

Table 3-11. Summary of orthophosphate, dissolved, Klamath River (mg/L as P).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KR18952	Klamath River below Iron Gate Dam	185	0.106	0	0.24	5/16/1962	12/15/1988
KR17923	Klamath River at R Collier Rest Stop	4	0.105	0.04	0.18	12/28/1977	4/25/1983
KR14906	Klamath River above Hamburg Res Site	71	0.105	0.01	0.2	5/13/1959	12/15/1988
KR12855	Klamath River near Seiad Valley	90	0.082	0.01	0.19	5/13/1959	12/15/1988
KR06593	Klamath River below Salmon River	11	0.047	0	0.15	5/6/1959	5/11/1964
KR05912	Klamath River at Orleans	27	0.037	0	0.15	5/11/1964	12/5/1988
KR04039	Klamath River below Trinity River	1	0.03	0.03	0.03	8/4/1972	8/4/1972
KR00822	Klamath River south of Hoopa	31	0.256	0	2.9	10/19/1970	2/13/1979
KR00579	Klamath River at Klamath Glen	108	0.032	0	0.5	5/5/1959	9/26/1995

Table 3-12. Summary of NH3, dissolved data, Klamath River (mg/L as N).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KR18973	Iron Gate Dam Outflow	8	0.124	0.07	0.24	4/24/1996	10/8/1997
KR18952	Klamath River below Iron Gate Dam	35	0.13	0	0.52	1/3/1979	6/12/1984
KR18238	Klamath River u/s Cottonwood Creek	7	0.108	0.025	0.15	4/24/1996	10/8/1997
KR17607	Klamath River d/s Shasta River	8	0.102	0.025	0.2	4/24/1996	10/8/1997
KR16075	Klamath River d/s Beaver Creek	8	0.091	0.025	0.19	4/24/1996	10/8/1997
KR14260	Klamath River d/s Scott River	8	0.091	0.025	0.16	4/24/1996	10/8/1997
KR05912	Klamath River at Orleans	4	0.035	0	0.12	12/5/1983	5/1/1984
KR00822	Klamath River south of Hoopa	1	0.02	0.02	0.02	1/2/1979	1/2/1979
KR00579	Klamath River at Klamath Glen	95	0.027	0	0.29	10/25/1979	9/26/1995

Table 3-13. Summary of NH3, total data, Klamath River (mg/L as N).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KR18973	Iron Gate Dam Outflow	8	0.148	0.08	0.28	4/24/1996	10/8/1997
KR18952	Klamath River below Iron Gate Dam	52	0.153	0.01	0.74	2/2/1977	6/2/1985
KR18238	Klamath River u/s Cottonwood Creek	7	0.131	0.05	0.18	4/24/1996	10/8/1997
KR17923	Klamath River at R Collier Rest Stop	1	0.78	0.78	0.78	12/28/1977	12/28/1977
KR17607	Klamath River d/s Shasta River	8	0.119	0.025	0.23	4/24/1996	10/8/1997
KR16075	Klamath River d/s Beaver Creek	8	0.154	0.025	0.43	4/24/1996	10/8/1997
KR14260	Klamath River d/s Scott River	8	0.113	0.025	0.26	4/24/1996	10/8/1997
KR05912	Klamath River at Orleans	5	0.08	0	0.2	11/10/1971	6/2/1985
KR00822	Klamath River south of Hoopa	17	0.016	0	0.07	2/1/1977	11/6/1978
KR00579	Klamath River at Klamath Glen	73	0.024	0	0.16	10/19/1977	11/17/1992

3.4.1.2.3 Dissolved Oxygen

Dissolved oxygen data for the Klamath River are available from 30 monitoring stations in California. Table 3-14 below provides a summary of the available dissolved oxygen data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The table includes all stations with at least 5 DO observations.

Table 3-14. Summary of DO data, Klamath River (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KR18973	Iron Gate Dam Outflow	35	8.29	6	10.8	1/9/1962	2/14/1989
KRBIGD	Klamath River below Iron Gate Dam	216	8.38	5.45	12.62	3/17/1998	6/18/2003
KR18952	Klamath River below Iron Gate Dam	514	10.21	5	15.8	12/5/1961	4/4/1962
KR18417	Klamath River at Klamathon Bar	5	11.06	10.7	11.7	5/15/1962	10/10/1972
KR18334	Klamath River near Henley	82	10.43	7	13	4/5/1996	10/8/1997
KR18238	Klamath River u/s of Cottonwood Creek	34	10.33	7.7	14.2	9/6/1973	8/20/1985
KR17923	Klamath River at R Collier Rest Stop	31	9.43	6.6	13.5	4/5/1996	10/8/1997
KRUSHR	Klamath River u/s of Shasta River	19	8.48	6.45	10.52	8/7/2000	6/12/2003
KR17607	Klamath River d/s of Shasta River	34	8.91	7.2	11.2	4/3/1996	10/24/1997
KRGRA	Klamath River at Gottsville Road Access	10	10.79	9.03	12.62	2/27/2002	6/17/2003
KR16075	Klamath River d/s of Beaver Creek	33	9.4	6.9	10.8	12/2/1958	2/14/1989
KR14906	Klamath River above Hamburg Res Site	287	10.45	4.5	14	4/3/1996	10/24/1997
KRDEVC	Klamath River d/s of Everill Creek	10	10.93	8.99	12.53	2/27/2002	6/17/2003
KRUSCR	Klamath River u/s of Scott River	14	8.46	6.83	9.76	6/5/200	6/12/2003
KR14260	Klamath River d/s of Scott River	33	9.54	7	12.2	5/14/1985	1/22/1986
KR14174	Klamath River at Sarah Totten Campground	6	11.73	10	12.4	9/10/1958	2/14/1989
KRSV	Klamath River at Seiad Valley	219	9.36	6.58	14.33	3/18/1998	6/17/2003
KR12855	Klamath River near Seiad Valley	394	10.75	7.5	14.1	1/21/1986	1/22/1986
KR10839	Klamath River above Happy Camp	5	12	11.7	12.3	8/14/1985	1/22/1986
KR10066	Klamath River above Oak Flat Creek	6	11.7	8.7	12.4	8/14/1985	1/22/1986
KR09415	Klamath River above Independence Creek	5	1.74	9.4	12.7	2/26/1985	1/23/1986
KR08434	Klamath River above Dillon Creek	9	11.13	8.7	13.2	8/13/1985	1/23/1986
KR08060	Klamath River above Ti Creek	6	11.2	8.5	12.5	1/22/1986	1/23/1986
KR06608	Klamath River above Salmon River	5	12.92	12.4	13.3	4/10/1951	5/11/1964
KR06593	Klamath River below Salmon River	90	10.69	7.2	14.2	1/16/1964	2/6/1989
KR05912	Klamath River at Orleans	471	11.21	7.7	14.8	8/4/1972	8/4/1972
KROR	Klamath River at Orleans	5	12.64	10.85	14.7	10/16/2002	6/11/2003
KR00822	Klamath River South of Hoopa	154	10.75	8	14	2/10/1965	3/13/1979
KR00579	Klamath River at Klamath Glen	605	10.6	0.1	14.7	7/17/1951	9/26/1995
KRKG	Klamath River at Klamath Glen	5	11.39	9.77	13.79	10/15/2002	6/10/2003

3.4.1.2.4 Chlorophyll a

Chlorophyll a data for the Klamath River are available from 5 monitoring stations in California. Table 3-15 below provides a summary of the available chlorophyll a data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The table includes all stations with at least 5 chlorophyll a observations.

Table 3-15. Summary of chlorophyll a data, Klamath River (ug/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KR18973	Iron Gate Dam Outflow	7	5.49	1.7	10	4/24/1996	10/8/1997
KR18238	Klamath River u/s of Cottonwood Creek	7	9.63	1.7	33	4/24/1996	10/8/1997
KR17607	Klamath River d/s of Shasta River	7	5.63	2.3	12	4/24/1996	10/8/1997
KR16075	Klamath River d/s of Beaver Creek	7	5.54	2.3	14	4/24/1996	10/8/1997
KR14260	Klamath River d/s of Scott River	7	6.03	2.1	17	4/24/1996	10/8/1997

3.4.2 Lost River

The Oregon 2002 303(d) list reported that the Lost River (within Oregon) was impaired because of temperature, fecal coliforms, dissolved oxygen, and chlorophyll a. Public, private and industrial water supply, irrigation, livestock watering, resident fish and aquatic life, fishing, boating, hunting, water contact recreation and salmonid fish spawning and rearing beneficial uses were impaired by these causes in 2002. The discussion below provides a review of available data to evaluate the water quality impairment status.

3.4.2.1 Temperature

Temperature data for the Lost River are available from 20 monitoring stations in Oregon and California (Figure 3-7). Table 3-16 below provides a summary of the available temperature data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The stations are listed in downstream order starting downstream of Malone Dam. The table includes all stations with at least 10 temperature observations and includes only instantaneous temperature measurements not continuous measurements from a data logger.

Table 3-16. Summary of temperature data, Lost River (°C).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
LRDM	Lost River d/s of Malone Dam	314	12.43	0.18	28.95	6/1/1993	11/12/2003
LRJR	Lost River at Johnson Road	232	12.66	0.42	30.43	6/1/1993	3/2/1999
LRGR	Lost River at Gift Road	207	12.63	-0.30	28.85	6/1/1993	3/2/1999
LRCRF	Lost River at Cheese Factory Road	191	12.10	1.00	26.95	6/1/1993	8/27/2003
LRKB	Lost River at Keller Bridge	328	12.86	0.21	25.40	6/1/1993	10/16/2003
LR70	Lost River at Hwy 70	289	14.51	-0.21	28.09	6/1/1993	8/27/2003
LRHRB	Lost River at Harpold Road Bridge	421	14.93	3.99	27.76	6/1/1993	8/27/2003
LRHD	Lost River u/s of Harpold Dam	159	17.38	0.00	24.49	6/2/1993	11/10/2003
LRHDB	Lost River at Harpold Dam Bridge	507	14.87	3.35	27.76	6/1/1993	10/16/2003
LRSP	Lost River at Stevenson Park	11	14.16	2.52	23.28	8/1/2000	3/7/2001
LROG	Lost River at Olene Gap	356	14.41	1.17	27.49	6/1/1993	8/19/2003
LRWRC*	Lost River at Wilson Reservoir at Crystal Springs Road	909	14.78	0.81	32.05	6/2/1993	11/14/2003
LRRR	Lost River at Reeder Road	255	15.56	0.81	26.35	6/2/1993	9/19/2000
LRDR	Lost River at Dehlinger Road	44	15.54	1.74	25.06	1/181998	8/28/2003
LRSB	Lost River at Stukel Bridge	207	15.47	-0.26	25.47	6/2/1993	3/2/1999
LR39	Lost River at Hwy 39	150	13.77	1.00	25.60	4/8/1970	8/27/2003
LRFR	Lost River at Falvey Road	34	14.62	0.02	24.47	3/4/1998	1/28/1999
LRAR*	Lost River at Anderson-Rose Reservoir	451	14.37	0.89	25.53	5/13/1993	11/13/2001
LRMR	Lost River at Malone Road	248	13.33	0.00	28.95	5/13/1993	11/12/2003
LRWB	Lost River at Wooden Bridge	260	14.54	1.55	26.08	6/2/1993	12/16/1998
LRSR	Lost River at Stateline Road	162	14.18	0.60	24.00	5/31/1996	10/16/2000
LREW	Lost River at East West Road	200	14.61	0.09	26.18	6/2/1993	9/19/2002

*Includes all samples taken in reservoir at different depths

Figures 3-8 through 3-10 show the average and maximum temperature at stations along the Lost River.

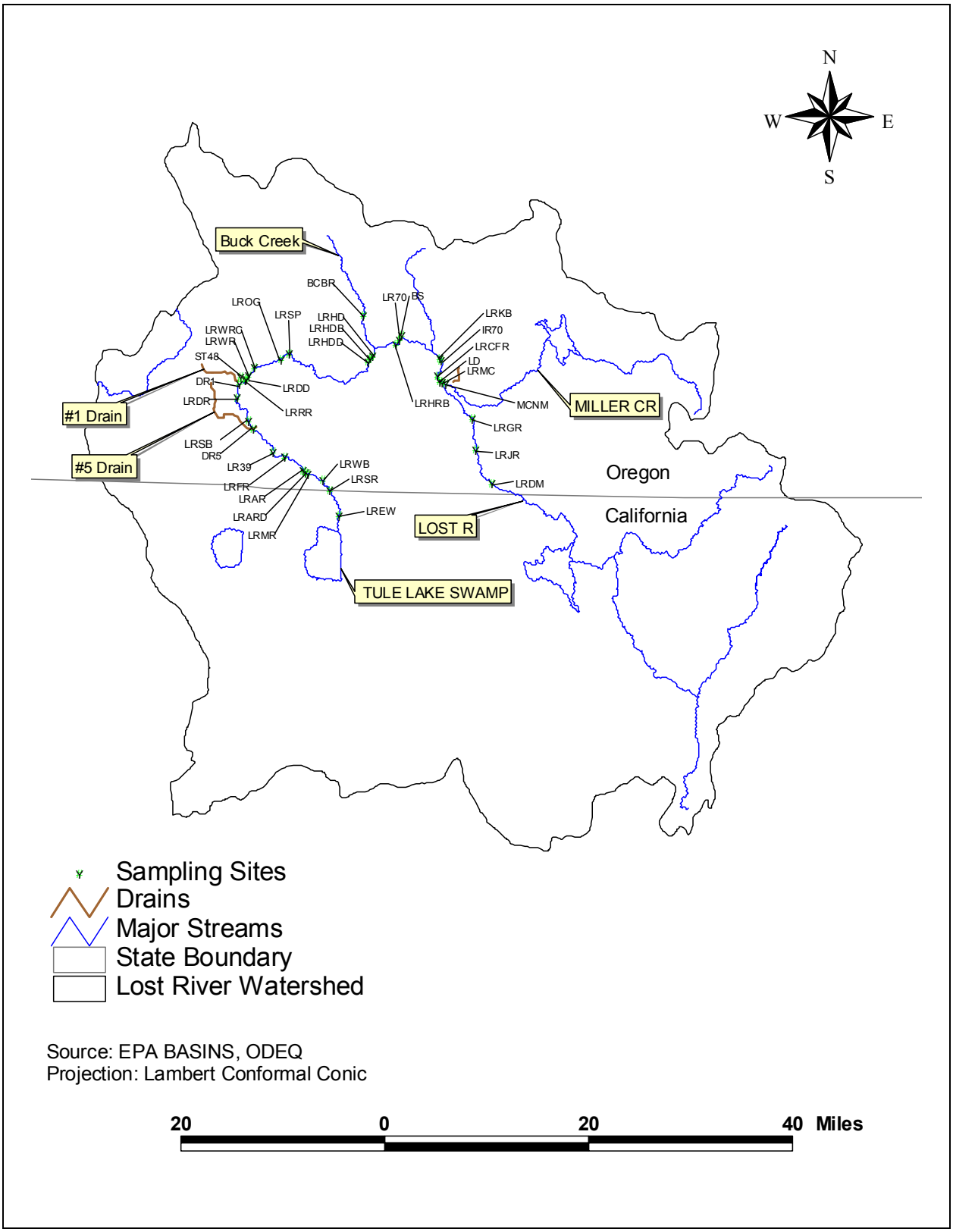

Figure 3-7. Sampling sites along the Lost River

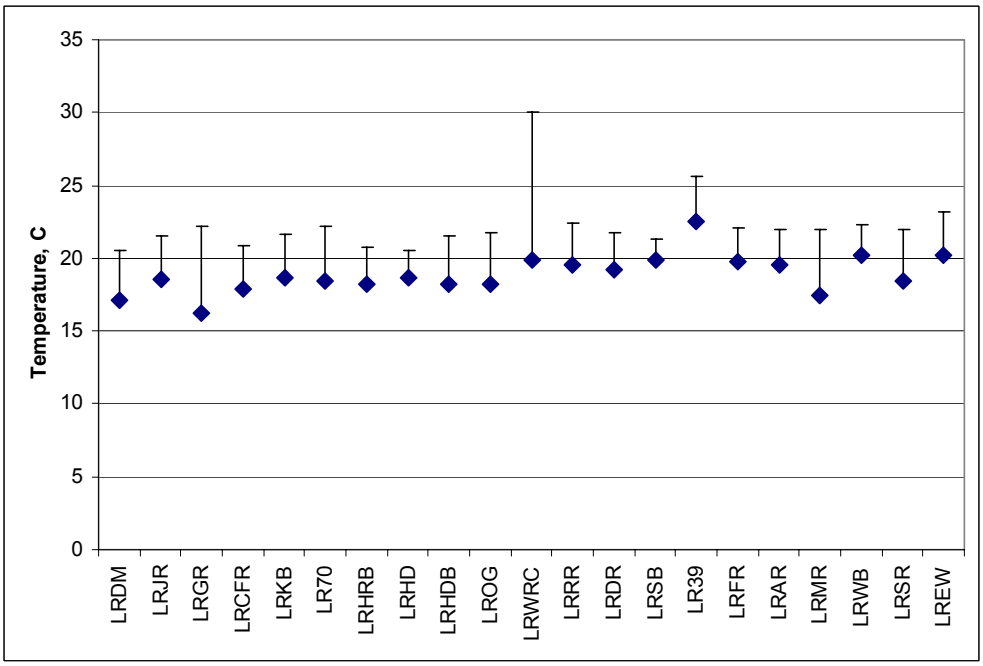

Figure 3-8. June average and maximum temperatures along the Lost River.

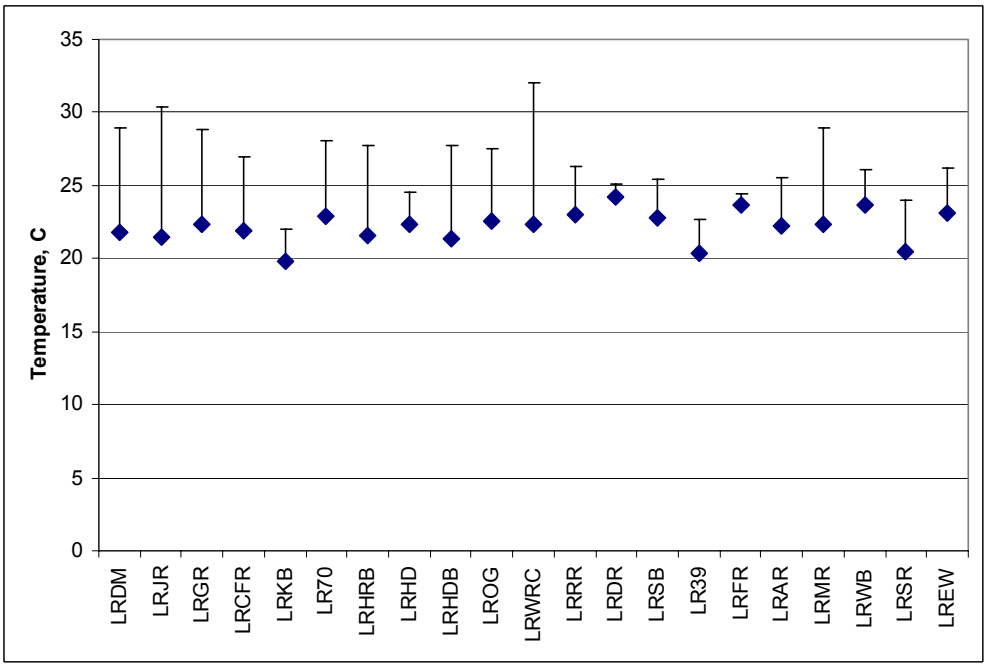

Figure 3-9. July average and maximum temperatures along the Lost River.

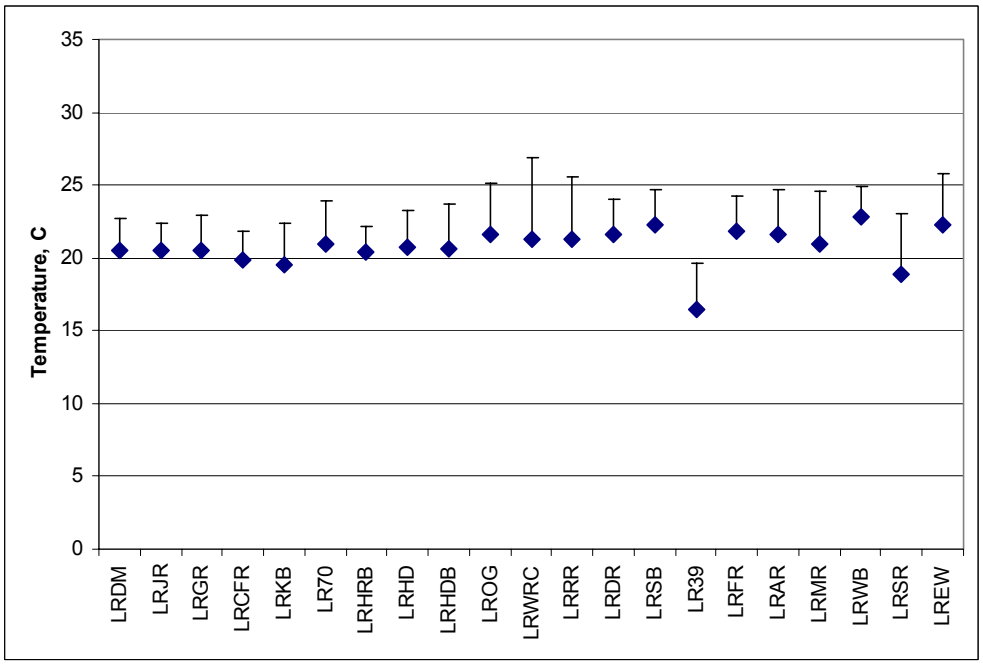

Figure 3-10. August average and maximum temperatures along the Lost River.

In July, the average water temperatures increase to between about 20°C and 25°C and this pattern continues into August. The only exception is at station LR39, where the average temperature decreases from June to August. The maximum water temperature observed each month was at the same station, LRWRC (Lost River at Wilson Reservoir Crystal Springs Road).

There are three major natural tributaries to the Lost River and numerous drains that discharge to the Lost River. Temperature data are available from 6 monitoring stations on incoming waterbodies. Table 3-17 below provides a summary of available temperature data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. Miller Creek and Buck Creek have more than one sampling station but only the station closest to their confluence with the Lost River are included here. The table includes all stations with at least 10 temperature observations.

Table 3-17. Summary of temperature data, tributaries to Lost River (°C).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
MCNM	Miller Creek near Mouth	16	16.66	6.6	24.96	12/5/2002	10/16/2003
BS	Big Springs	277	14.76	-0.21	28.09	6/1/1993	11/13/2001
BCBR	Buck Creek at Burgdorf Road	87	12.15	0.20	23.94	7/30/1996	8/27/2003
ST48	Station 48	50	13.98	2.70	24.30	7/30/1996	8/9/2001
DR1	#1 Drain	89	14.17	1.88	25.82	7/30/1996	8/28/2003
DR5	#5 Drain	84	12.82	0.12	23.41	2/3/1998	8/27/2003

3.4.2.2 Bacteria

The Oregon standard for bacteria uses the indicator E. coli to determine water quality standard exceedances. E. coli data for the Lost River are available from 10 monitoring stations in Oregon. Table

3-18 below provides a summary of the available E. coli data including the minimum value, maximum value and geometric mean value observed at each station in addition to the number of observations and the period of record. The table includes all stations with at least 2 E. coli observations. Table 3-19 below provides a summary of the stations with exceedances of the E. coli standard.

Table 3-18. Summary of E. coli data, Lost River (MPN/100 mL or CFU/100 mL).

Site ID	Site Name	Count	Geomean	Min	Max	Start Date	End Date
LRCFR	Lost River at Cheese Factory Road	3	331.5	194	754	5/21/2003	8/27/2003
LRKB	Lost River at Keller Bridge	3	79.9	31	135	5/21/2003	8/27/2003
LR70	Lost River at Hwy 70	3	103.1	10	2382	5/21/2003	8/27/2003
LRHD	Lost River u/s of Harpold Dam	3	11.9	8	21	5/21/2003	8/27/2003
LRHRB	Lost River at Harpold Road Bridge	3	9.9	8	15	5/21/2003	8/27/2003
LRWRC	Lost River at Wilson Reservoir Crystal Springs Road	3	12.1	8	28	5/21/2003	8/27/2003
LRDR	Lost River at Dehlinger Road	4	82.3	41	216	5/21/2003	8/27/2003
LRARD	Lost River at Anderson-Rose Dam	4	354.2	86	3784	5/20/2003	8/27/2003
LRMR	Lost River at Malone Road	7	126.4	8	6867	5/20/2003	8/27/2003
LR39	Lost River at Hwy 39	28	51.8	4	203	7/23/2002	8/27/2003
LR39*	Lost River at Hwy 39	66	42.9	2	660	5/14/1996	3/27/2002

*E. coli reported in CFU/100 mL all others in MPN/100 mL

Table 3-19. Summary of E. coli exceedances at stations on the Lost River.

Site ID	Site Name	Time Period	Total Number of Samples	Number of Samples ≥ 406	Percent of Samples ≥ 406
LRCFR	Lost River at Cheese Factory Road	5/22/2003	3	1	33%
LR70	Lost River at Hwy 70	5/22/2003	3	1	33%
LRARD	Lost River at Anderson-Rose Dam	5/21-22/2003	4	2	50%
LRMR	Lost River at Malone Road	5/21-22/2003	7	2	29%
LR39*	Lost River at Hwy 39	5/13/1997	66	2	3%

*E. coli reported in CFU/100 mL

Table 3-20 below provides a summary of available E. coli data for the tributaries to the Lost River including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. Miller Creek and Buck Creek have more than one sampling station but only the station closest to their confluence with the Lost River are included here.

Table 3-20. Summary of E. coli data, tributaries to Lost River (MPN/100 mL).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
BCBR	Buck Creek at Burgdorf Road	3	1375	42	3282	5/21/2003	8/27/2003
DR1	#1 Drain	4	291	91	738	5/21/2003	8/28/2003
DR5	#5 Drain	2	134.5	107	162	8/26/2003	8/27/2003

3.4.2.3 Dissolved Oxygen

Dissolved oxygen data for the Lost River are available from 22 monitoring stations in Oregon and California. Table 3-21 below provides a summary of the available dissolved oxygen data including the minimum value, maximum value and average value observed at each station in addition to the number of

observations and the period of record. The stations are listed in downstream order starting downstream of Malone Dam. The table includes all stations with at least 10 dissolved oxygen observations.

Table 3-21. Summary of DO data, Lost River (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
LRDM	Lost River d/s of Malone Dam	314	9.27	4.75	12.78	6/1/1993	11/12/2002
LRJR	Lost River at Johnson Road	238	7.96	3.64	12.87	6/1/1993	3/2/1999
LRGR	Lost River at Gift Road	183	8.19	4.1	12.53	6/1/1993	3/2/1999
LRCRF	Lost River at Cheese Factory Road	187	9.07	5.05	14.22	6/1/1993	8/27/2003
LRKB	Lost River at Keller Bridge	332	8.21	3.76	14.27	6/1/1993	10/16/2003
LR70	Lost River at Hwy 70	288	7.61	4.00	11.70	6/1/1993	8/27/2003
LRHRB	Lost River at Harpold Road	430	7.47	1.08	12.80	6/1/1993	8/27/2003
LRHD*	Lost River u/s of Harpold Dam	163	6.99	0.29	14.40	6/2/1993	11/10/2003
LRHDB*	Lost River at Harpold Dam Bridge	501	7.95	1.08	13.83	6/1/1993	10/16/2003
LROG	Lost River at Olene Gap	359	7.36	0.03	13.82	6/1/1993	8/19/2003
LRWRC*	Lost River at Wilson Reservoir at Crystal Springs Road	1076	6.71	0.01	24.6	5/16/1972	11/14/2003
LRRR	Lost River at Reeder Road	264	7.57	0.68	24.60	06/2/1993	9/19/2000
LRDR	Lost River at Dehlinger Road	43	7.17	2.70	13.00	1/8/1998	8/28/2003
LRSB	Lost River at Stukel Bridge	210	7.43	1.84	16.71	6/2/1993	3/2/1999
LR39	Lost River at Hwy 39	150	8.12	1.80	21.00	4/8/1970	8/27/2003
LRFR	Lost River at Falvey Road	32	7.19	3.36	11.19	3/4/1998	1/28/1999
LRAR*	Lost River at Anderson-Rose Reservoir	642	7.21	0.24	20.79	5/16/1972	6/3/2003
LRMR	Lost River at Malone Road	252	8.90	0.84	16.13	5/13/1993	11/12/2003
LRWB	Lost River at Wooden Bridge	255	9.26	1.68	17.2	6/2/1993	12.16/1998
LRSR	Lost River at Stateline Road	30	8.55	3.70	15.60	5/31/1996	6/24/1998
LREW	Lost River at East West Road	191	9.75	0.60	18.14	6/2/1993	9/19/2002

*Includes all samples taken in reservoir at different depths

Figures 3-11 through 3-13 show the average dissolved oxygen concentration at each of the above stations along with the minimum DO observed and Oregon's absolute minimum standard for DO for the critical summer months of July, August and September.

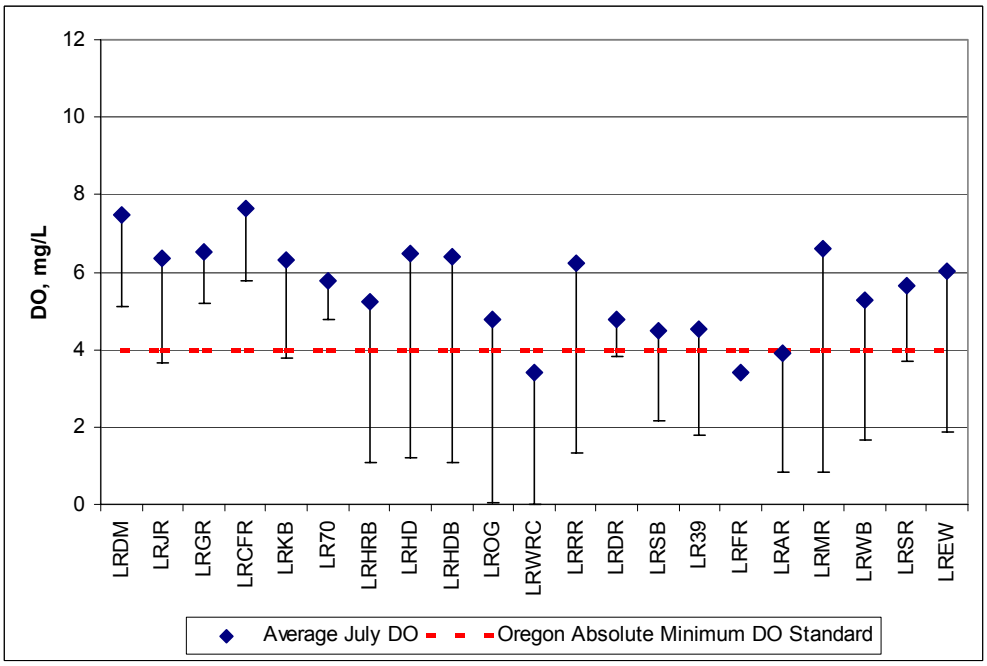

Figure 3-11. July average and minimum DO concentrations along the Lost River.

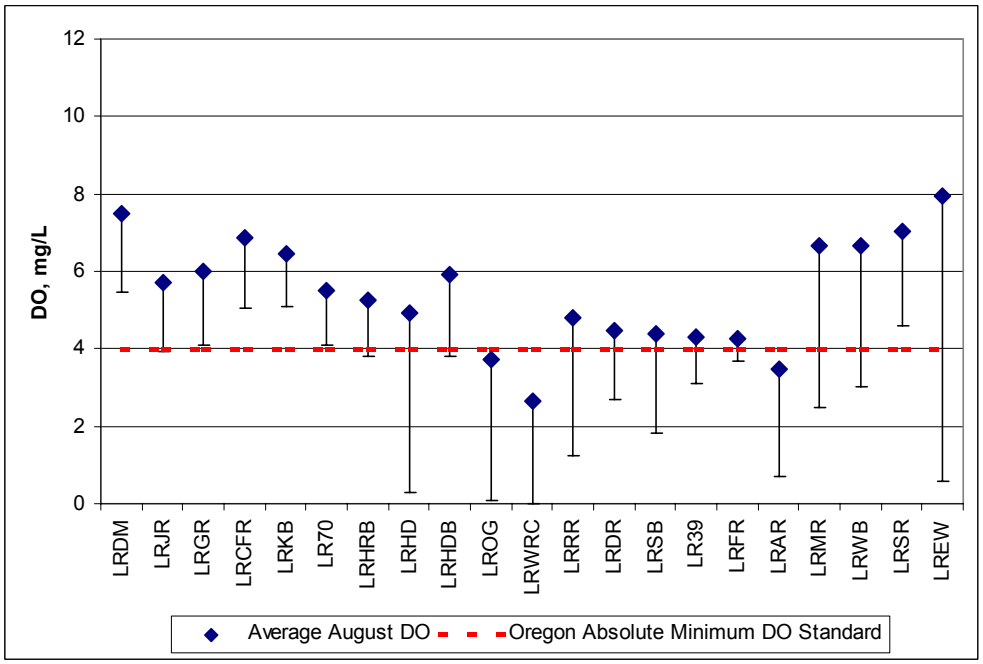

Figure 3-12. August average and minimum DO concentrations along the Lost River.

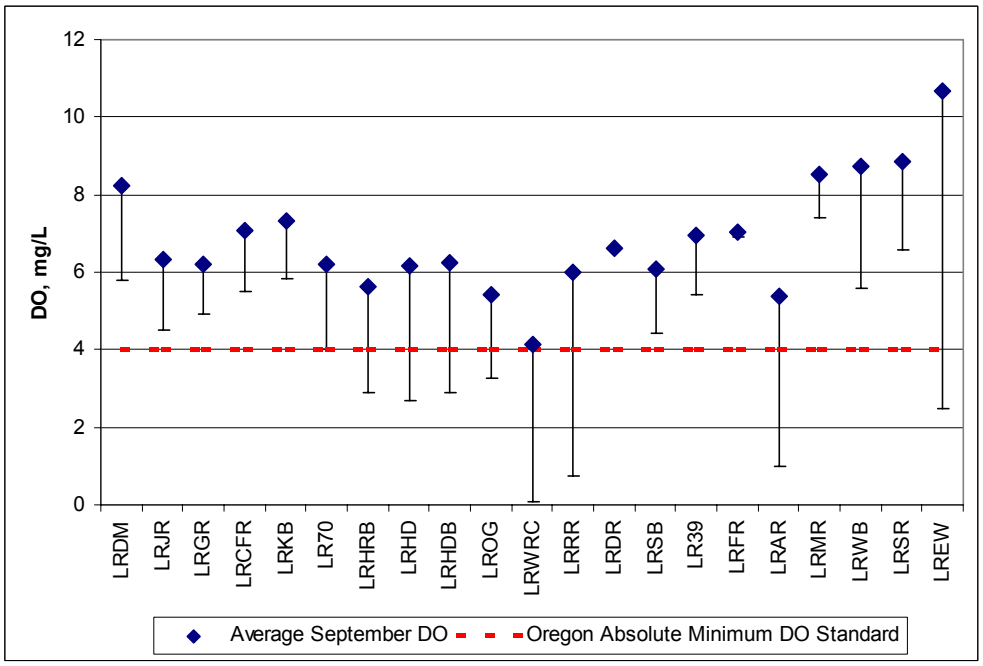

Figure 3-13. September average and minimum DO concentrations along the Lost River.

The station LRWRC (Lost River at Wilson Reservoir at Crystal Springs Road) generally had the lowest average DO of all three months, with the average value less than Oregon's absolute minimum DO of 4.0 mg/L in the months of July and August and the average value just above the standard in September. This station also had the highest average summer temperature as discussed in the section 3.4.2.1.

Dissolved oxygen data are available from 6 monitoring stations on tributaries to the Lost River. Table 3-22 below provides a summary of available DO data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. Miller Creek and Buck Creek have more than one sampling station but only the stations closest to their confluence with the Lost River are included here.

Table 3-22. Summary of DO data, tributaries to Lost River (°C).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
MCNM	Miller Creek near Mouth	14	12.36	5.94	15.95	12/5/2002	10/16/2003
BS	Big Springs	272	7.85	4.0	12.36	6/1/1993	11/13/2001
BCBR	Buck Creek at Burgdorf Road	87	10.32	4.48	19.00	7/30/1996	8/27/2003
ST48	Station 48	53	8.10	1.07	12.15	7/30/1996	8/9/2001
DR1	#1 Drain	96	7.21	2.00	12.90	7/30/1996	8/28/2003
DR5	#5 Drain	81	8.21	1.80	15.75	2/3/1998	8/27/2003

3.4.2.4 Chlorophyll a

Chlorophyll a data for the Lost River are available from 9 monitoring stations in Oregon and California. Table 3-23 below provides a summary of the available chlorophyll a data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The table includes all stations with at least 5 chlorophyll a observations.

Table 3-23. Summary of chlorophyll a data, Lost River (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
LRKB	Lost River at Keller Bridge	52	0.0106	0.0019	0.200	5/12/1999	8/27/2003
LRHDB*	Lost River at Harpold Dam Bridge	51	0.0072	0.0005	0.034	5/12/1999	11/13/2001
LROG	Lost River at Olene Gap	19	0.0089	0.0016	0.036	6/20/2000	11/13/2001
LRWRC*	Lost River at Wilson Reservoir at Crystal Springs Road	81	0.0122	0.0020	0.120	8/12/1999	8/27/2003
LRRR	Lost River at Reeder Road	27	0.0188	0.0025	0.120	5/12/1999	9/19/2000
LR39	Lost River at Hwy 39	72	0.0161	0.0015	0.1182	7/20/1993	8/27/2003
LRAR*	Lost River at Anderson-Rose Reservoir	93	0.0220	0.0020	0.016	5/12/1999	11/13/2001
LRMR	Lost River at Malone Road	6	0.0048	0.0013	0.0081	5/20/2003	8/27/2003
LREW	Lost River at East West Road	54	0.0259	0.0005	0.160	5/12/1999	9/19/2002

*Includes all samples taken in reservoir at different depths

Oregon's standard for chlorophyll a is 0.015 mg/L. Eight of the above stations exceeded the chlorophyll a standard during the period of record. Table 3-24 below provides a summary of the chlorophyll a exceedances.

Table 3-24. Summary of chlorophyll a exceedances, Lost River.

Site ID	Site Name	Number of Samples	Number of Samples >0.015 mg/L	Total % of Exceedances
LRKB	Lost River at Keller Bridge	52	4	7.7%
LRHDB*	Lost River at Harpold Dam Bridge	51	4	7.8%
LROG	Lost River at Olene Gap	19	3	15.8%
LRWRC*	Lost River at Wilson Reservoir at Crystal Springs Road	81	17	21.0%
LRRR	Lost River at Reeder Road	27	10	37.0%
LR39	Lost River at Hwy 39	72	20	27.8%
LRAR*	Lost River at Anderson-Rose Reservoir	93	21	22.6%

The station with the highest chlorophyll a concentrations was LREW (Lost River at East West Road). Figure 3-14 shows the average monthly concentration and range of the chlorophyll a observations at that station.

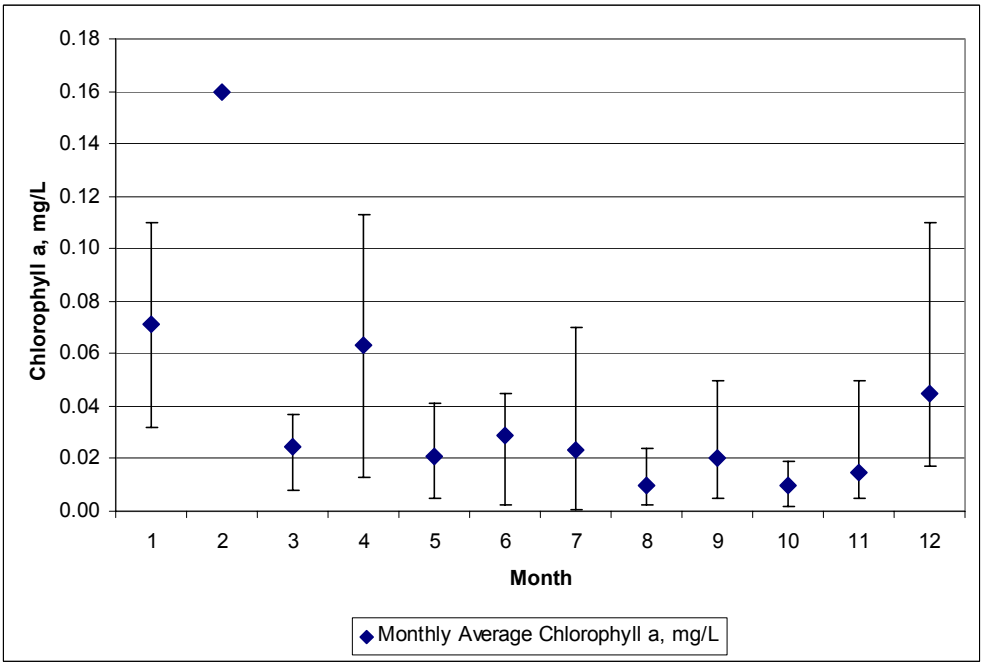

Figure 3-14. Monthly average chlorophyll a concentration and range for LREW (Lost River at East West Road).

Chlorophyll a data are available from 6 monitoring stations on the tributaries to the Lost River. Table 3-25 below provides a summary of available chlorophyll a data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. Miller Creek and Buck Creek have more than one sampling station but only the station closest to their confluence with the Lost River is included here. The table includes all stations with at least 5 chlorophyll a observations.

Table 3-25. Summary of chlorophyll a data, tributaries to Lost River (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
BS	Big Springs	45	0.00638	0.0015	0.083	5/12/1999	11/13/2001
BCBR	Buck Creek at Burgdorf Road	55	0.01250	0.0014	0.072	5/12/1999	8/27/2003
ST48	Station 48	44	0.01747	0.0025	0.1126	5/12/1999	8/9/2001
DR1	#1 Drain	55	0.01976	0.002	0.110	5/12/1999	8/28/2003
DR5	#5 Drain	53	0.03218	0.002	0.270	5/12/1999	8/27/2003

3.4.2.5 Nutrients

Although the Lost River is not listed as impaired for nutrients, high nutrient concentrations can cause organic enrichment and low dissolved oxygen levels. Tables 3-26 through 3-28 below provide summaries of the available nutrient data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. Also included in Table 3-29 is the only available nutrient data (orthophosphate) for the tributaries to the Lost River.

Table 3-26. Summary of total phosphorous data, Lost River (mg/L)

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
LR39	Lost River at Hwy 39	1	0.3	0.3	0.3	9/11/2001	9/11/2001
LRWRC	Lost River at Wilson Reservoir at Crystal Springs Road	166	0.35	0.03	2.90	2/26/1973	6/3/2003
LRAR	Lost River at Anderson-Rose Dam	199	0.56	0.01	6.10	2/26/1976	6/3/2003
LRSR	Lost River at Stateline Road	140	0.31	0.06	0.81	4/24/1996	10/16/2000
LREW	Lost River at East West Road	3	0.31	0.29	0.32	7/18/2002	9/19/2002

Table 3-27. Summary of orthophosphate data, Lost River (mg/L asP)

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
LRKB	Lost River at Keller Bridge	40	0.118	0.05	0.20	5/12/1999	12/18/2000
LRHDB	Lost River at Harpold Dam Bridge	42	0.116	0.05	0.20	5/12/1999	12/18/2000
LRSP	Lost River at Stevenson Park	4	0.225	0.20	0.30	8/1/2000	9/6/2000
LROG	Lost River at Olene Gap Road	10	0.150	0.10	0.20	6/20/2000	12/18/2000
LRWRC	Lost River at Wilson Reservoir at Crystal Springs Road	146	0.205	0.027	0.56	2/26/1973	6/3/2003
LRRR	Lost River at Reeder Road	27	0.233	0.05	0.50	5/12/1999	9/19/2000
LRAR	Lost River at Anderson-Rose Reservoir	186	0.321	0.032	0.78	2/26/1973	9/3/2003
LREW	Lost River at East West Road	42	0.244	0.05	0.7	5/12/1999	12/18/2000

Table 3-28. Summary of total nitrogen data, Lost River (mg/L)

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
LRSR	Lost River at Stateline Road	132	2.364	1.205	6.299	1/13/1999	10/16/2000

Table 3-29. Summary of orthophosphate data, tributaries to Lost River (mg/L as P).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
BS	Big Springs	38	0.087	0.05	0.20	5/12/1999	12/18/2000
BCBR	Buck Creek at Burgdorf Road	43	0.252	0.05	0.50	5/12/1999	12/18/2000
ST48	Station 48	43	0.149	0.05	0.40	5/12/1999	12/18/2000
DR1	#1 Drain	43	0.349	0.10	0.70	5/12/1999	12/18/2000
DR5	#5 Drain	43	0.316	0.10	0.70	5/12/1999	12/18/2000

3.4.2.6 Oxygen Consuming Constituents

Although the Lost River is not listed as impaired for oxygen consuming constituents (BOD or COD), high BOD or COD concentrations can cause low dissolved oxygen levels. Tables 3-30 through 3-31 below provide summaries of the available BOD and COD data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The tables include all stations with at least 3 observations.

Table 3-30. Summary of BOD data, Lost River (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
LRCFR	Lost River at Cheese Factory Road	3	2.20	1.80	3.00	5/21/2003	8/27/2003
LRKB	Lost River at Keller Bridge	3	2.00	1.30	2.60	5/21/2003	8/27/2003
LR70	Lost River at Hwy 70	3	2.47	2.00	3.20	5/21/2003	8/27/2003
LRHRB	Lost River at Harpold Road	3	2.27	1.80	3.00	5/21/2003	8/27/2003
LRHD	Lost River u/s of Harpold Dam	3	2.60	2.20	3.10	5/21/2003	8/27/2003
LRWRC	Lost River at Wilson Reservoir at Crystal Springs	3	3.57	2.70	5.00	5/21/2003	8/27/2003
LRDR	Lost River at Dehlinger Road	3	3.83	3.10	4.80	5/21/2003	8/26/2003
LR39	Lost River at Hwy 39	146	3.17	0.30	10.30	4/8/1970	8/27/2003
LRARD	Lost River at Anderson-Rose Dam	4	6.60	3.50	8.80	5/20/2003	8/27/2003
LRMR	Lost River at Malone Road	7	2.41	0.70	4.50	5/20/2003	8/27/2003
LRSR*	Lost River at Stateline Road	8	3.61	1.50	9.40	4/24/1996	6/24/1998

*original data noted as BOD_5, other stations listed as simply BOD

Table 3-31. Summary of COD data, Lost River (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
LRCFR	Lost River at Cheese Factory Road	3	20.67	17.00	25.00	5/21/2003	8/27/2003
LRKB	Lost River at Keller Bridge	3	24.00	19.00	28.00	5/21/2003	8/27/2003
LR70	Lost River at Hwy 70	3	25.00	22.00	28.00	5/21/2003	8/27/2003
LRHRB	Lost River at Harpold Road	3	19.00	13.00	23.00	5/21/2003	8/27/2003
LRHD	Lost River u/s of Harpold Dam	3	22.00	19.00	24.00	5/21/2003	8/27/2003
LRWRC	Lost River at Wilson Reservoir at Crystal Springs	3	24.00	20.00	29.00	5/21/2003	8/27/2003
LRDR	Lost River at Dehlinger Road	4	28.25	23.00	39.00	5/21/2003	8/27/2003
LR39	Lost River at Hwy 39	134	21.82	9.00	34.00	5/25/1993	8/27/2003
LRARD	Lost River at Anderson-Rose Dam	4	28.75	22.00	36.00	5/20/2003	8/27/2003
LRMR	Lost River at Malone Road	7	25.29	19.00	32.00	5/20/2003	8/27/2003
LRSR	Lost River at Stateline Road	8	30.50	24.00	38.00	4/24/1996	6/24/1998

3.4.3 Tule Lake, Lower Klamath Lake National Wildlife Refuge and the Klamath Straits Drain

The Oregon 2002 303(d) list reported that the Klamath Straits Drain was impaired because of temperature, dissolved oxygen, pH, chlorophyll a and ammonia toxicity. The California 303(d) list reported that Tule Lake and the Lower Klamath Lake National Wildlife Refuge was impaired because of pH. Livestock watering, water supply, resident fish and aquatic life, water contact recreation, anadromous fish passage, and salmonid fish spawning and rearing beneficial uses were impaired by these causes in 2002. The discussion below provides a review of available data to evaluate the water quality impairment status.

3.4.3.1 Temperature

Temperature data for the Klamath Straits Drain are available from 5 monitoring stations in Oregon (Figure 3-15). Table 3-32 below provides a summary of the available temperature data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The table includes all available temperature observations.

Table 3-32. Summary of temperature data, Klamath Straits Drain (°C).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KSDSR	Klamath Straits Drain at Stateline Road	160	16.30	1.00	27.60	5/31/1996	8/28/2003
KSDTR	Klamath Straits Drain at Township Road	19	13.96	4.05	23.99	3/23/1999	11/30/1999
KSDPSF	Klamath Straits Drain at Pump Station F	282	14.71	1.00	28.40	5/7/1968	8/27/2003
KSD97	Klamath Straits Drain at Hwy 97	250	14.83	0.60	25.48	3/17/1998	11/14/2000
KSDM	Klamath Straits Drain at mouth	1	5.00	5.00	5.00	3/1/2000	3/1/2000

Figures 3-16 through 3-18 show the average and maximum temperature at stations along the Klamath Straits Drain.

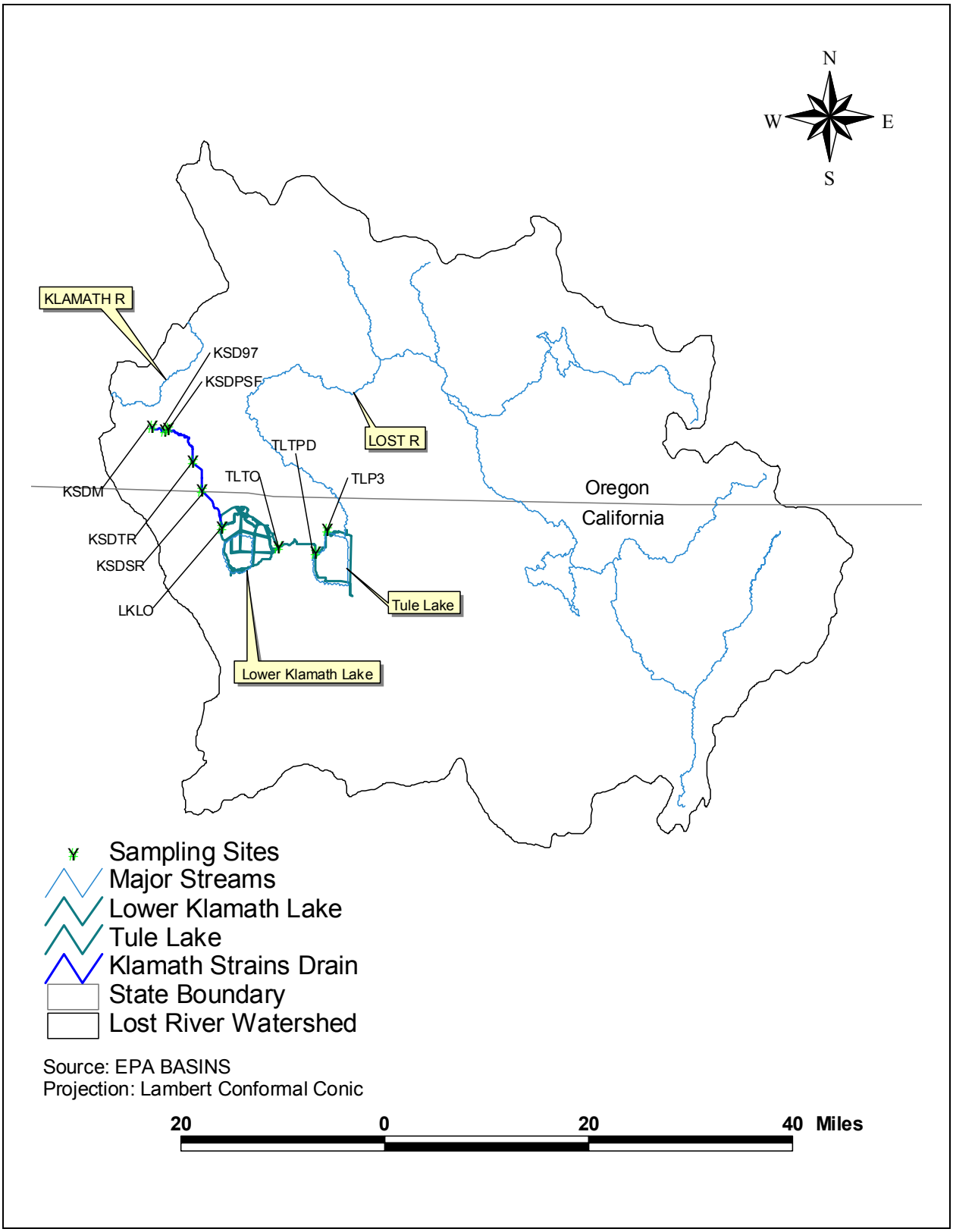

Figure 3-15. Sampling sites in Tule Lake, Lower Klamath Lake and Klamath Straits Drain

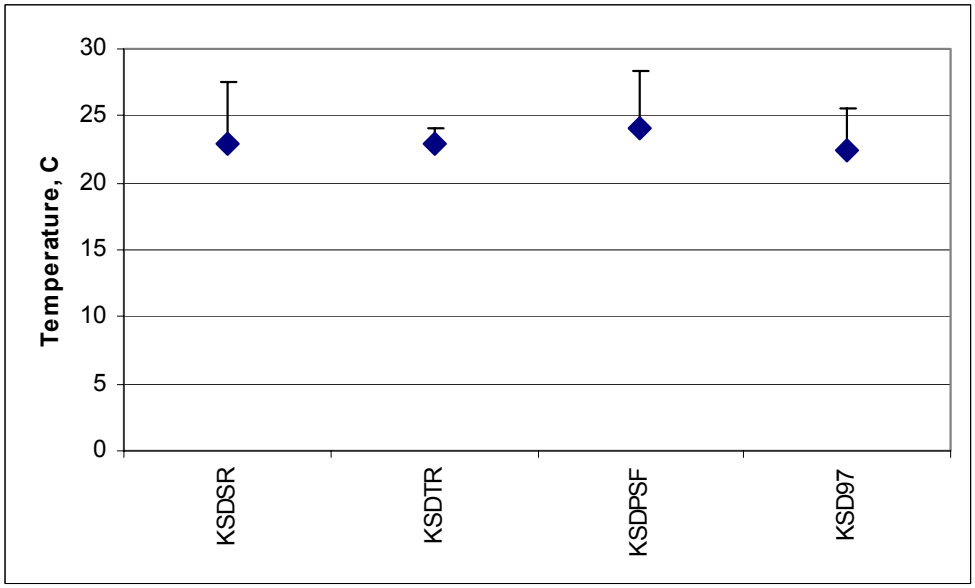

Figure 3-16. June average and maximum temperature along the Klamath Straits Drain

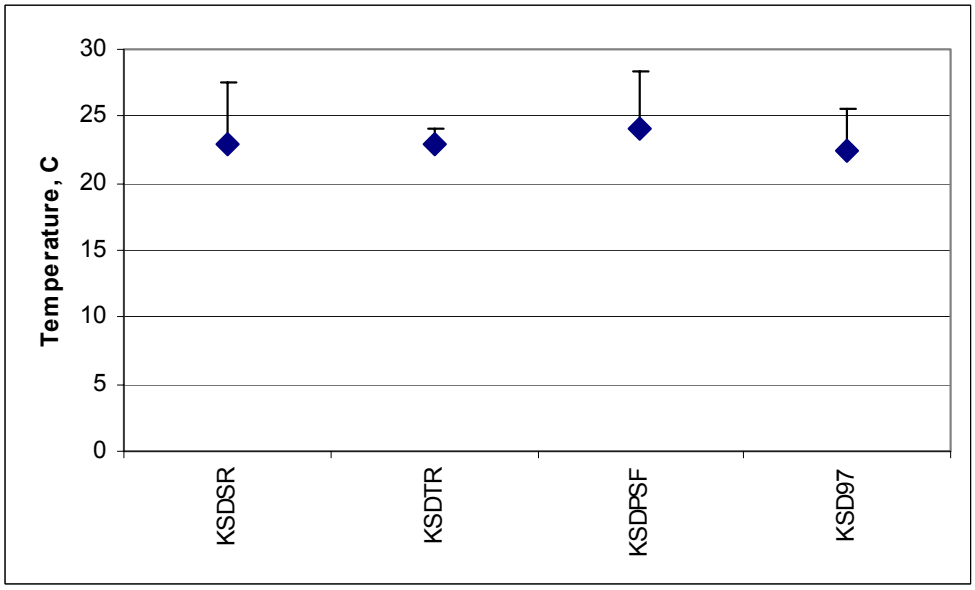

Figure 3-17. July average and maximum temperature along the Klamath Straits Drain

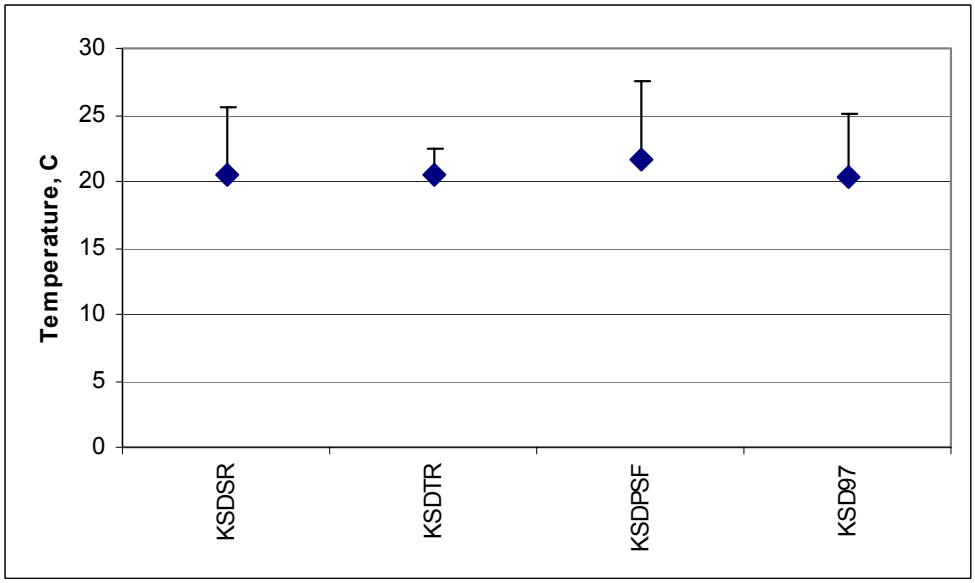

Figure 3-18. August average and maximum temperature along the Klamath Straits Drain

3.4.3.2 Dissolved Oxygen

Dissolved oxygen data for the Klamath Straits Drain are available from 5 monitoring stations in Oregon and California. Table 3-33 below provides a summary of the available dissolved oxygen data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The table includes all available DO observations.

Table 3-33. Summary of DO data, Klamath Straits Drain (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KSDSR	Klamath Straits Drain at Stateline Road	101	7.88	0.93	21.04	2/23/1994	8/28/2003
KSDTR	Klamath Straits Drain at Township Road	19	7.05	2.28	11.39	3/23/1999	11/30/1999
KSDPSF	Klamath Straits Drain at Pump Station F	573	6.36	0.30	15.30	2/23/1994	8/28/2003
KSD97	Klamath Straits Drain at Hwy 97	219	6.41	0.60	16.40	5/16/1972	6/3/2003
KSDM	Klamath Straits Drain at mouth	1	10.1	10.1	10.1	3/1/2000	3/1/2000

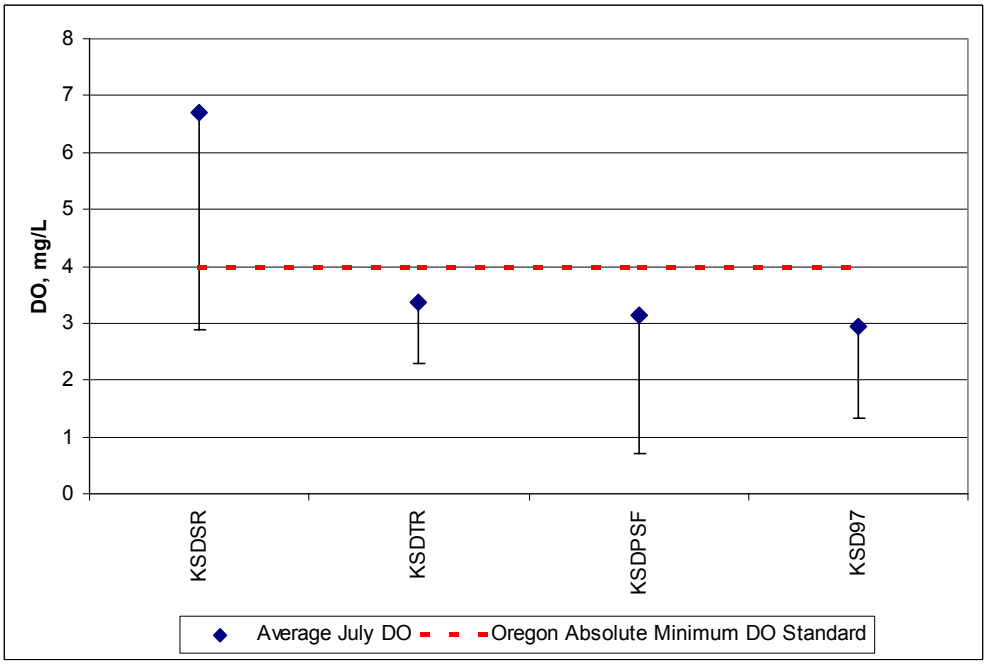

Figure 3-19. July average and minimum DO along the Klamath Straits Drain

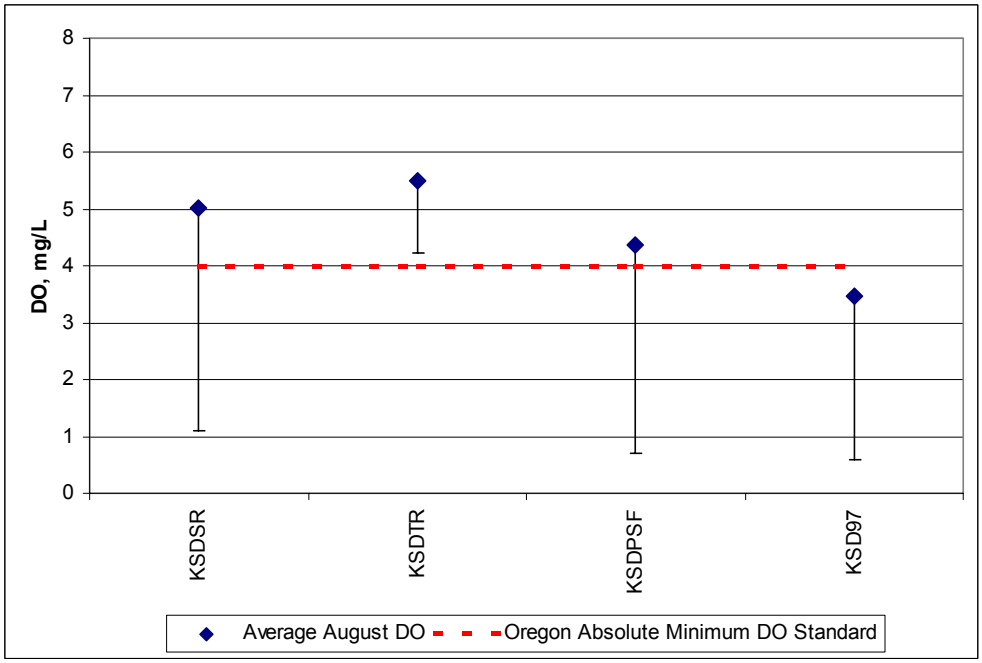

Figure 3-20. August average and minimum DO along the Klamath Straits Drain

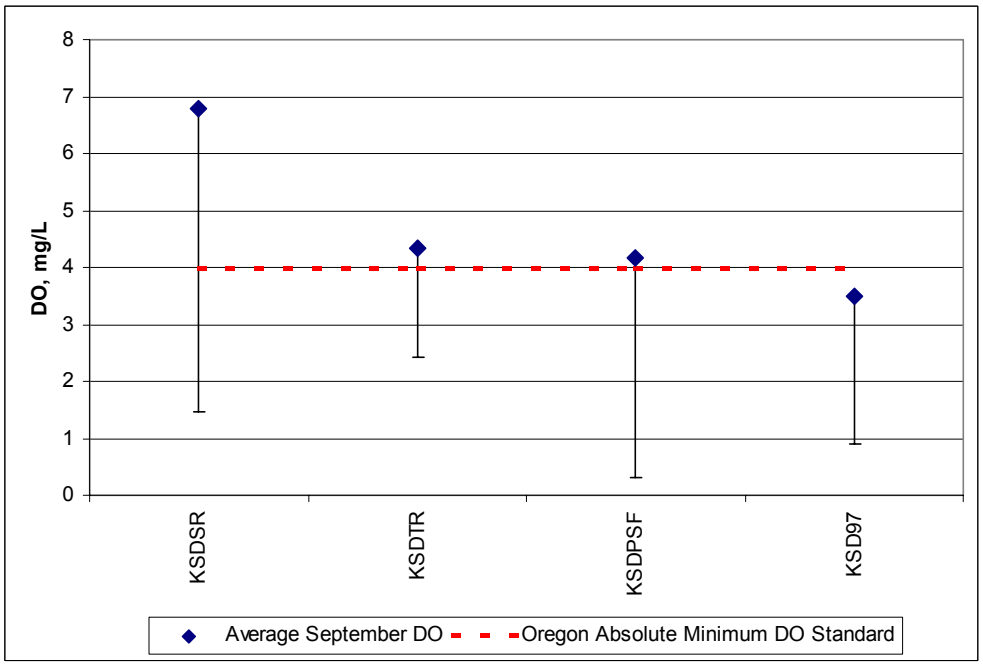

Figure 3-21. September average and minimum DO along the Klamath Straits Drain

In general, the average DO tends to decrease moving downstream along the Klamath Straits Drain. In July, the average DO is less than the Oregon absolute minimum of 4.0 mg/L at the three most downstream stations. Only KSDSR (Klamath Straits Drain at Stateline Road) had an average DO greater than the absolute minimum of 4.0 mg/L. In August KSDTR (Klamath Straits Drain at Township Road) had a higher average DO concentration than KSDSR (Klamath Straits Drain at Stateline Road) but by September the trend of DO decreasing moving downstream has resumed.

3.4.3.3 Chlorophyll a

Chlorophyll a data for the Klamath Straits Drain are available from 3 monitoring stations in Oregon. Table 3-34 below provides a summary of the available chlorophyll a data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The table includes all available chlorophyll a observations.

Table 3-34. Summary of chlorophyll a data, Klamath Straits Drain (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KSDSR*	Klamath Straits Drain at Stateline Road	3	0.01310	0.0061	0.026	5/20/2003	8/27/2003
KSDSR*	Klamath Straits Drain at Stateline Road	14	0.03169	0.0008	0.136	5/1/2000	11/14/2003
KSDPSF	Klamath Straits Drain at Pump Station F	166	0.03173	0.0007	0.450	7/11/1978	8/27/2003
KSD97	Klamath Straits Drain at Hwy 97	14	0.01559	0.0000	0.075	5/1/2000	11/14/2000

*station listed twice as original data reported in two different units and was converted to mg/L for display in table.

3.4.3.4 pH

PH data for the Klamath Straits Drain are available from 5 monitoring stations in Oregon. Table 3-35 below provides a summary of the available pH data including the minimum value, maximum value and

average value observed at each station in addition to the number of observations and the period of record. Table 3-36 provides a summary of the exceedances of the pH standard.

Table 3-35. Summary of pH data, Tule Lake, Lower Klamath Lake and Klamath Straits Drain.

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
TLP3	Tule Lake Pump 3 (Iin)	31	8.10	7.20	9.40	4/24/1996	6/24/1998
TLTPD	Tule Lake Tunnel at Pump Station D	301	8.95	6.70	10.83	5/16/1972	6/3/2003
TLTO	Tule Lake Tunnel Outlet	31	9.25	8.30	9.90	3/23/1999	11/14/2000
LKLO	Lower Klamath Refuge Outlet at Hwy	120	8.10	6.09	9.40	1/13/1999	9/20/2000
KSDSR	Klamath Straits Drain at Stateline Road	195	8.43	6.59	10.26	2/23/1994	8/28/2003
KSDTR	Klamath Straits Drain at Township Road	19	8.36	7.44	9.13	3/23/1999	11/30/1999
KSDPSF	Klamath Straits Drain at Pump Station F	635	8.19	0.05	9.60	5/7/1968	8/27/2003
KSD97	Klamath Straits Drain at Hwy 97	398	8.13	6.10	10.26	5/16/1972	6/3/2003
KSDM	Klamath Straits Drain at mouth	1	8.20	8.20	8.20	3/1/2000	3/1/2000

Table 3-36. Summary of pH exceedances, Tule Lake, Lower Klamath Lake and Klamath Straits Drain.

Site ID	Site Name	Number of Samples	Number of Samples <6.5	Number of Samples >9.0	Total % of Exceedances
TLP3	Tule Lake Pump 3	31	0	1	3.2%
TLTPD	Tule Lake Tunnel at Pump Station D	301	1	135	45.2%
TLTO	Tule Lake Tunnel Outlet	31	0	23	74.2%
LKLO	Lower Klamath Lake Outlet	120	12	13	20.8%
KSDSR	Klamath Straits Drain at Stateline Road	195	0	54	27.7%
KSDTR	Klamath Straits Drain at Township Road	19	0	3	15.8%
KSDPSF	Klamath Straits Drain at Pump Station F	635	2	48	7.9%
KSD97	Klamath Straits Drain at Hwy 97	398	5	56	15.35

3.4.3.4 Ammonia Toxicity

Ammonia data for the Klamath Straits Drain are available from 5 monitoring stations in Oregon. Table 3-37 below provides a summary of the available ammonia data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. Table 3-38 provides a summary of the exceedances of the ammonia toxicity acute standard.

Table 3-37. Summary of ammonia data, Klamath Straits Drain (mg/L as N).

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KSDSR	Klamath Straits Drain at Stateline Road	150	0.28	0.0009	5.58	2/23/1994	8/27/2003
KSDTR	Klamath Straits Drain at Township Road	18	0.31	0.09	0.61	3/23/1999	11/30/1999
KSDPSF	Klamath Straits Drain at Pump Station F	313	0.63	0.02	11.30	5/7/1968	8/27/2003
KSD97	Klamath Straits Drain at Hwy 97	245	0.31	0.001	3.68	2/23/1994	6/3/2003
KSDM	Klamath Straits Drain at mouth	1	0.13	0.13	0.13	3/1/2000	3/1/2000

Table 3-38. Summary of ammonia toxicity exceedances, Klamath Straits Drain.

Site ID	Site Name	Number of Samples	Number of Acute Standard Exceedances over Period of Record
KSDSR	Klamath Straits Drain at Stateline Road	150	2
KSDTR	Klamath Straits Drain at Township Road	18	0
KSDPSF	Klamath Straits Drain at Pump Station F	313	2
KSD97	Klamath Straits Drain at Hwy 97	245	2

3.4.3.5 Nutrients

Tables 3-39 through 3-41 below provide summaries of the available nutrient data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record.

Table 3-39. Summary of total phosphorous data, Klamath Straits Drain (mg/L)

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KSDSR	Klamath Straits Drain at Stateline Road	168	0.460	0.05	7.30	2/23/1994	6/3/2003
KSDTR	Klamath Straits Drain at Township Road	18	0.360	0.21	0.70	3/23/1999	11/30/1999
KSDPSF	Klamath Straits Drain at Pump Station F	385	0.528	0.08	5.57	2/26/1973	6/3/2003
KSD97	Klamath Straits Drain at Hwy 97	337	0.357	0.05	2.21	2/26/1973	6/3/2003

Table 3-40. Summary of orthophosphate data, Klamath Straits Drain (mg/L as P)

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KSDSR	Klamath Straits Drain at Stateline Road	66	0.341	0.038	1.09	2/23/1994	6/3/2003
KSDTR	Klamath Straits Drain at Township Road	18	0.208	0.013	0.526	3/23/1999	11/30/1999
KSDPSF	Klamath Straits Drain at Pump Station F	120	0.275	0.05	1.10	2/6/1973	6/3/2003
KSD97	Klamath Straits Drain at Hwy 97	197	0.183	0.034	0.66	2/26/1973	6/3/2003

Table 3-41. Summary of total nitrogen data, Klamath Straits Drain (mg/L as P)

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KSDSR	Klamath Straits Drain at Stateline Road	93	3.497	1.936	6.50	7/30/1999	10/16/2000
KSD97	Klamath Straits Drain at Hwy 97	126	3.995	1.904	10.70	1/13/1999	10/16/2000

3.4.3.6 Oxygen Consuming Constituents

Although the Klamath Straits Drain is not listed as impaired for oxygen consuming constituents (BOD or COD), high BOD or COD concentrations can cause low dissolved oxygen levels. Tables 3-42 through 3-43 below provide summaries of the available BOD and COD data including the minimum value, maximum value and average value observed at each station in addition to the number of observations and the period of record. The tables include all stations with at least 3 observations.

Table 3-42. Summary of BOD, BOD_5 and BOD_{20} data, Klamath Straits Drain (mg/L)

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KSDSR	Klamath Straits Drain at Stateline Road	23	5.57	1.50	19.00	4/24/1996	11/14/2000
KSDSR[1]	Klamath Straits Drain at Stateline Road	4	4.20	4.00	4.50	5/20/2003	8/27/2003
KSDPSF	Klamath Straits Drain at Pump Station F	3	34.33	14.00	73.00	8/20/1991	8/21/1991
KSDPSF[1]	Klamath Straits Drain at Pump Station F	264	5.98	0.10	44.00	5/7/1968	8/27/2003
KSDPSF[2]	Klamath Straits Drain at Pump Station F	11	19.18	7.00	26.00	6/14/1990	9/26/1990
KSD97	Klamath Straits Drain at Hwy 97	14	5.57	3.00	8.00	5/1/2000	11/14/2000
KSDM	Klamath Straits Drain at Mouth	1	3.40	3.40	3.40	3/1/2000	3/1/2000

[1]original data is BOD_5
[2] original data is BOD_{20}

Table 3-43. Summary of COD data, Klamath Straits Drain (mg/L)

Site ID	Site Name	Count	Average	Min	Max	Start Date	End Date
KSDSR	Klamath Straits Drain at Stateline Road	13	63.04	3.50	129.00	4/24/1996	8/27/2003
KSDPSF	Klamath Straits Drain at Pump Station F	150	59.17	5.00	125.00	10/11/1977	8/27/2003
KSDM	Klamath Straits Drain at Mouth	1	33.00	33.00	33.00	3/1/2000	3/1/2000

4.0 TECHNICAL APPROACH

This section presents proposed modeling approaches for Klamath and Lost River TMDL development. A proposed approach and an alternative approach are first presented for the Klamath River, with primary emphasis on the proposed approach. These are followed by proposed and alternative approaches for modeling the Lost River. All approaches are based on evaluation of technical, regulatory, and user criteria for the Klamath and Lost River systems. Technical criteria refer to the model's simulation of the physical system in question, including watershed and/or stream characteristics/processes and constituents of interest. Regulatory criteria make up the constraints imposed by regulations, such as water quality standards or procedural protocol. User criteria comprise the operational or economical constraints imposed by the end-user and include factors such as hardware/software compatibility and financial resources. Specifics regarding each criterion will be included throughout the following sections.

4.1 Klamath River Proposed Approach

4.1.1 Overview

To develop TMDLs for the Klamath River downstream of Upper Klamath Lake, it is recommended that a dynamic modeling framework be implemented. The proposed approach is to combine a series of alternating 1-dimensional models for riverine sections and 2-dimensional models for impoundments and tidal regions. Specifically, the RMA-2 and RMA-11 models will be applied for Link River, Keno Dam to J.C. Boyle Reservoir, Bypass Reach, the Full Flow Reach, and Iron Gate Dam to Turwar. RMA-2 simulates hydrodynamics while RMA-11 represents water quality processes. The CE-QUAL-W2 model will be applied for Lake Ewauna-Keno Dam, J.C. Boyle Reservoir, Copco Reservoir, Iron Gate Reservoir, and the Klamath River from Turwar to the Pacific Ocean. Table 4-1 identifies the proposed modeling elements. Application of the CE-QUAL-W2 model to the Klamath River downstream of Turwar is subject to the availability of bathymetric data and sufficient water quality monitoring data to support model calibration. To date, insufficient data have been identified to support the model's application, however, data collection over the upcoming year is anticipated to provide the required data.

Table 4-1. Proposed model components.

Modeling Segment	Segment Type	Model(s)
Link River	River	RMA-2/RMA-11
Lake Ewauna-Keno Dam	Reservoir	CE-QUAL-W2
Keno Dam to J.C. Boyle Reservoir	River	RMA-2/RMA-11
J.C. Boyle Reservoir	Reservoir	CE-QUAL-W2
Bypass Reach	River	RMA-2/RMA-11
Full Flow Reach	River	RMA-2/RMA-11
Copco Reservoir	Reservoir	CE-QUAL-W2
Iron Gate Reservoir	Reservoir	CE-QUAL-W2
Iron Gate Dam to Turwar	River	RMA-2/RMA-11
Turwar to Pacific Ocean	Estuary	CE-QUAL-W2

The linkages between the riverine and reservoir/estuary models identified above will be made by transferring time-variable flow and water quality from one model to the next (e.g. output from the Link River model becomes input for the Lake Ewauna-Keno Dam model). This proposed modeling framework will be consistent with available models appropriate for application to riverine/reservoir systems and will include a review of previous modeling approaches (e.g., PacifiCorp Klamath River model). Selected algorithms will be considered for augmentation of the modeling framework to address specific processes. Enhancements to the basic code for RMA and CE-QUAL-W2 will be considered for

processes such as periphyton simulation. We have developed several such algorithms used in previous TMDL studies and will also consider adapting documented PacifiCorp processes from earlier studies. As necessary, we will review and evaluate relevant elements of the PacifiCorp model and will determine (on a case-by-case basis) their utility for application to developing the TMDL model.

There are many advantages to implementing a dynamic modeling framework that considers similar processes and functions as existing applications for the Klamath River, such as the PacifiCorp model, including:

- The models are capable of predicting hydrodynamics, nutrient cycles, dissolved oxygen, temperature, and other parameters and processes pertinent to the TMDL development effort.
- The models are capable of simulating the multiple flow control structures along the length of the Klamath River.
- The framework is dynamic (time-variable) and thus capable of representing the highly variable flow and water quality conditions within years and between years.
- The model is capable of considering the steep channel slope of the Klamath River.
- This framework uses hydrodynamic and water quality models with a proven track record in the environmental arena, including historical application to the Klamath River.
- Most stakeholders in the watershed are already familiar with the previously applied models.
- Model results can be directly compared to ODEQ and NRWQCB water quality criteria.
- The PacifiCorp modeling framework has been previously calibrated for the Klamath River and its applicability demonstrated.
- Previously developed and applied modifications to RMA code for simulation of periphyton growth in the Klamath River can be incorporated into the TMDL modeling framework.
- The multi-model framework allows independent river/reservoir sections to be simulated independently, making it more efficient for calibration and TMDL scenario assessment.
- The modeling system developed for the TMDL application using the public domain versions of CE-QUAL-W2 and RMA can be distributed to the public.

Potential limitations that have currently been identified include:

- While the multi-model framework may be efficient for calibration, it is also cumbersome in terms of data management and transfer between models. Additionally, due to differences in algorithms and state parameters for RMA and CE-QUAL-W2 (e.g., for nutrient components), conversion of pollutant loads between models may potentially result in slight inaccuracies.
- Although the RMA model can be distributed to the public, it may require additional expenses for public users.
- The RMA model is a finite element-based numerical model, which means it may be computationally intensive and time-consuming to apply.
- There may be limitations in representing DO levels for groundwater contributions.

4.1.2 Model Background

RMA

The hydrodynamic component of the RMA modeling suite, RMA-2, is a model specifically designed to assess flow response in complex river systems (Deas, 2000). RMA-2 solves the full-flow equations, known as the St. Venant Equations. These equations use all terms of the conservation of momentum formulation and provide a complete description of dynamic flow conditions. The model has been widely applied (it is one of the most used full hydrodynamic models in the United States) to a variety of river and estuary systems in the United States as well as internationally.

The water quality component, RMA-11, is a general-purpose water quality model, compatible in geometry with the configuration of the RMA-2 hydrodynamic model. The model simulates advective heat transport and air-water heat exchange processes, as well as fate and transport of water quality parameters, to produce dynamic descriptions of temperature and constituent concentration along the river reach. Input requirements include temperatures and quality of boundary flows, and meteorological data defining atmospheric conditions governing heat exchange at the air-water interface. Model output is in the form of longitudinal profiles of temperature and quality parameters along river reaches, or time series at fixed locations.

CE-QUAL-W2

The U.S. Army Corps of Engineers' CE-QUAL-W2 is a two-dimensional, longitudinal/vertical (laterally averaged), hydrodynamic and water quality model (Cole et al 2000). The model allows for application to streams, reservoirs, and estuaries with variable grid spacing, time-variable boundary conditions, and multiple inflows and outflows from point/nonpoint sources and precipitation.

The two major components of the model include hydrodynamics and water quality kinetics. Both of these components are coupled, i.e. the hydrodynamic output is used to drive the water quality at every timestep. The hydrodynamic portion of the model predicts water surface elevations, velocities, and temperature. The ULTIMATE-QUICKEST numerical scheme used in the CE-QUAL-W2 model is designed to reduce the numerical diffusion in the vertical direction to a minimum and in areas of high gradients reduce the undershoots and overshoots which may produce small negative concentrations. The water quality portion can simulate 21 constituents including dissolved oxygen (DO), nutrients, and phytoplankton interactions, and pH.

4.1.3 Model Configuration

Spatial scale

The modeling framework will include the entire Klamath River from Link Dam (at the outlet of the Upper Klamath Lake) to the Pacific Ocean. The river is impounded by five dams along its length: Keno, J.C. Boyle, Copco, Copco 2, and Iron Gate Dam. The modeling framework will be composed of 10 separate modeling components as described above.

Within each of these separate modeling components, the primary waterbody (either a Klamath River section or a reservoir) will be subdivided into higher resolution elements. It is anticipated that the TMDL modeling framework components will be segmented similarly to the existing PacifiCorp model. For the reservoir/lake models in the existing PacifiCorp model (Lake Ewauna, J.C. Boyle Reservoir, Copco Reservoir, and Iron Gate Reservoir), the corresponding CE-QUAL-W2 models have layer thicknesses ranging from 0.61 to 2.5 meters and segment lengths ranging from 37 to 714 meters. For the riverine reaches (Link River, Keno reach, Bypass/full flow reach downstream of J.C. Boyle Reservoir, and Klamath River from Iron Gate Dam to Turwar), the corresponding finite element model RMA has node distances ranging from 75 to approximately 300 meters (and are assumed to be homogeneous in the vertical direction). It is anticipated that the tidal portion of the Klamath River from Turwar to the Pacific Ocean, which is not included in the existing PacifiCorp model, will be segmented into approximately 20 segments with layer thicknesses ranging from 0.5 to 2 meters. This segmentation is subject to the availability of bathymetric data and flow and water quality monitoring data that to date have not been identified.

A special feature of the tidally-influenced estuarine portion is bi-directional flow (in contrast to the uni-directional flow for the upstream river sections). The tidal water will not only transport saline water into the estuary and change the density flow pattern and DO saturation level, but it will also cause a significant amount of organic matter to settle. This may result in elevated sediment oxygen demand (SOD) levels. In addition, unlike the rapid flow environment upstream, the estuary will provide a condition for phytoplankton to flourish, given sufficient nutrients.

Only the main-stem Klamath River and its reservoirs will be simulated within the TMDL modeling framework. All tributaries to the river will be represented as boundary conditions (i.e., they will not be explicitly modeled). More detailed information regarding the specific tributaries to be included or inflows to the model are included in Appendix D. They will be represented by flow and water quality constituent time series based on historical monitoring data or possibly results from other modeling efforts. Thus, the tributaries can ultimately be given allocations, however, the variability of flow and water quality within each tributary cannot be evaluated. Source-based allocations can only be provided for individual tributaries if sufficient data are available to distinguish between source contributions. This is further described in the TMDL Analysis section of this document.

The resolution offered by the proposed modeling framework is sufficient to meet the regulatory requirements identified by ODEQ and NRWQCB. As identified by the agencies, output is needed from the following locations:

- Link River
- Upstream and downstream of Lost River Diversion and Klamath Straits Drain
- Upstream and downstream of point source discharges (Spring Street and South Suburban STPs, Collins Forest Products Columbia Plywood)
- Upstream and downstream of Keno and JC Boyle Dams
- Downstream of JC Boyle powerhouse
- Upstream of regional spring discharges in the JC Boyle bypass reach
- Downstream of Shovel Creek
- OR/CA state line
- Upstream and downstream of Copco Reservoirs 1 and 2
- Upstream and downstream of Iron Gate Dam
- Upstream and downstream of Shasta River
- Downstream of Walker Creek
- Upstream and downstream of Scott River
- Downstream of Seiad Creek
- Upstream of Salmon River
- Downstream of Salmon River
- Downstream of Orleans
- Upstream of Trinity River
- Downstream of Trinity River
- Downstream of Blue Slide Creek
- Downstream of Klamath Glen
- Klamath River Estuary

Time Step

The current modeling system operates on a sub-hourly time-step. Based on the resolution of the modeling grids, it is anticipated that the modeling timestep will be between 60 seconds and 2 minutes. Therefore,

model output can be generated for any time step greater than this, including hourly, daily, weekly, monthly, and annually.

Time Period

Based on a preliminary review of hydrologic conditions and monitoring data, it is anticipated that the time period 1996 to 2004 will be modeled. This period is subject to the adequacy of monitoring data to fully support hydrodynamic and water quality calibrations. A portion of this time period will be used for model calibration and validation (which is discussed later in this section). This period represents a range of hydrologic conditions and inherently considers seasonal variability and critical conditions (from both a sub-annual and multi-year standpoint). Table 4-2 provides a summary of annual precipitation totals at two stations in the basin (giving a general sense of hydrologic state throughout the proposed modeling period).

Table 4-2. Summary of Precipitation Data at the Klamath River Mouth and Tule Lake for 1996-2002

Year	Annual Precipitation at Tule Lake (inches)	Annual Precipitation Percentile at Tule Lake Based on 1950-2002	Annual Precipitation at Klamath River Mouth (inches)	Annual Precipitation Percentile at Klamath River Mouth Based on 1950-2002
1996	14.39	86.50%	113.56	98.00%
1997	11.56	63.40%	73.40	38.40%
1998	19.49	100.00%	109.15	92.30%
1999	9.02	30.70%	76.54	42.30%
2000	12.03	67.30%	70.78	32.60%
2001	8.10	15.30%	67.54	26.90%
2002	7.13	7.60%	69.74	30.70%

Source: NOAA

The existing PacifiCorp modeling framework has been applied for 2000, 2001, and 2003. For the Klamath River downstream of Iron Gate Reservoir, the model has also been run for 1996 and 1997 (although this was based on an older version of the model).

Model Processes and Parameters

The focus of TMDL development for the Klamath River downstream of Upper Klamath Lake is on DO, nutrients, ammonia toxicity, temperature, and pH. Therefore, the proposed modeling framework will address all these parameters and their interactions. The model will be capable of predicting DO dynamics and the influence of reaeration, oxidation of carbonaceous and nitrogenous materials, aquatic life respiration, algae and plant productivity, and oxygen demand exerted by sediments. Each of these components is impacted by numerous additional factors, which will also be represented, including temperature, light availability, and external contributions of nutrients and biochemical oxygen demand (from point and nonpoint sources).

Key observations identified in the data review section include:

- Chlorophyll a concentrations and nutrient concentrations indicate that the Klamath River is highly productive.
- DO and temperature impairments generally occur in the summer.

- The impact of SOD is not fully understood based on monitoring data, however it may play a role in oxygen depletion throughout slower-moving sections of the system (e.g., the tidal region).

A diagram of the key water quality modeling components and interactions represented in the RMA-11 model is shown if Figure 4-1 (Deas, 2000).

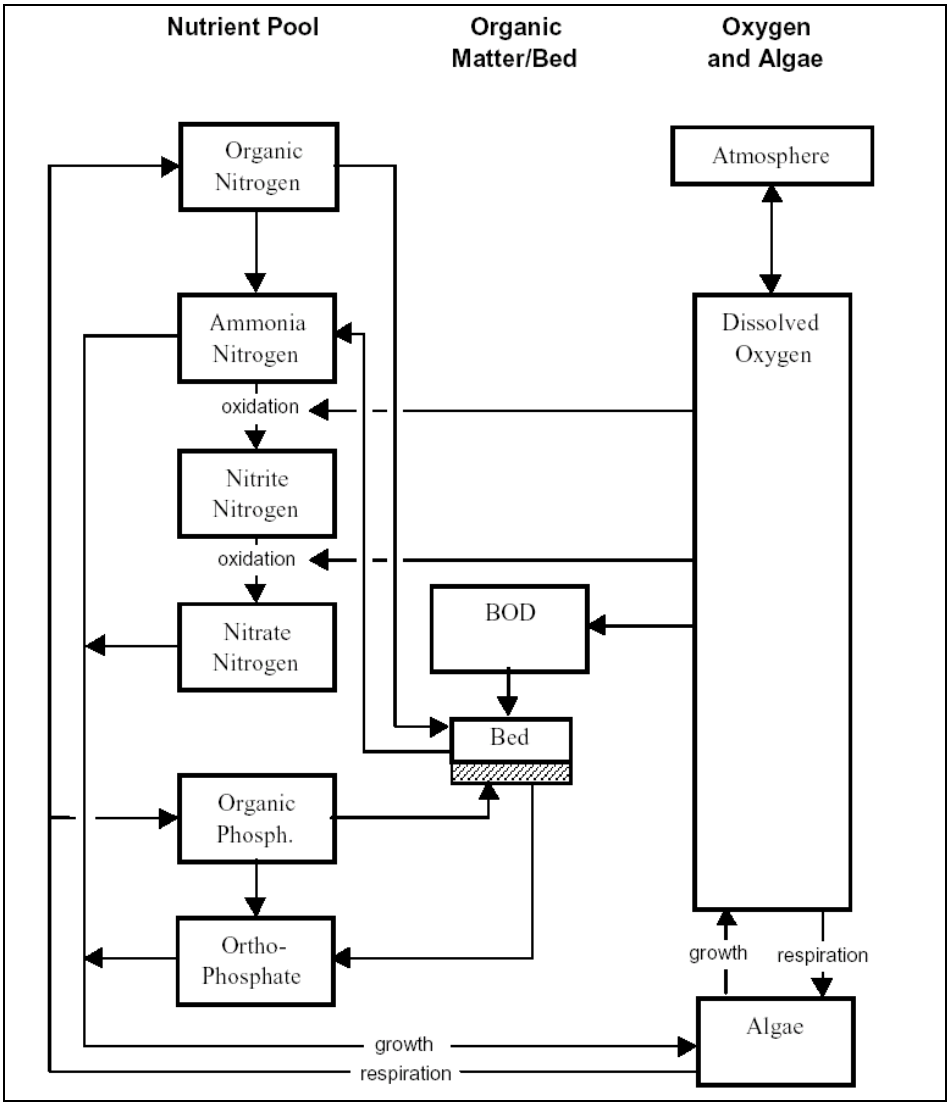

Figure 4-1. RMA-11 Water Quality Representation.

Algae represented in the RMA model is in the form of periphyton. The basic RMA algorithms do not include a pH simulation module, however, the existing PacifiCorp modeling framework does include an external pH simulation routine. It is anticipated that this routine will be reviewed for its applicability to the TMDL model.

A diagram of the key modeling components and interactions represented in the CE-QUAL-W2 model is shown in Figure 4-2 (Deas, 2000).

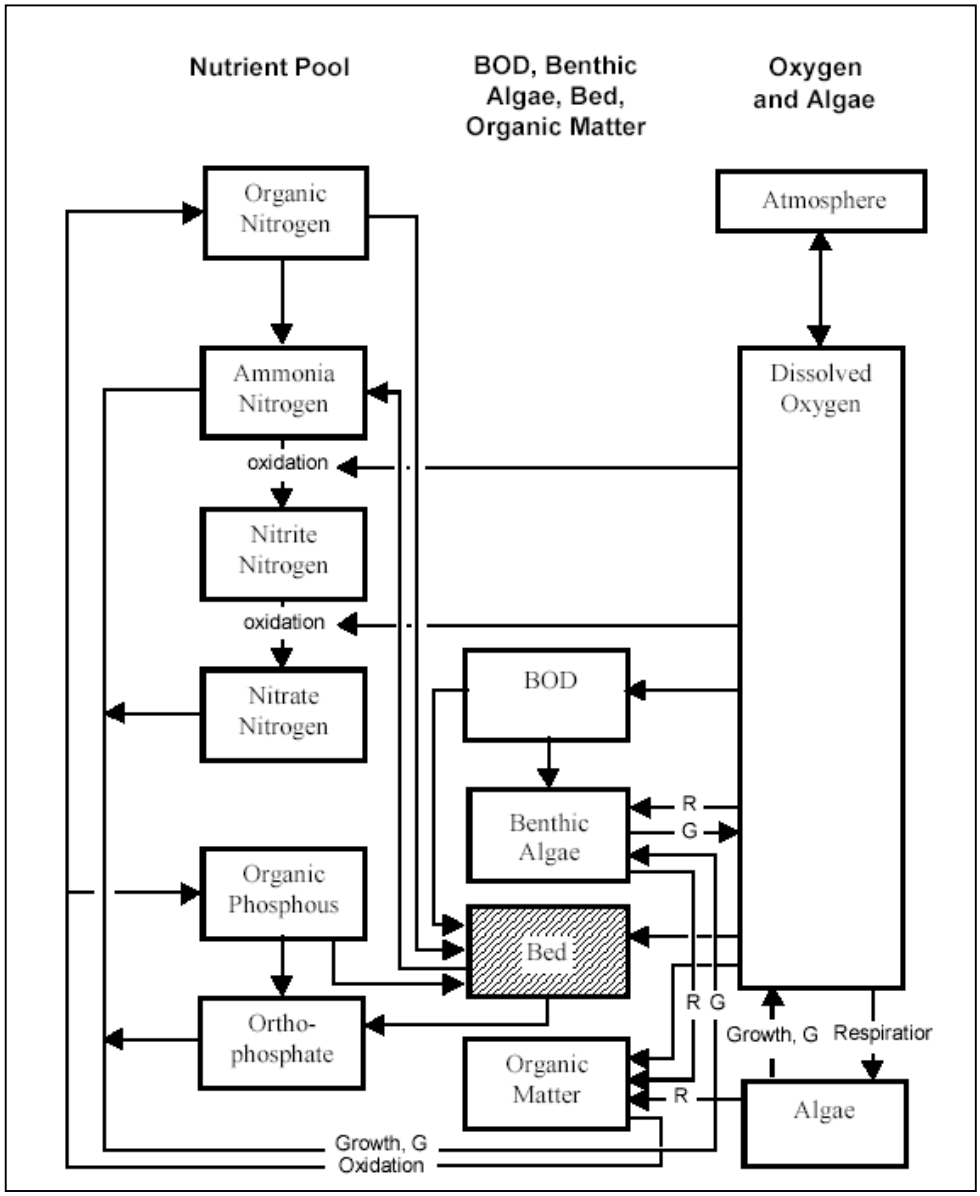

Figure 4-2. CE-QUAL-W2 Water Quality Representation

For the reservoirs and the estuarine portion of the Klamath River, it is possible that sediment oxygen demand (SOD) plays a major role in oxygen depletion. This is possible due to the low velocities and high contribution of organics to the system. In the event that the CE-QUAL-W2 modeling framework is insufficient for conducting predictive routines (with regards to SOD), due to its use of a relatively static SOD factor, a dynamic sediment diagenesis subroutine may be built into the model. The need for this routine will be determined during the model calibration process.

Source Representation

Primary sources of pollution to the Klamath must be accurately represented in the modeling process. Accurate representation of contributions from permitted point sources and nonpoint source contributions from urban, agricultural, and natural areas is critical in properly representing the system and ultimately evaluating potential load reduction scenarios.

For each model in the proposed Klamath modeling framework, the upstream boundary flow and concentration will be provided based on the simulation results of the immediate upstream model. Major tributaries to the main-stem rivers and its reservoirs will be represented at discrete points by time-variable flow and water quality concentrations based on monitoring data (or potentially, watershed modeling results), in a manner consistent with the existing PacifiCorp modeling framework. Point source contributions will also be represented at discrete points along the main-stem river and represented by time-variable flow and water quality. Nonpoint source contributions will be represented in two ways: 1) as lateral inflows directly to the main-stem river (for "intervening zones" or zones that don't first feed into a tributary prior to draining into the Klamath River) and 2) inherently through major tributary time-series inputs. Individual nonpoint source categories are not represented explicitly in the proposed modeling framework, because major tributaries are only represented as distinct time-series inputs and lateral inflows are represented as gross loads for each segment. In order to distinguish among contributing sources, a separate analysis will be necessary or a watershed model must be implemented.

The proposed modeling framework will enable identification of critical load contributions to the system (tributaries, point sources, upstream contributions, etc.) so that spatial allocations can be performed.

An additional source/input that will be represented is the Lost River, which contributes to the Klamath River via the Lost River Diversion Channel (depending on the time of year) and the Klamath Straits Drain. Flow data monitored in the Diversion Channel will be used to represent outflow to the Lost River during the spring, summer, and fall. Incoming flow and water quality constituents transported through the Diversion Channel and Klamath Straits Drain will be predicted by the Lost River Model, which is being developed concurrently.

Calibration

The RMA and CE-QUAL-W2 models will be calibrated and validated for both hydrodynamics and water quality. Steps will include checking the water balance, calibrating the hydrodynamics and temperature, and calibrating water quality compartments. The water balance will be calibrated through comparison of predicted surface water elevation to measured elevation. After the water budget is checked, the temperature, dissolved oxygen, and other parameters simulated by the models will be compared with monitoring data. Necessary adjustments to model parameters will then be made.

Calibration will likely be performed for the same years the PacifiCorp modeling framework was calibrated (2000 and 2001). It will be validated for a longer time period, in order to ensure its applicability to a wider range of hydrologic conditions (1996 – 1999 and 2002 – 2004). This assumes that hydrodynamic and water quality monitoring data are adequate throughout this period.

Model calibration and validation results will be presented in both statistical and graphical form. Graphical results will consist of modeled time series plots for each constituent (including water surface elevation, temperature, DO, NH3, NO3/NO2, PO4, algae [chlorophyll a], and pH) compared to observation data. Statistical comparisons will additionally be made. These statistical analyses may include non-parametric pair-wise comparisons among predicted and observed constituent concentrations

(e.g., Wilcoxon paired-sample test) or comparisons among distributions of predicted versus observed constituent concentrations (e.g., Kolmogorov-Smirnov or Chi-square distribution tests).

Model calibration and validation will be performed at selected monitoring station locations along the length of the Klamath River. The specific locations will be determined based on adequacy/comprehensiveness of data. Data for monitoring stations along the Klamath River are in the process of being compiled into a single, comprehensive database, and thus the final calibration/validation locations have not yet been selected. Insufficient data have been identified to perform calibration in the tidal portion of the river. Data collection during the spring/summer/fall of 2004 will be critical to support calibration of this region.

Upon completion of model calibration and verification, model accuracy will be further evaluated through sensitivity analyses. These analyses will evaluate the relative impact of model parameters on predictions.

4.1.4 Alternative Approach

An alternative to developing a modeling framework based on alternating RMA and CE-QUAL-W2 models (similar to the PacifiCorp modeling framework) is to develop a Klamath River Model using only CE-QUAL-W2. This model would also be configured for the length of the Klamath River from Upper Klamath Lake to the Pacific Ocean, however, it would be a single, integrated model. All reservoirs would be represented in a manner consistent with the "Proposed Approach," however, CE-QUAL-W2 would also be used to represent all riverine segments. For riverine segments, each cell would be represented by a surface and bottom layer (rather than a single layer as in RMA).

The primary advantages of using a single CE-QUAL-W2 model for the entire Klamath River are as follows:

- Through representation as an integrated system, a single model run can simulate the hydrodynamics and water quality for the entire reservoir-river system (i.e., not transfer of data is necessary between CE-QUAL-W2 and RMA models).
- CE-QUAL-W2 is a public domain model and is therefore freely available for download from the U.S. Army Corp of Engineers.
- CE-QUAL-W2 is a finite difference based numerical modeling system with advanced numerical schemes, such as ULTIMATE-QUICKEST scheme, and it is therefore computationally efficient
- It is a fully dynamic model and is equipped with hydrodynamics, temperature, eutrophication, and pH simulation functions. External simulation of pH is not necessary.

Although this approach offers some advantages, there are a number of potential limitations:

- CE-QUAL-W2 does not contain a periphyton module, therefore, additional effort would be required to develop and incorporate this type of module into the CE-QUAL-W2 framework.
- Although CE-QUAL-W2 is expected to be able to simulate hydrodynamics for a steep-sloped channel, it is possible that Klamath River's slope might create model instability problems.
- The Klamath River begins at a high elevation with respect to the ocean (where it drains). CE-QUAL-W2 does not currently allow the user to vary meteorological conditions (such as air temperature) spatially. Additional effort would be required to incorporate this function.
- CE-QUAL-W2 is essentially a 2-D model that is designed for multiple-layer longitudinal systems. It cannot represent trapezoidal channel geometry unless at least a 2-layer configuration is used. Using a 2-layer configuration from Iron Gate Dam to the Pacific Ocean would introduce significant computational time and may cause instability issues.
- Running a single model for the entire Klamath River will require that the lower region be simulated even if only the upper region needs to be evaluated (as in the case of determining flow

and water quality transfer between the Klamath and Lost Rivers). This will result in significant unnecessary computational burden.

The general procedure for developing and applying an integrated CE-QUAL-W2 modeling framework for the Klamath River is similar to that for the "Proposed Approach." Configuration would involve using a longitudinal-vertical 2-D model for the entire system. Modeling segment lengths would likely range from 100 to 1,000 meters (depending on river/reservoir geometry and water quality characteristics). Spatially variable layer thicknesses would be implemented. Two layers would likely be used to represent riverine segments while more than 2 layers would be used for reservoir and estuarine portions (similar to that in the existing PacifiCorp Modeling Framework).

The modeling time period would be consistent with that in the "Proposed Approach." CE-QUAL-W2 has the capability of auto-stepping, therefore the time step could be adjusted internally by the model during a simulation (depending on the flow and loading conditions). Thus, it may not require a 60-second timestep for the entire modeling period. Model processes and parameters would be consistent with those described previously for the CE-QUAL-W2 model, except that a periphyton module would be additionally implemented. Sources would be represented in the same manner as for the "Proposed Approach" (i.e., major tributaries including the Lost River and point sources represented as discrete time-series inputs to the system). No transfer of data and conversion of loadings from one set of model state variables to another would be necessary since only one model would be implemented. Model calibration and validation would be identical to that described for the "Proposed Approach."

4.2 Lost River Proposed Approach

4.2.1 Overview

A dynamic modeling framework is also recommended to support TMDL development for the Lost River. The proposed approach is to develop a CE-QUAL-W2 model for the entire Lost River system from Malone Dam to the outlet of the Klamath Straits Drain (into the Klamath River). The model will include the Lost River itself, Tule Lake (and Tule Lake Sump), the P Canal, the Lower Klamath Lakes, and the Klamath Straits Drain. All other canals and drains in the Klamath Project will be incorporated into the modeling framework as time-series flow and water quality inputs at discrete locations (based on available monitoring data and literature, as necessary). These canals and drains will not be explicitly simulated in the modeling framework.

The proposed dynamic modeling framework will ultimately be linked to the proposed dynamic model of the Klamath River (from Upper Klamath Lake to the Pacific Ocean) via transfer of modeled time-variable flow and water quality constituents.

There are several advantages to implementing a dynamic modeling framework using CE-QUAL-W2:

- CE-QUAL-W2 is proposed for simulation of the Lake Ewauna model in both the "Proposed" and "Alternative" modeling frameworks for the Klamath River. Therefore, the linkage between the Lost River and Klamath River modeling frameworks (via the Lost River Diversion and Klamath Straits Drain) can be made using identical base models.
- CE-QUAL-W2 is capable of predicting hydrodynamics, nutrient cycles, dissolved oxygen, temperature, and other parameters and processes pertinent to the TMDL development effort.
- CE-QUAL-W2 is capable of simulating the multiple flow control structures along the length of the Lost River (i.e., dams and pumping stations).

- CE-QUAL-W2 is dynamic (time-variable) and thus capable of representing the highly variable flow and water quality conditions within years and between years.
- CE-QUAL-W2 has a proven track record in the environmental arena.
- Most stakeholders in the watershed are already familiar with CE-QUAL-W2 and its application to the Klamath River.
- Model results can be directly compared to ODEQ and NRWQCB water quality criteria.
- CE-QUAL-W2 is a public domain model and is therefore freely available for download from the U.S. Army Corp of Engineers.
- CE-QUAL-W2 is a finite difference based numerical modeling system with advanced numerical schemes, such as ULTIMATE-QUICKEST scheme, and it is therefore computationally efficient.

Potential limitations include:

- CE-QUAL-W2 does not contain a periphyton module, therefore, additional effort will be required to develop and incorporate this type of module into the CE-QUAL-W2 framework.
- CE-QUAL-W2 is essentially a 2-D model that is designed for multiple-layer longitudinal systems. It cannot represent trapezoidal channel geometry unless at least a 2-layer configuration is used.

4.2.2 Model Configuration

Spatial scale

The modeling framework will include the entire Lost River (from Malone Dam to Tule Lake), Tule Lake and Sump, P Canal, Lower Klamath Lake, and the Klamath Straits Drain. Although the entire Lost River system will be represented under a single framework, it will be divided internally into separate waterbodies, in order to address the different characteristics of the river segments and reservoirs. A schematic that identifies the primary components and key inputs and withdrawals is included is shown in Figure 4-3.

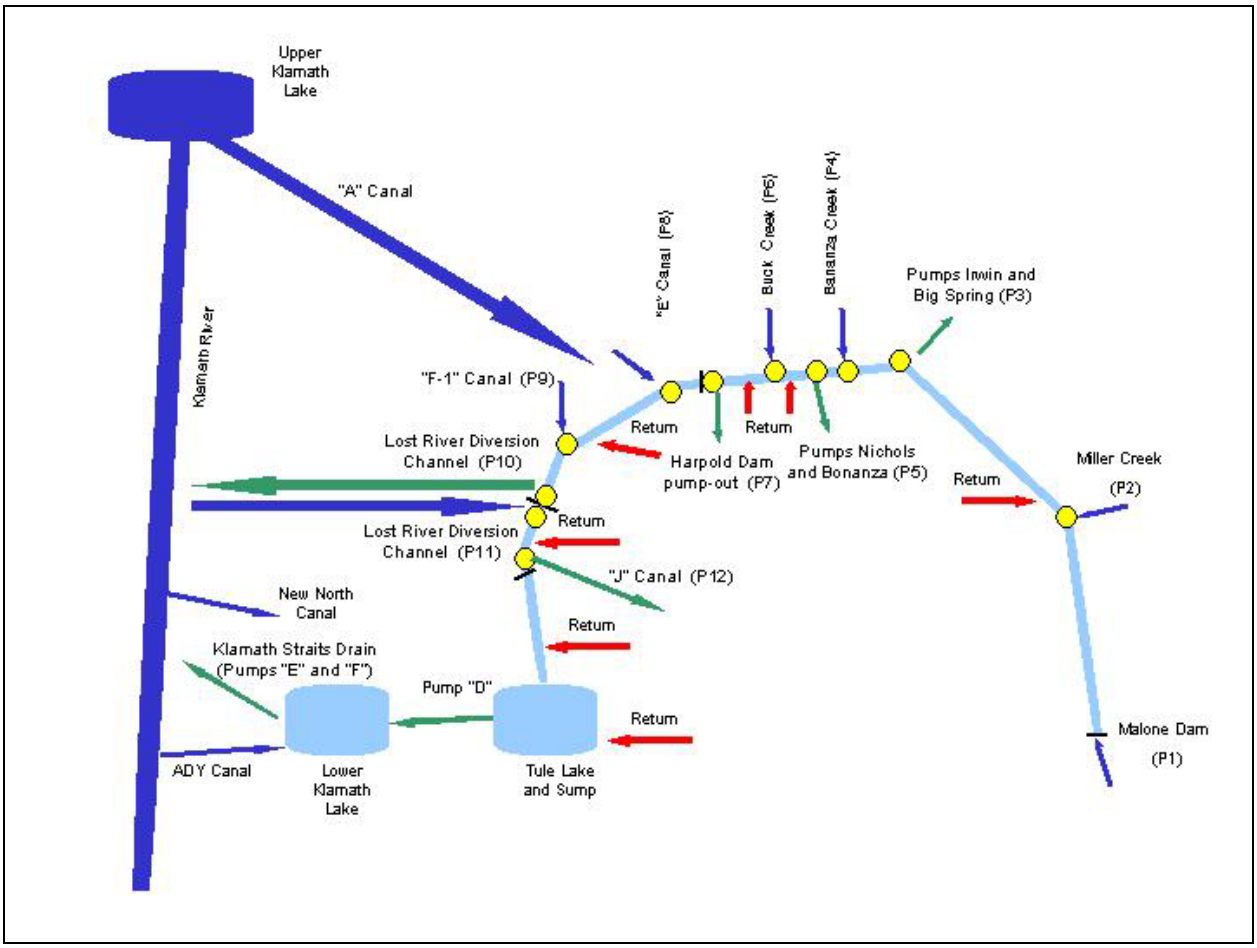

Figure 4-3. Schematic of the Lost River System.

For the Lost River (from Malone Diversion Dam to Tule Lake), segment lengths are expected to be between 100 and 1,000 meters. At least two layers will be configured to represent the channel (wider for the top segment than the bottom), and layer thickness will be determined based on the depth of water and computational requirements. Cross-sectional data have not yet been obtained for the Lost River. In the event that sufficient cross-sectional data are not acquired, segment widths and depths will be derived from USGS Quad Maps, aerial photos, and assumptions relating surface width to bottom width.

In sections of the river where dams are located (Harpold Dam, the Lost River Diversion Dam, and the Anderson-Rose Dam), unique layer thicknesses will be instituted to represent the characteristics of each reservoir. The dam discharge/spill flow will be set as an internal boundary condition, in order to link upstream and downstream river sections.

Tule Lake and Lower Klamath Lake will be configured as two separate waterbodies linked using the pumping flow time series at Pump Station D, in order to provide the ability to estimate a rough assimilative capacity for TMDL purposes. For each lake, a one-segment model will be configured to represent the water quality dynamics without detailed consideration of transport. Representation of these lakes with multiple elements is limited by the available water quality data. Tule Lake will receive water from the Lost River and drainage return flow.

Only the main-stem Lost River (including the lake created by Harpold Dam, Wilson Reservoir, and Anderson-Rose Lake), Tule Lake and Tule Lake Sump, the P Canal, the Lower Klamath Lake, and the Klamath Straits Drain will be simulated within the TMDL modeling framework. All tributaries, canals, and drains feeding into the river will be represented as boundary conditions (i.e., they will not be explicitly modeled). More detailed information regarding representation of models inflows and outflows are is included in Appendix E. This appendix also identifies more detailed information regarding data availability and limitation for modeling support. They will be represented by flow and water quality constituent time series based on historical flow and monitoring data. In some situations, it may be necessary to represent multiple drains and/or canals as a single input due to water quality monitoring data limitations. That is, not every canal and tributary has sufficient monitoring data to estimate time-variable flow and water quality. The tributaries, canals, and drains (or combinations of multiple canals and/or drains) can ultimately be given allocations, however, the variability of flow and water quality within each waterbody cannot be fully evaluated. Source-based allocations can only be provided for individual tributaries, canals, and drains if sufficient data are available to distinguish between source contributions. Alternatively, a watershed model may be implemented (although the current project scope does not include development watershed model at this time) or literature values for various source categories can be used to support a more detailed source allocation.

The resolution offered by the proposed modeling framework is sufficient to meet the regulatory requirements identified by ODEQ and NRWQCB. As identified by the agencies, output is needed from the following locations:

- Malone Dam to Harpold Dam
- Harpold Dam to Anderson-Rose Dam
- Lost River at the OR/CA Border
- Tule Lake and Tule Lake Sump (E/W Bridge and D Pump)
- Klamath Wildlife Refuge (P Canal and Klamath Straits Drain at Stateline)
- Klamath Straits Drain Outlet to the Klamath River

Time Step

Using CE-QUAL-W2's autostepping capability, a fixed time step will not be required. Instead, the model will determine the most appropriate time step for simulation and will adjust accordingly. A maximum time step of 1 hour will be specified.

Time Period

The Lost River will be simulated for the same time period as the Klamath River modeling framework (1996 to 2004) due to the interaction between the two river systems (assuming data adequacy). The models must ultimately be synchronized to generate appropriate boundary conditions for one another. As with the Klamath model, a portion of this time period will be used for model calibration and validation (which is discussed later in this section). This period represents a range of hydrologic conditions and inherently considers seasonal variability and critical conditions (from both a sub-annual and multi-year standpoint).

Model Processes and Parameters

The focus of TMDL development for the Lost River is similar to that for the Klamath River (DO, nutrients, ammonia toxicity, temperature, and pH), with the addition of bacteria. Therefore, the proposed modeling framework will address all these parameters and their interactions. The model will be capable

of predicting DO dynamics and the influence of reaeration, oxidation of carbonaceous and nitrogenous materials, aquatic life respiration, algae and plant productivity, and oxygen demand exerted by sediments. Each of these components is impacted by numerous additional factors, which will also be represented, including temperature, light availability, and external contributions of nutrients and biochemical oxygen demand (from point and nonpoint sources). Bacteria transport and die-off will also be simulated.

Key observations identified in the data review section are similar to those for the Klamath River and include:

- Chlorophyll a concentrations and nutrient concentrations indicate that the Lost River is highly productive.
- DO and temperature impairments generally occur in the summer.
- The impact of SOD is not fully understood based on monitoring data, however it may play a role in oxygen depletion throughout slower-moving sections of the system (e.g., impounded areas). This is evidenced by the fact that DO is generally lowest in the impounded areas.

A diagram of the key modeling components and interactions represented in the CE-QUAL-W2 model was shown in Figure 4-1.

As noted earlier in this document, it will likely be necessary to incorporate an algorithm for simulation of periphyton into the CE-QUAL-W2 code. Further data review and monitoring will provide greater insight into this potential need. Additionally, further monitoring of SOD and the benthic nutrient flux is necessary to determine their role in Lost River oxygen depletion. As with periphyton, if a dynamic sediment diagenesis module or improvement of the first-order formulation currently in CE-QUAL-W2 is deemed necessary, updates to the CE-QUAL-W2 code will be made.

Another key aspect of the system that must be accurately represented in the modeling framework is irrigation withdrawal and return. The Lost River water is highly utilized for irrigation and is often used and reused multiple times during its transport throughout the system. Thus, the return flow water quality is dependent not only on the local farming practices, but also on the water quality from where it is originally diverted. This direct correlation must be considered in the modeling framework to accurately represent scenarios. The CE-QUAL-W2 model will be upgraded with an appropriate function to track the use and reuse of water throughout the system. A look-up table will be formulated to associate the return flow water quality with the source water concentration and its location.

Source Representation

Primary sources of pollution to the Lost River must be accurately represented in the modeling process. Accurate representation of contributions from permitted point sources and nonpoint source contributions from urban, agricultural, and natural areas is critical in properly representing the system and ultimately evaluating potential load reduction scenarios.

Major tributaries, canals, and drains to (and diversions from) the main-stem river and its reservoirs will be represented at discrete points by time-variable flow and water quality concentrations based on monitoring data (or potentially, watershed modeling results). The amount of irrigation flow and return flow will be estimated based on the Bureau or Reclamations flow records (currently being analyzed), through a flow balance approach calculated for river sections, and/or using irrigation efficiency coefficients. The irrigation flow will be configured as outflow at the diversion or pumping location, while return flows will be represented as inflows at appropriate locations.

Point source contributions will also be represented at discrete points along the main-stem river and represented by time-variable flow and water quality. Nonpoint source contributions will be represented in two ways: 1) as lateral inflows directly to the main-stem river (for "intervening zones" or zones that don't first feed into a tributary prior to draining into the Lost River) and 2) inherently through major tributary time-series inputs. Individual nonpoint source categories are not represented explicitly in the proposed modeling framework, because major tributaries are only represented as distinct time-series inputs and lateral inflows are represented as gross loads for each segment. In order to distinguish among contributing sources, a separate analysis will be necessary or a watershed model must be implemented. An upstream boundary condition will be defined at the Malone Diversion Dam.

The proposed modeling framework will enable identification of critical load contributions to the system (tributaries, point sources, upstream contributions, etc.) so that spatial allocations can be performed.

An additional source/input that will be represented is the Klamath River, which contributes to the Lost River via the A Canal and the Lost River Diversion Channel (depending on the time of year). Flow data monitored in these canals will be used to represent inflow to the Lost River (and will be consistent with the values used in the Klamath model) during the spring, summer, and fall.

Linkage to the Klamath River Model

The linkage between the Klamath and Lost River Models will be implemented using the following "alternating scheme" (using the year 2000 as an example):

- The Lost River Model will be run from day 1 of the year 2000 until the beginning of irrigation period. The water quality concentrations at the locations where the Lost River Diversion Dam is located will be saved.
- The Klamath River Model (from the Link River Dam through Lake Ewauna) will be run from day 1 of the year 2000 until the end of irrigation season using the boundary conditions generated above at the Lost River Diversion Dam.
- The Lost River Model will then be run from the beginning of the irrigation season until the beginning of the irrigation season for the next year using the boundary conditions obtained for the Lost River Diversion Dam using the Klamath River Model in the previous step.

The above process will be repeated in order to cover the complete simulation time period.

Calibration

The CE-QUAL-W2 model will be calibrated and validated for both hydrodynamics and water quality as described in the "Proposed" and "Alternative" Klamath models above. Steps will include checking the water balance, calibrating the hydrodynamics and temperature, and calibrating water quality compartments. The water balance will be calibrated through comparison of predicted surface water elevation to measured elevation. After the water budget is checked, the temperature, dissolved oxygen, and other parameters simulated by the models will be compared with monitoring data. Necessary adjustments to model parameters will then be made.

Calibration will be performed for the same years as the Klamath Model (2000 and 2001), assuming data are sufficient. Based on a preliminary review of the data, this appears plausible. It will be validated for a longer time period, in order to ensure its applicability to a wider range of hydrologic conditions (1996 – 1999 and 2002 – 2004). This assumes monitoring data are adequate.

Model calibration and validation results will be presented in both statistical and graphical form. Model calibration and validation will be performed at selected monitoring station locations along the length of the Lost River. The specific locations will be determined based on adequacy/comprehensiveness of data.

Upon completion of model calibration and verification, model accuracy will be further evaluated through sensitivity analyses. These analyses will evaluate the relative impact of model parameters on predictions.

4.2.3 Alternative Approach

An alternative to developing a modeling framework based on CE-QUAL-W2 is to develop a Lost River Model using a 1-dimensional version of EFDC (Environmental Fluid Dynamics Code) for riverine portions of the Lost River (from Malone Diversion Dam to Tule Lake) and WASP/EUTRO box models for Tule Lake/Tule Lake Sump and Lower Klamath Lake.

Advantages of this approach include:

- EFDC is capable of predicting hydrodynamics, nutrient cycles, dissolved oxygen, temperature, and other parameters and processes pertinent to the TMDL development effort for the riverine section, while WASP/EUTRO can represent the nutrient cycles, dissolved oxygen, and other pertinent parameters for the lake TMDL analyses.
- EFDC is capable of simulating the multiple flow control structures along the length of the Lost River (i.e., dams and pumping stations).
- Both models are dynamic (time-variable) and thus capable of representing the highly variable flow and water quality conditions within years and between years.
- Both models have a proven track record in the environmental arena – particularly with regard to TMDLs.
- Model results can be directly compared to ODEQ and NRWQCB water quality criteria.
- Both models are EPA-endorsed and supported and are included in the EPA TMDL Modeling Toolbox. They are public domain models, fully transparent (i.e., model code), and are available free of charge. EPA also provides training and support on their application free of charge.
- The EFDC water quality module possesses a fully numerical sediment diagenesis module to predict SOD and benthic nutrient flux based on organic loading to the water body. Tetra Tech has also upgraded WASP/EUTRO5 to include predictive sediment diagenesis capabilities. This improves the reliability of the models for DO and nutrient TMDLs.

Potential limitations include:

- WASP/EUTRO does not have hydrodynamic prediction capabilities internally; therefore, if higher resolution of information (such as spatial gradient of pollutant concentrations, water circulation patterns, or mass transport) are needed, it is unsuitable.
- WASP/EUTRO does not contain a periphyton module, therefore, additional effort will be required to develop and incorporate this type of module into the model code.
- While the multi-model framework may be efficient for calibration, it is also cumbersome in terms of data management and transfer between models. Additionally, due to differences in algorithms and state parameters for EFDC and WASP/EUTRO, conversion of pollutant loads between models may potentially result in slight inaccuracies.
- EFDC is best-suited to simulation of multi-dimensions. When it is applied to 1-D configuration, it only provides for a rectangular approximation to the river channel.
- Neither the EFDC nor the WASP/EUTRO models have the capability of simulating pH. Additional code modifications would be required for both.

4.2.3.1 Model Background

EFDC

EFDC is a general purpose modeling package for simulating one- or multi-dimensional flow, transport, and bio-geochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. This model is now being supported by US Environmental Protection Agency (EPA) and has been used extensively to support TMDL development throughout the country. In addition to hydrodynamic, salinity, and temperature transport simulation capabilities, EFDC is capable of simulating cohesive and non-cohesive sediment transport, near field and far field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants in the water and sediment phases, and the transport and fate of various life stages of finfish and shellfish. The EFDC model has been extensively tested, documented, and applied to environmental studies world-wide by universities, governmental agencies, and environmental consulting firms.

The structure of the EFDC model includes four major modules: (1) a hydrodynamic model, (2) a water quality model, (3) a sediment transport model, and (4) a toxics model. The water quality portion of the model simulates the spatial and temporal distributions of 22 water quality parameters including dissolved oxygen, suspended algae (3 groups), attached algae, various components of carbon, nitrogen, phosphorus and silica cycles, and fecal coliform bacteria (Figure 4-4). Salinity, water temperature, and total suspended solids are needed for computation of the twenty-two state variables, and they are provided by the hydrodynamic model.

The sediment process model uses a slightly modified version of the Chesapeake Bay three-dimensional model. Upon receiving the particulate organic matter deposited from the overlying water column, it simulates their diagenesis and the resulting fluxes of inorganic substances (ammonium, nitrate, phosphate and silica) and sediment oxygen demand back to the water column. The coupling of the sediment process model with the water quality model not only enhances the model's predictive capability of water quality parameters but also enables it to simulate the long-term changes in water quality conditions in response to changes in nutrient loads.

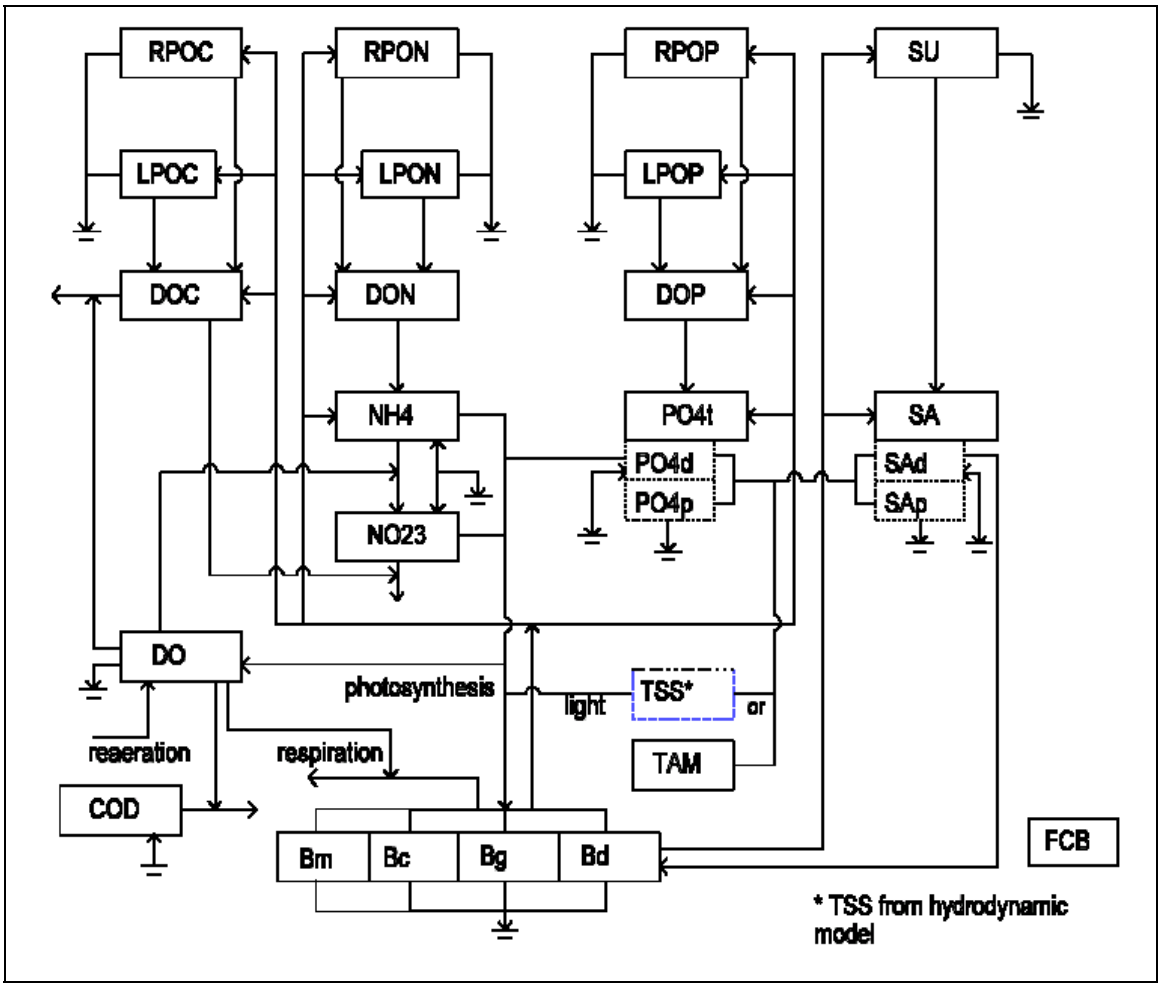

Figure 4-4. EFDC Water Quality Model Components.

WASP/EUTRO

WASP/EUTRO is a general modeling framework designed to simulate the fate and transport of nutrients and corresponding biological response in receiving waterbodies in any spatial dimension (Ambrose et al., 1993). WASP/EUTRO allows users to interpret and predict water quality response due to natural and man-made impacts for water quality management. It is a dynamic finite segment modeling system for aquatic systems and includes both the water column and underlying sediment column. The WASP portion of the model represents time-variable advection, dispersion, point and distributed mass loading, and boundary exchanges of mass. The EUTRO module represents the kinetic reactions of nutrients, organic matter, and dissolved oxygen. The combination of mass transport and bio-chemical reaction simulation results in an integrated modeling framework for representing receiving water processes for conventional pollutants.

The reactions involved in the standard WASP/EUTRO model can be described by four interacting systems:

- phytoplankton kinetics,
- the phosphorus cycle,

- the nitrogen cycle, and
- the dissolved oxygen balance.

The standard EUTRO module (i.e., EUTRO version 5) consists of eight constituent systems, including Ammonium (NH4+), Nitrite/Nitrate (NO2-/NO3-), Ortho-phosphate (PO4), Chlorophyll-a (CHLA), Carbonaceous Biochemical Oxygen Demand (CBOD), DO, Organic Phosphorus (Org P), and Organic Nitrogen (Org N). The kinetics structure and interactions between these systems, as represented in WASP/EUTRO, are illustrated in Figure 4-5.

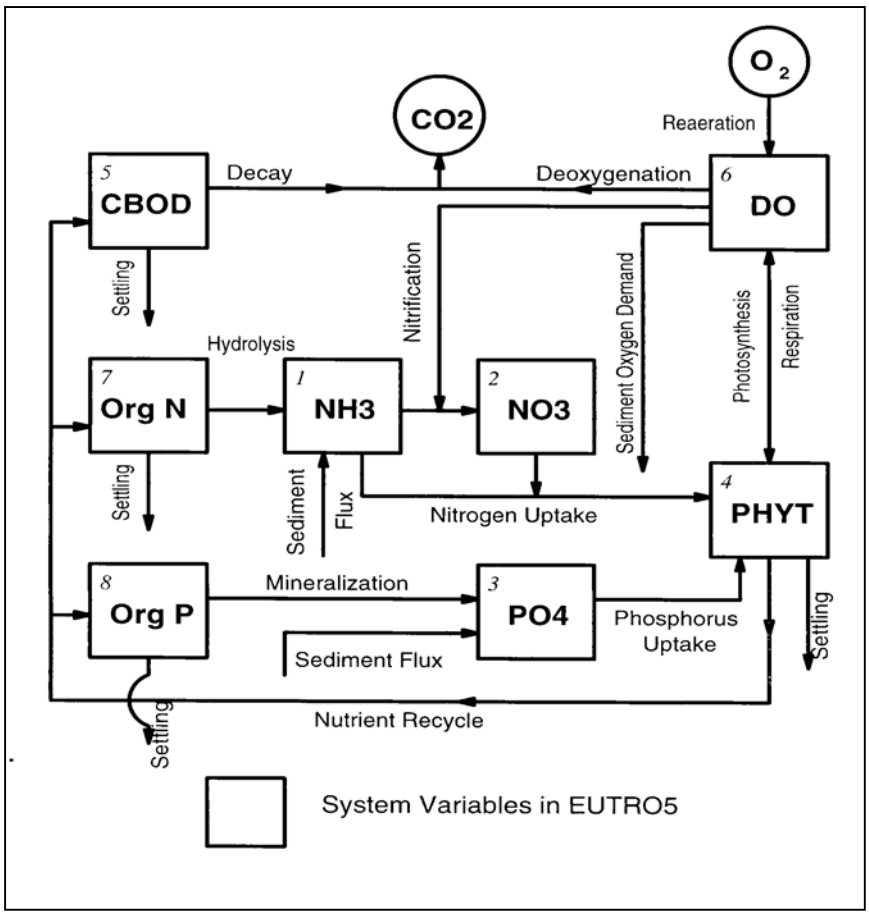

Figure 4-5. Kinetic Structure in the WASP/EUTRO Model

While the standard EUTRO model does not have a predictive sediment process model, Tetra Tech has incorporated a simplified sediment diagenesis module based on DiToro (1990) into the WASP/EUTRO5 modeling framework. The upgraded model has been successfully applied to TMDL development for the Appoquinimink River, in Delaware.

4.2.3.2 Overview

The general procedure for developing and applying the EFDC and WASP/EUTRO models is similar to the approaches previously described. In particular, it's similar to the combination of RMA and CE-QUAL-W2 models proposed for the Klamath River. Output from the EFDC model of the Lost River

(from the Malone Diversion Dam to Tule Lake) would become input for the WASP/EUTRO model of Tule Lake and the Tule Lake Sump. Output from Tule Lake and the Tule Lake Sump would become input for an EFDC model of the P Canal. P Canal EFDC model output would, in turn, become input for a WASP/EUTRO model of Lower Klamath Lake, and Lower Klamath Lake output would become input for an EFDC model of the Klamath Straits Drain. This model configuration is presented in Table 4-3.

Table 4-3. Lost River Model Components – Alternative Approach

Modeling Segment	Segment Type	Model(s)
Lost River (Malone Dam to Tule Lake)	River/Reservoir	EFDC
Tule Lake and Tule Lake Sump	Reservoir	WASP/EUTRO
P Canal	River	EFDC
Lower Klamath Lake	Reservoir	WASP/EUTRO
Klamath Straits Drain	River	EFDC

Application of EFDC will require segmentation of the Lost River into multiple grid cells and definition of hydraulic characteristics and boundary conditions. A 1-dimensional representation with segment lengths of 100 to 1,000 meters depending on the channel dimensions and flow regime will be used. The three dams will be configured as internal flow control structures. Boundary conditions for all major tributaries, canals, and diversions would be instituted in the same manner as for the "Proposed" Lost River approach. However, due to the inherent solutions of the EFDC water quality model, it will be necessary to utilize Total Organic Carbon (TOC) data rather than BOD data. The standard version of EFDC does not have a pH state variable, however, modification of the model code to incorporate pH simulation capability can be pursued.

Tule Lake, Tule Lake Sump, and Lower Klamath Lake will be configured as single box models due to their shapes and depths, the need for an estimate of assimilative capacity for each, and monitoring data limitations. Alternatively, a vertical 1-dimensional representation can be used (if depth-variable water quality is highly variable and critical to the TMDL analysis). The WASP/EUTRO code will be updated to include periphyton simulation, and sediment diagenesis (as necessary). Although WASP/EUTRO does not simulate pH, a modification to the code can be implemented to link the pH simulation with external loading and internal dynamics such as algae growth and respiration.

The modeling time period for this alternative approach would be consistent with that in the "Proposed Approach." The time step for this modeling approach is expected to be between 10 seconds and 100 seconds for the river model and longer (likely minute or hourly) for the lake models.

Model processes and parameters would be consistent with those described previously for the CE-QUAL-W2 model, except that a pH module would be additionally implemented. Sources would be represented in the same manner as for the "Proposed Approach" (i.e., major tributaries including the Lost River and point sources represented as discrete time-series inputs to the system). Minor efforts regarding transfer of data and conversion of loadings from one set of model state variables to another would be necessary. Model calibration and validation would be identical to that described for the "Proposed Approach."

4.2 TMDL Analysis

The ultimate goal of the TMDL is to determine the assimilative capacities of the Klamath River (from Upper Klamath Lake to the Pacific Ocean) and the Lost River system (from Malone Diversion Dam through the Klamath Straits Drain) and ensure that the rivers and their reservoirs meet prescribed water quality criteria along its length. The TMDL process involves selection of appropriate targets and development of source loading scenarios that meet the targets.

4.2.1 TMDL Targets

ODEQ and NCRWQCB have identified TMDL targets for the 303d-listed water quality constituents, as described earlier in this document. Numeric targets have been identified for temperature, DO, nutrients, ammonia toxicity, pH, and bacteria. Each of these targets must be met throughout the entire length of the Klamath River under all conditions (including critical conditions). Critical conditions are the set of environmental conditions for which controls designed to protect water quality will ensure attainment of objectives for all other conditions. This is typically the period of time in which the waterbody exhibits the most vulnerability. Although no numerical chlorophyll a water quality criteria exist for OR or CA, targets to achieve may be identified by ODEQ and NCRWQCB.

The proposed and alternative models presented for the Klamath and Lost Rivers are capable of predicting time-variable (hourly or more frequently) water quality conditions and thus can be compared directly to the TMDL targets. Even averaging periods, such as the 30-day median and 30-day log mean calculations required by OR's and CA's water quality standards for bacteria (respectively) can be accommodated. The Klamath and Lost River models will be run for a length of time that covers a range of potential hydrologic conditions (i.e., the calibration and validation years: 1996 – 2004), in order to ensure that critical conditions are sufficiently represented. Time-series model results for the entire system will first be compared to the prescribed water quality targets (i.e., state water quality criteria) and reviewed to identify water quality target exceedance locations and time periods.

The sensitivity analyses conducted for the models will help to identify the critical influences on water column water quality and will provide a basis for selecting appropriate inputs to reduce. For example, phosphorus may be identified as the primary factor influencing algae growth, while organic matter may be the most critical influence on DO levels. Once the impairment locations and time periods have been identified for each constituent, and the most sensitive input parameters have been identified, a series of hypothetical scenarios will be simulated.

4.2.2 Scenarios

A preliminary list of scenarios has been provided by ODEQ and NCRWQCB. This list includes a range of scenarios to potentially be simulated with the fully-calibrated and validated modeling systems. The TMDL Workgroup will prioritize the scenarios and identify those to run under the current project scope. Table 4-4 identifies the scenarios and describes the anticipated steps in conducting the scenario analysis.

Table 4-4. Potential Modeling Scenarios

Scenario	Approach
1: Iterative load reduction (TMDL compliance) scenarios	*Lost River:* Maintain current flow levels for tributaries, canals, drains, dams, and pumps. Adjust temperature and constituent concentrations for incoming tributaries, canals, and drains; and perform iterative runs until TMDL targets are met under all conditions throughout the system. These scenarios must be implemented in conjunction with updated boundary conditions based on the Klamath River scenario analysis.

Scenario	Approach
	Klamath River: Maintain current flow levels for tributaries and dams. Adjust temperature and constituent concentrations for incoming tributaries; and perform iterative runs until TMDL targets are met under all conditions throughout the system. These scenarios must be implemented in conjunction with updated boundary conditions based on the Lost River scenario analysis.
2: Modification of Klamath Project flows – 10-year operation plan	*Lost River:* Boundary conditions (including flow, temperature, and water quality concentrations) for canals and drains feeding into the Lost River system will be adjusted according to BOR's 10-year operation plan. An iterative load reduction (TMDL compliance) analysis will then be performed in the same manner as Scenario 1. *Klamath River:* Boundary conditions for the Klamath Straits Drain and Lost River Diversion Dam (and potentially Link River Dam) will vary depending on results of the Lost River modeling for this scenario. An iterative load reduction (TMDL compliance) analysis will then be performed in the same manner as Scenario 1.
3. Modified hydro facility operations	*Lost River:* *Klamath River:*
4: Modification of Klamath Project flows – Hardy Phase 2 flows	*Lost River:* Boundary conditions for canals and drains feeding into the Lost River system will be adjusted according to the Hardy Phase 1 analysis. An iterative load reduction (TMDL compliance) analysis will then be performed in the same manner as Scenario 1. *Klamath River:* Boundary conditions for the Klamath Straits Drain and Lost River Diversion Dam (and potentially Link River Dam) will vary depending on results of the Lost River modeling for this scenario. An iterative load reduction (TMDL compliance) analysis will then be performed in the same manner as Scenario 1.
5: Modification of Klamath Project flows – BOR's undepleted natural flows	*Lost River:* Boundary conditions for canals and drains feeding into the Lost River system will be adjusted according to BOR's undepleted natural flows. An iterative load reduction (TMDL compliance) analysis will then be performed in the same manner as Scenario 1. *Klamath River:* Boundary conditions for the Klamath Straits Drain and Lost River Diversion Dam (and potentially Link River Dam) will vary depending on results of the Lost River modeling for this scenario. An iterative load reduction (TMDL compliance) analysis will then be performed in the same manner as Scenario 1.
6: Flow modification for Malone, Harpold, Lost River Diversion, and Anderson-Rose Dams	*Lost River:* Flow conditions for each dam will be set prescribed by ODEQ and NCRWQCB (e.g., to maintain specified outflow levels or water surface elevations). An iterative load reduction (TMDL compliance) analysis will then be performed in the same manner as Scenario 1. *Klamath River:* Boundary conditions for the Klamath Straits Drain and Lost River Diversion Dam (and potentially Link River Dam) will vary depending on results of the Lost River modeling for this scenario. An iterative load reduction (TMDL compliance) analysis will then be performed in the same manner as Scenario 1.

Scenario	Approach
7: No dams scenario	*Klamath River:* Dams along the length of the Klamath River will be removed from the model (Lake Ewauna-Keno Dam, J.C. Boyle, Copco1, Copco2, and Iron Gate). This will require major reconfiguration of the modeling framework. An iterative load reduction (TMDL compliance) analysis will then be performed in the same manner as Scenario 1.
8: Shasta TMDL Conditions	*Klamath River:* Same as Scenario 1, except set Shasta River contributions at levels designated in the Shasta TMDL.
9: Restored riparian conditions for tributaries	*Klamath River:* Although shading by riparian vegetation is not a component of the proposed modeling approach, it is possible to adjust incoming tributary temperature levels to represent tributary shading improvements. Scenario 1 will identify the required incoming tributary temperatures to comply with TMDL targets and these can be compared to the anticipated levels resulting from restored riparian vegetation. Stream morphology can also be adjusted in the model based on recommendations from the TMDL workgroup.

4.2.3 Allocations

The scenarios described above will enable the TMDL workgroup to evaluate potential management alternatives for the Klamath and Lost Rivers and the feasibility of these alternatives. Scenario 1 (the iterative load reduction/TMDL compliance scenario) will determine the assimilative loading capacity of the waterbodies based on current flow conditions/allocations. Maximum allowable incoming constituent loading levels that enable the waterbodies to achieve the TMDL targets will be determined. The subsequent scenarios will further evaluate the feasibility of potential management alternatives.

In general, the maximum allowable incoming constituent loading levels (i.e., the assimilative capacity/TMDLs) will be presented in the following terms for the parameters of interest:

- Nutrient loads for individual nitrogen and phosphorus components (including ammonia, nitrate-nitrite, organic nitrogen, orthophosphorus, and organic phosphorus) will be specified on a daily timestep, at a minimum. It is anticipated that these specifications will address the nutrient, ammonia toxicity, and DO impairments (as they are generally the driver for algal productivity and oxygen depletion).
- Required incoming water temperature levels (for individual or a combination of tributaries, canals, and drains) will be specified on a time-variable basis rather than specifying a thermal load. The plausibility of identifying required shade increases for the Klamath River will be evaluated and discussed with the TMDL workgroup, although the proposed Klamath Modeling Approach does not include an explicit shade simulation module.
- Bacteria loads will be specified for fecal coliform bacteria on a daily timestep, at a minimum, for the Lost River. A correlation between fecal coliform and E. coli will be developed using monitoring data for the Lost River (data permitting), and this will be used to ensure that CA's bacteria criteria are met (for allocations based on meeting OR's criteria). Bacteria loads will be specified for E. coli as necessary.

Point Sources

Allocations will be made to individual point sources in each of the basins. Point sources that have been identified are included in Table 4-5.

Table 4-5. Permitted Facilities in Lost River and Lower Klamath River Watersheds

Klamath River	Lost River
OR0023876 - South Suburban Sanitary District	OR0020486 - City of Merrill – STP (activated sludge)
OR0002542 - Collins Products Klamath Falls Plant	CA0023272 - City of Tulelake

The individual permits and discharge monitoring reports (DMRs) for each of these permits will be further reviewed to ascertain their historical and permitted contributions and to confirm that they contribute to the Lost and Klamath River systems. During the sensitivity analysis and scenario analysis phases, the impact of each permitted facility's contribution to in-stream water quality will be evaluated. Ultimately, wasteload allocations will be made for each facility based on input from the TMDL workgroup.

In addition to the individual permits identified above, allocations must also be given to storm water discharges from separate storm sewer systems (MS4s). EPA's stormwater permitting regulations require municipalities to obtain permit coverage for all storm water discharges from MS4s. Implementation of these regulations are phased such that large and medium sized municipalities were required to obtain storm water permit coverage in 1990 and small municipalities by March 2003. Allocations can be provided for these permits to be consistent with ODEQ and NCRWQCB policy. The potential influences from these permits can be evaluated in much the same manner that they are evaluated for the permitted facilities identified above. It should be noted, however, that because a watershed model is not proposed for incorporation into the Lost or Klamath River modeling efforts at this stage, the potential contributions from MS4s will need to be estimated based on literature and available monitoring data.

Confined Animal Feeding Operations (CAFO) also exist in the Lost River subbasin. The CAFO facilities existing in the Lost River subbasins are regulated by Oregon Department of Agriculture (ODA). Each CAFO has an NPDES permit that stipulates no discharge to surface water and/or groundwater. The overall goal of Oregon's CAFO program is to prevent discharge of CAFO waste to waters of the state.

Nonpoint Sources

The proposed Klamath and Lost River modeling approaches will enable allocations to be made to major tributaries, drains, and canals (or combinations of drains and canals), as well as lateral (intervening zone) nonpoint source contributions. The proposed modeling framework will not explicitly simulate loading dynamics from different landuse categories. For example, it will not explicitly simulate processes such as the application of fertilizer to irrigated lands, the percolation of nutrient-laden water through the subsurface, or the uptake of nutrients by vegetation. It will, however, distinguish between load contributions on a spatial basis. A source-specific analysis can be performed externally to provide higher allocation resolution for source categories (such as irrigated agriculture, non-irrigated agriculture, residential/urban, and forested/undeveloped areas). For example, the load allocated to a tributary can be distributed to the various landuse/source categories contributing to the tributary based on the landuse distribution and typical loading rates from the appropriate landuse categories.

In the event that more detailed source-specific allocations are necessary, a watershed model may be implemented (although the current project scope does not include development watershed model). A watershed model can predict time-variable source-specific loadings (from a sub-hourly timestep to a seasonal timestep depending on model complexity) contributing to tributaries, drains, and canals. Predictions are generally made using a combination of algorithms that predict surface and subsurface hydrology (driven by meteorological monitoring data such as precipitation and evapotranspiration); application or accumulation of a water quality constituent based on land practices; and washoff of constituents based on meteorological conditions. Watershed models provide the capability of predicting

source-based loadings under both historical and hypothetical scenarios. A watershed model would also help to provide a more detailed allocation to MS4s in the contributing watershed.

A simple, dynamic watershed model that would be applicable to the Klamath and Lost River systems for estimation of agricultural and background water quality constituent loadings is the Generalized Watershed Loading Functions (GWLF) model. The P8 model is a simple, dynamic watershed model that is applicable to urbanized watersheds. If higher resolution model output and consideration of snowfall/snowmelt impacts on hydrology and pollutant transport are necessary, a number of models are applicable, including LSPC (a modernized version of the HSPF model), HSPF, SWAT, and SWMM. Each of these models has its own advantages and limitations, however they all generally require significant monitoring data to support calibration.

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APPENDIX A: MAJOR LAND RESOURCE AREAS DATA DESCRIPTION

6—Cascade Mountains, Eastern Slope

Land use: About 60 percent of this area is federally owned; most of the remainder is in farms, ranches, or privately owned woodland. About 75 percent is forested. Lumbering is an important industry. Much of the woodland is grazed by cattle. This area is also important for recreation and for wildlife habitat. Less than 5 percent, mostly in the valleys, is cropland, most of which is irrigated. Crops include tree fruits, small grains, and forage crops

Elevation and topography: Elevation ranges from 300 to 2,400 m, but some mountain crests are 3,000 m. Strongly sloping mountains and U-shaped glaciated valleys are dominant. Some gently sloping crests and benches are dissected by many streams.

Climate: Average annual precipitation 500 to 1,775 mm, generally increasing with elevation, but on some mountain crests it is 2,550. Precipitation falls mainly during the winter, spring, and fall; summers are relatively dry. All areas receive snow in winter. Average annual temperature--4 to 10 C, but it is lower on mountain crests. Average freeze-free period--60 to 120 days, decreasing with elevation.

Water: Precipitation and perennial streams provide ample water. This area supplies water from the perennial streams and reservoirs to drier and lower Iying MLRA's. Ground-water supplies are mostly untapped.

Soils: The dominant soils are Orthods, Andepts, Ochrepts, Xerolls, and Xeralfs. They have a mesic, frigid, or cryic temperature regime. Cryorthods and Haplorthods formed in residuum from weathered bedrock, alpine glacial till, and volcanic debris. Cryandepts (Surgh series) and Vitrandepts (Choralmont, Molson, and Palmich series) formed in recent and weathered volcanic ash. Shallow to deep Xerochrepts (Ardenvoir, Kartar, and Nevine series) formed in bedrock residue, glacial drift, and a mixed mantle of volcanic debris. Deep Haploxerolls (Conconully series) formed in glacial till. Haploxeralfs (Cle Elum and Varelum series) formed in material weathered from sandstone. Detailed soil survey information is lacking for most of the area.

Potential natural vegetation: This area supports conifer forest and grass vegetation. The kind of vegetation gradually changes with increases in elevation and in precipitation. Important species in grasslands at the lowest elevations are bluebunch wheatgrass, Sandberg bluegrass, big sagebrush, bitterbrush, Idaho fescue, and Cusick bluegrass. Ponderosa pine forest has an understory of bluebunch wheatgrass and Idaho fescue. Douglas-fir forest has an understory of pinegrass, bearberry, and currant. Grand fir western larch, and lodgepole pine have an understory of vacciniums and menziesia. Pacific silver fir, mountain hemlock, subalpine fir, and whitebark pine are at the highest elevations.

15—Central California Coast Range

Land use: More than four-fifths of this area is in farms and ranches; most of the remainder is federally owned. About 10 percent is dry-farmed to grain, and slightly more that 50 percent is in range of native grasses and brush. Open woodland, also used for grazing, makes up nearly 35 percent of the area. Small acreages are forests and urban areas. The erosion hazard is severe in dry-farmed orchards and grainfields. If the plant cover is removed from the soils by fire, overgrazing, cultivation, or logging, the hazard of erosion is severe because of steep slopes and high-intensity rainfall.

Elevation and topography: Elevation ranges from sea level to 800 m in most of the area, but it is 1,500 m in some mountains. Gently sloping to steep low mountains underlain mostly by shale and sandstone and partly by igneous and volcanic rocks cover most of the area. Coastal plains are narrow and discontinuous, and stream valleys are narrow and widely separated.

Climate: Average annual precipitation 300 to 1,025 mm, but it is 375 to 750 mm in most of the area. Precipitation is evenly distributed throughout fall, winter, and spring but is very low in summer. Coastal areas receive some moisture from fog in summer. Average annual temperature 13 to 18 C. Average freeze-free period--120 to 270 days.

Water: The low to moderate rainfall and moderate streamflow limit agriculture to dryfarming in most of the area. Ground-water supplies are limited.

Soils: The dominant soils are Xererts, Xerolls, Ochrepts, Xeralfs, Orthents, and Psamments. They have a thermic temperature regime (mesic at the highest elevations). Soils on hills are the rolling to steep Chromoxererts (Altamont series), Argixerolls (Chamise and Los Osos series), Xerochrepts (Millsholm series), Haploxeralfs (Dibble series), and Haploxerolls (San Benito, Linne, and Santa Lucia series). Also on hills are the gently sloping to steep Palexeralfs (Spreckles series), Xerorthents (Shedd series), and Haploxerolls (Nacimiento series). Soils on uplands are the strongly sloping to steep Xeropsamments (Arnold series), Xerorthents (Gaviota series), Argixerolls (Los Gatos, Gilroy, and Henneke series), Haploxerolls (Montara, Sheridan, and Sur series), Xerochrepts (Maymen and Toomes series), and Haploxeralfs (Vallecitos series). Rock outcrop is common.

Potential natural vegetation: This area supports grasses, grass-oak, and shrub vegetation. Naturalized annuals, including soft chess, bromes, fescues, wild oats, filaree, and burclover characterize the open and oak grasslands. Blue oak, valley oak, and canyon live oak are the dominant trees. California sagebrush, coyotebrush, chamise, manzanita, ceanothus, and scrub oak are the major brush species. Along the west side of the Coast Range are forests of Douglasfir, madrone, grand fir, tanoak, bigleaf maple, and a few remnant stands of redwood trees. Stands of ponderosa pine with madrone, black oak, live oaks, California buckeye, manzanita, and ceanothus are on drier sites.

21—Klamath and Shasta Rivers Valleys and Basins

Land use: About one-half of this area is federally owned; the remainder is in farms and ranches. Between 5 and 10 percent of the land is irrigated and used for growing potatoes, grain, seed crops, hay, and pasture. An additional 1 or 2 percent is dryfarmed to grain. Most of the remaining land, both privately and publicly owned, is grazed. Some forest trees are harvested for lumber. Maintaining good drainage is the principal concern of management in the valley basins. Some sites need protection from overflow, and others are affected by alkali. The erosion hazard is slight except for gullying and flood scour.

Elevation and topography: Elevation ranges from 800 to 1,400 m, but on some mountain peaks it is 1,800 m or more. Lava plateaus and many valleys and basins make up most of the area. Steep mountain spurs and rimrock escarpments surround the plateaus.

Climate: Average annual precipitation 250 to 500 mm in most of the area but as much as 750 mm at higher elevations. Summers are dry. Average annual temperature 7 to 11 C. Average freeze-free period—70 to 140 days, decreasing with elevation.

Water: The low precipitation and the consequent erratic flow of local streams limit the supply of water for agriculture. Ground water is scarce in the dense lava rocks underlying much of the area. On sites underlain by more porous rocks, ground-water supplies are large but mostly untapped.

Soils: The dominant soils are Xerolls, Aquolls, Aquepts, Aquents, Xererts, Albolls, and Argids. They have a mesic or frigid temperature regime. Soils in basins and on flood plains and terraces are Andaquepts (Tulana series), Argialbolls (Goose Lake series), Pelloxererts (Pitts series), Durargids (Trosi series), Halaquepts (Lolak series), Natrargids (Rumbo series), Durixerolls (Bieber series), Haploxerolls (Mottsville series), Argixerolls (Trojan, Galeppi, and Drews series), and Haplaquolls (Ramelli and Deven series). Soils on upland plateaus and mountains are Argixerolls (McQuarrie series), Haplargids (Casuse and Saralegui series), Chromoxererts (Karcal series), and Durargids (Packwood series). Large areas of rock outcrop are on the plateaus and in the mountains.

Potential natural vegetation: This area supports a cover of shrubs interspersed with annual and perennial grasses. Nevada bluegrass, Sandberg bluegrass, Idaho fescue, bluebunch wheatgrass, and cheatgrass are major species. Soils in basins and meadows have a cover of sedges, wiregrass, slender wheatgrass, creeping wildrye, and bluegrass. Sagebrush, rabbitbrush, bitterbrush, and mountainmahogany are the dominant shrubs. Western juniper is common, and scattered ponderosa pine grows in places where precipitation is less than 375 mm. In zones where precipitation is higher than 375 mm, there are forests of ponderosa pine, Douglas-fir, white fir, and California red fir, and bitterbrush and ceanothus are in the understory.

23—Malhuer High Plateau

Land use: About three-fourths of this area is federally owned. Native range vegetation covers much of the area. Livestock production on range is the principal agricultural activity. About 1 or 2 percent of the area is irrigated, and grain and hay for winter feed and pasture are grown. Small areas on upper mountain slopes are forested.

Elevation and topography: Elevation ranges from 1,200 to 2,100 m, but on some mountains it is more than 2,700 m. Nearly level basins and valleys are bordered by long, gently sloping alluvial fans. North-south-trending mountain ranges and a few volcanic plateaus rise sharply above the valleys.

Climate: Average annual precipitation 200 to 350 mm in most of the area but as much as 500 mm on some of the higher mountain slopes. Precipitation is fairly evenly distributed throughout fall, winter, and spring but is low in summer. Average annual temperature 5 to 10 C. Average freeze-free period—30 to 140 days, decreasing with elevation.

Water: Water is scarce except at higher elevations where precipitation is greater. Streamflow is erratic and depends mostly on runoff from melting snow. The large ground-water supplies in the gravel- and sand-filled valleys are mostly untapped.

Soils: Most of the soils are Argids or Orthids. They are shallow to moderately deep, and have a medium textured to fine textured subsoil and a frigid or mesic soil temperature regime. Nearly level to sloping, well drained Durargids and Durorthids have a duripan and are on lake terraces and fans. Somewhat poorly drained Durorthids in low areas are commonly saline and sodic. Sloping to steep, well drained to excessively drained, shallow, stony Xerolls are on uplands.

Potential natural vegetation: This area supports a shrub-grass association. Big sagebrush, rabbitbrush, needlegrasses, and squirreltail are common on the extensive sandy and loamy soils. Big sagebrush and basin wildrye are on bottom lands. Spiny hopsage and bud sagebrush are on the drier sites. Greasewood, saltbush, and saltgrass grow on salty and sodic soils. Silver sagebrush grows on moist sites that have water intermittently, such as playas. Western juniper are on rocky sites. Growing at high elevations are aspen groves on moist sites and isolated stands of grand fir and whitebark pine.

17—Sacramento and San Joaquin Valleys

Land use: More than 90 percent of this MLRA is in farms and ranches. Much of the remainder is federally owned. About 2 or 3 percent is urban, and the acreage used for this purpose is increasing rapidly. Slightly more than half the area is cropland, three-fourths or more of which is irrigated. The cropland in this MLRA represents 60 percent of the cropland in California, and the irrigated cropland is 80 percent of the irrigated land in the state. Cotton, fruits, nuts, grapes, hay, grain, pasture, rice, alfalfa, citrus, and tomatoes are among the principal crops grown on irrigated land. The more sloping, nonirrigated cropland is dry-farmed to grain. About a third of the area is in native grasses, brush, and open woodland and is used mostly for grazing. If the plant cover on sloping soils on terraces is removed, erosion is a hazard. The hazard of wind erosion is severe on the sandy, wind-modified soils in the San Joaquin Valley if a plant cover is not maintained.

Elevation and topography: Elevation ranges from sea level to 200 m. This area includes the valley basins adjacent to the Sacramento and San Joaquin Rivers, fans and flood plains of tributary streams, and terraces around the edge of the valley.

Climate: Average annual precipitation--l25 to 625 mm. Summers are long, hot, and dry, and winters are cool and rainy. Average annual temperature 16 to 19 C in most of the area but as low as 13 C in the north. Average freeze-free period--230 to 350 days, increasing from north to south.

Water: Because of the low rainfall and relatively small streamflow, water is scarce in many parts of the area. Water for irrigated crops comes from stream diversions, wells, and canals of organized irrigation districts that obtain most of their water from state and federal water systems.

Soils: The dominant soils are Xeralfs, Xerolls, Xererts, Aquents, Aquolls, Ochrepts, Orthents, Fluvents, Psamments, and Argids. They have a thermic temperature regime. Soils in basins are Xerofluvents (Columbia series), Pelloxererts (Willows and Clear Lake series), Chromoxererts (Capay series), Haploxerolls (Merced series), Natrixeralfs (Solano and Pescadero series), Haploxeralfs (Traver series), Haplaquents (Tulare series), and Haplaquolls (Sacramento series). Soils on fans and flood plains are Xerorthents (Yolo and Hanford series), Haploxerolls (Chino and Grangeville series), Torriorthents (Panoche series), Xerofluvents (San Emigdio series), Haploxerolls (Sorrento series), Natrargids (Lethent series), Haploxeralfs (Wyman and Zamora series), and Haplargids (Panhill series). Soils on low terraces are Durixeralfs (Fresno and Madera series) and Durochrepts (El Peco series). Soils on terraces are Durixeralfs (SanJoaquin, Exeter, and Redding series) and Palexeralfs (Red Bluff and Corning series). Sandy soils in the San Joaquin Valley are Xeropsamments (Delhi, Calhi, and Tujunga series).

Potential natural vegetation: This area supports naturalized annuals and scattered trees. Wild barley, wild oats, soft chess, ripgut brome, red brome, foxtail fescue, burclover, and filaree are dominant species. Scattered oaks on terraces and oak, willow, and cottonwood grow along the rivers and streams and in the overflow areas. Saltgrass, along with such shrubs as iodinebush and Australian saltbush, grow on saline-sodic soils on terraces and in basins.

18—Sierra Nevada Foothills

Land use: About four-fifths of this MLRA is in farms and ranches; most of the remainder is federally owned. Production of livestock on range is the principal enterprise. Approximately 75 percent of the area is range, 5 percent cropland, and the remainder brushland and open forest. Most of the cropland is dry-farmed to grain, but small tracts are used for growing fruit, nuts, and grapes under irrigation. The hazard of erosion is moderate to severe on the soils if the plant cover is removed by overgrazing, cultivation, or fire.

Elevation and topography: Elevation ranges from 200 to 500 m, but on some isolated mountain peaks it is 1,200 m. In this area of rolling to steep dissected hills and low mountains, the stream valleys are narrow and fairly steep.

Climate: Average annual precipitation 350 to 900 mm. Summers are hot and dry, and winters are cool and moist. Average annual temperature 13 to 18PC. Average-freeze-free period--200 to 320 days.

Water: The moderate rainfall and intermittent streamflow are the major water sources. Ground-water supplies are small and mostly untapped. Numerous stock ponds are scattered throughout the area, but little has been done to construct small reservoirs for irrigation.

Soils: The dominant soils are Ochrepts, Xeralfs, Xerolls, and Orthents. They have a thermic temperature regime. Shallow soils include Xerochrepts (Hornitos, Toomes, and Auburn series), Xerorthents (Dauston, Whiterock, and Exchequer series), and Argixerolls (Henneke series). Moderately deep and deep soils are Haploxeralfs (Rescue, Argonaut, Ahwahnee, Aubeny, and Sierra series) and Xerochrepts (Vista series).

Potential natural vegetation: This area supports naturalized annual grasses, shrubs, and trees. Soft chess, wild oats, filaree, burclover, ripgut brome, and foxtail fescue are dominant species on rangeland. An overstory of scattered individuals to very dense stands of blue oak and Digger pine, with scrub live oak as an important component, grow in some places. Chamise, manzanita, wedgeleaf ceanothus, yerbasanta, and poison-oak are dominant on brushland. Scattered stands of ponderosa pine, mixed with manzanita and black oak, are at the upper elevations of the more moist sites. At the upper elevations, small stands of Douglas-fir grow on north slopes along major streams.

22—Sierra Nevada Range

Land use: More than one-half of this area is federally owned. The Yosemite and Sequoia National Parks are in this area. The remainder is privately owned woodland, farms, and ranches. About 90 percent of the land consists of forests used for timber, recreation, wildlife habitat, and watershed. Approximately 8 percent is pasture and range, and less than 1percent is cropland. The erosion hazard is severe if the soils are disturbed by logging, fires, overgrazing, and cultivation. Soils in mountain valleys and meadows are susceptible to gullying and streambank erosion.

Elevation and topography: Elevation ranges from 500 to 2,400 m, but on some mountain peaks (Mt. Shasta and Mt. Whitney) it is more than 4,300 m. Most of the area consists of strongly sloping to precipitous mountains cut by many steep valleys. Some plateau remnants and mesas are in this area.

Climate: Average annual precipitation 1,025 to 1,525 mm in much of the area but as low as 625 mm in the lower valleys and foothills and as much as 1,775 mm on the mountain peaks. Precipitation increases with elevation and from south to north. Summers are dry, but there are occasional thundershowers. Much of the winter precipitation is snow. Average annual temperature 2 to 14 C, decreasing with elevation. Average freeze-free period 30 to 180 days, decreasing with elevation.

Water: The abundant precipitation and snowfields on the higher mountain slopes supply water to many large perennial streams. Much of this water is stored in large reservoirs and is used in the Sacramento and San Joaquin Valleys and in southern California.

Soils: The dominant soils are Xerults, Humults, Xeralfs, Xerolls, Ochrepts, Umbrepts, Andepts, Orthents, Psamments, and Boralfs. They have a mesic, frigid, or cryic temperature regime, depending largely on elevation. Soils at an elevation below 1,200 to 1,500 m are Haplohumults (Sites and Aiken series), Haploxeralfs (Secca, Holland, and Cohasset series), Xerochrepts (Chaix and Maymen series), Haploxerults (Josephine and Mariposa series), Vitrandepts (Iron Mountain and Jiggs series), and Haploxerolls (Shaver series). Soils at higher elevations are Xerorthents (Dinkey series), Xeropsamments (Corbett and Toiyabe series), Cryopsamments (Cagwin series), Cryoboralfs (Fugawee series), Cryumbrepts (Meeks series), Cryochrepts (Umpa series), Cryandepts (Meiss and Waca series), and Dystrandepts (Windy series). Large areas of rock land are scattered throughout the area and on broad expanses on ridge crests and peaks above timberline (2,400 to 2,700 m). Soils in mountain valleys are Haploxerolls (Oak Glen series), Xeropsamments (Elmira series), Haploxeralfs (Inville series), Humaquepts (Chummy series), and Cryaquents. Soil survey information is lacking for extensive areas.

Potential natural vegetation: This area supports forest vegetation. Ponderosa pine, Douglas-fir, incense-cedar, sugar pine, white fir, California red fir, lodgepole pine, mountain hemlock, black oak, Oregon white oak, canyon live oak, and tanoak are major tree species. Bristlecone pine grows in protected draws at elevations above 2,400 to 2,700 m. Bluegrass, hairgrass, sedges, wiregrass, clovers, and wild iris grow in meadows. Sagebrush, blue wildrye, fescues, bluegrasses, and mountain brome grow under open stands of timber.

5—Siskiyou and Trinity Area

Land use: Nearly half of this area is federally owned. Most of the land is in conifer forests that are important for lumbering, wildlife habitat, and recreation. About 10 percent of the area is grazed, and a smaller acreage is cropped. Livestock is the principal farm enterprise. Truck crops are important in valleys where the water is adequate. On the more sloping parts of the valleys, small grains, hay, and pasture are grown as feed for dairy cattle and other livestock. The erosion hazard is high because of steep slopes, erodible soils, and high rainfall. The erosion hazard is severe if the plant cover is removed. Mass movement in the form of landslides is a serious problem and a major source of sediment in the rivers.

Elevation and topography: Elevation ranges from 100 to 1,400 m, but on some mountain peaks it is 2,700 m. Rounded but steeply sloping mountains that are underlain mainly by sandstone and shale but in some places by granodiorite, gabbro, and other intrusive rocks are dominant. The narrow valleys have gently sloping flood plains and alluvial fans and are bordered by strongly sloping foothills.

Climate: Average annual precipitation 450 mm in some valleys to 2,150 mm in the mountains. Precipitation is low in summer but is evenly distributed throughout the rest of the year. Average annual temperature 7 to 13 C. Average freeze-free period 60 to 250 days, decreasing with elevation.

Water: The moderate to high precipitation provides enough water in the mountains and higher valleys and, through streamflow, supplies irrigation water in the drier valleys. Ground water is abundant in alluvial deposits in most valleys.

Soils: The dominant soils are Ochrepts, Xerults, Orthents, Xeralfs, and Umbrepts. They have a mesic temperature regime and a xeric moisture regime. Principal soils of the mountains are Xerochrepts (Sheetiron and Hugo series), Haploxerults (Josephine series), shallow Xerorthents and Xerochrepts (Etsel and Maymen series), Haploxeralfs (Holland and Dubakella series), and Xerumbrepts (Masterson series). Xerothents and Xerofluvents are on flood plains and alluvial fans. Detailed soil survey information is lacking for much of the area.

Potential natural vegetation: This area supports forest, open forest, and prairie vegetation. Douglas-fir, ponderosa pine, sugar pine, incense-cedar, white fir, red fir, tanoak, Oregon white oak, California black oak, canyon live oak, and madrone are the dominant tree species. Poison-oak, snowberry, ceanothus, manzanita, rose, and whipplea characterize the forest understory. Blue wildrye, fescues, bluegrass, mountain brome, and some browse species are in the understory in open stands of timber. Soft chess, wild oats, burclover, fescues, and bromes are major prairie species.

APPENDIX B: MULTI-RESOLUTION LAND CHARACTERISTICS (MRLC) CONSORTIUM DATA DESCRIPTION

Land Cover Classes:

Water
11 Open Water
12 Perennial Ice/Snow

Developed
21 Low-Intensity Residential
22 High-Intensity Residential
23 Commercial/Industrial/Transportation

Barren
31 Bare Rock/Sand/Clay
32 Quarries/Strip Mines/Gravel Pits
33 Transitional

Vegetated Natural Forested Upland
41 Deciduous Forest
42 Evergreen Forest
43 Mixed Forest

Shrubland
51 Shrubland

Nonnatural Woody
61 Orchards/Vineyards/Other

Herbaceous Upland
71 Grasslands/Herbaceous

Herbaceous Planted/Cultivated
81 Pasture/Hay
82 Row Crops
83 Small Grains
84 Fallow
85 Urban/Recreational Grasses

Wetlands
91 Woody Wetlands
92 Emergent Herbaceous Wetlands

Land Cover Classification System and Land Cover Class Definitions:

Water – All areas of open water or permanent ice/snow cover.

11. Open Water – areas of open water, generally with less than 25 percent or greater cover of water (per pixel).

12. Perennial Ice/Snow – all areas characterized by yearlong cover of ice or snow.

Developed – Areas characterized by high percentage (approximately 30percent or greater) of constructed materials (e.g., asphalt, concrete, buildings).

21. Low-Intensity Residential – areas with a mixture of constructed materials and vegetation. Constructed materials account for 30 to 80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high-intensity residential areas.

22. High-Intensity Residential – heavily built up urban centers where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to 100 percent of the cover.

23. Commercial/Industrial/Transportation – infrastructure (e.g., roads, railroads) and all highways and developed areas not classified as High-Intensity Residential.

Barren – Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

31. Bare Rock/Sand/Clay – perennially barren areas of bedrock, desert, pavement, scarps, talus, slides, volcanic material, glacial debris, and other accumulations of earthen material.

32. Quarries/Strip Mines/Gravel Pits – areas of extractive mining activities with significant surface expression.

33. Transitional – areas of sparse vegetative cover (less than 25 percent that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g., fire, flood).

Vegetated Natural Forested Upland – Areas characterized by tree cover (natural or seminatural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25 to 100 percent of the cover.

41. Deciduous Forest – areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest – areas characterized by trees where 75 percent or more of the tree species maintain their leaves all year. Canopy is never without green foliage.

43. Mixed Forest – areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

Shrubland – Areas characterized by natural or seminatural woody vegetation with aerial stems, generally less than 6 meters tall with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

51. Shrubland – areas dominated by shrubs; shrub canopy accounts for 25 to 100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases where the cover of other life forms (e.g., herbaceous or trees) is less than 25 percent, and shrub cover exceeds the cover of the other life forms.

Nonnatural Woody – Areas dominated by nonnatural woody vegetation; nonnatural woody vegetative canopy accounts for 25 to 100 percent of the cover. The nonnatural woody classification is subject to the availability of sufficient ancillary data to differentiate nonnatural woody vegetation from natural woody vegetation.

61. Orchards/Vineyards/Other – orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals.

Herbaceous Upland – Upland areas characterized by natural or seminatural herbaceous vegetation; herbaceous vegetation accounts for 75 to 100 percent of the cover.

71. Grasslands/Herbaceous – areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but are often utilized for grazing.

Herbaceous Planted/Cultivated – Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75 to 100 percent of the cover.

81. Pasture/Hay – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.

82. Row Crops – areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.

83. Small Grains – areas used for the production of graminoid crops such as wheat, barley, oats, and rice.

84. Fallow – areas used for the production of crops that are temporarily barren or with sparse vegetative cover as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.

85. Urban/Recreational Grasses – vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.

Wetlands – Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.

91. Woody Wetlands - areas where forest or shrubland vegetation accounts for 25 to 100 percent of the cover, and the soil or substrate is periodically saturated with or covered with water.

92. Emergent Herbaceous Wetlands – areas where perennial herbaceous vegetation accounts for 75 to 100 percent of the cover, and the soil or substrate is periodically saturated with or covered with water

APPENDIX C: Data Summary for Stations Above Iron Gate Dam

Table C-1. Summary of pH data, Klamath River above Iron Gate Dam

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19198	IRON GATE RESERVOIR 61102	9	7.80	7.1	9.1	03/27/75	10/31/75
KR19621	KLAMATH RIVER BELOW FALL CREEK NEAR COPCO	117	7.39	6.8	8.1	04/09/51	09/11/61
KR19645	COPCO DAM OUTFLOW	35	8.13	7	9.2	04/05/96	10/08/97
KR19874	COPCO LAKE NR COPCO	5	7.76	7	9	06/30/77	09/19/85
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	36	8.25	7.5	8.8	04/05/96	10/08/97
KR21970	KLAMATH R BL JOHN C BOYLE PP NR KENO,OREG.	8	7.46	7.2	7.7	09/12/61	06/12/63
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	285	7.97	6.3	9.1	07/07/59	03/13/01
KR22505	JC BOYLE RESERVOIR AT DEEPEST POINT	14	7.73	6.9	8.8	09/11/81	09/09/84
KR23193	KLAMATH RIVER NEAR KENO	106	7.73	6.9	8.8	04/05/61	04/09/69
KR23334	KLAMATH RIVER D/S OF KENO DAM	2	8.15	8.1	8.2	03/28/95	03/29/95
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	2096	8.48	6.5	10	07/07/59	03/13/01
KR23503	KLAMATH R.BLW BIG BEND POWER PL	57	8.14	7.1	9.1	10/05/75	06/13/78
KR23519	KENO ELEMENTARY SCHOOL,KENO	1	7.80	7.8	7.8	11/28/89	11/28/89
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	38	8.39	7.2	9.4	08/28/90	02/29/00
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	536	8.49	7.2	9.8	06/13/90	03/02/00
KR23973	KLAMATH RIVER D/S GORR IS @ TEETERS LANDING	3	8.20	8.1	8.3	02/29/00	03/02/00
KR24013	KLAMATH RIVER 1000' D/S KLAMATH STRAIT	4	9.30	9.3	9.3	08/08/90	08/08/90
KR24047	KLAMATH RIVER 150' D/S KLAMATH STRAIT	2	9.10	9.1	9.1	08/08/90	08/08/90
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	67	8.68	7.4	9.5	06/13/90	03/02/00
KR24057	KLAMATH RIVER 20' U/S KLAMATH STRAIT	2	9.80	9.8	9.8	08/08/90	08/08/90
KR24077	KLAMATH RIVER 1000' U/S KLAMATH STRAIT	3	9.70	9.7	9.7	08/08/90	08/08/90
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	5	9.80	8.4	10.2	08/08/90	02/29/00
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	513	8.60	7.7	10.1	06/13/90	03/01/00
KR24171	KLAMATH RIVER AT RIVER MILE 242	12	8.67	8.2	9.4	06/13/90	08/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	234	8.34	7.2	9.6	06/13/90	03/01/00
KR24589	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	49	8.19	7.2	9.2	06/12/90	11/19/97
KR24594	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	43	8.23	7.2	9.2	06/12/90	03/23/98
KR24713	WEYERHAEUSER KLAMATH FALLS /BOX 9	11	8.40	7.2	9.6	06/01/83	06/01/83
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	41	8.25	7.1	9.3	08/28/90	08/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	734	8.74	6.8	9.5	07/07/59	03/29/95
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	221	8.01	6.06	10.26	05/16/72	06/20/01
KR24901	KLAMATH RIVER AT HWY 97 BR NE	43	7.87	6.8	9.6	10/12/60	03/23/98
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	568	8.97	7.9	9.8	06/12/90	08/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	14	8.74	7.9	9.3	06/12/90	08/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	572	8.81	7.6	9.9	06/11/90	03/23/98
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	51	8.90	7.9	9.8	06/12/90	08/16/94

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR25149	KLAMATH RIVER 200' D/S S SUBURBAN STP DISCHARGE	2	9.30	9.3	9.3	08/07/90	08/07/90
KR25158	KLAMATH RIVER 100' D/S S SUBURBAN STP DISCHARGE	2	8.80	8.8	8.8	08/07/90	08/07/90
KR25164	KLAMATH RIVER 30' D/S S SUBURBAN STP DISCHARGE	4	8.95	8.7	9.2	08/07/90	08/07/90
KR25166	KLAMATH RIVER 20' D/S S SUBURBAN STP DISCHARGE	1	8.40	8.4	8.4	08/07/90	08/07/90
KR25168	KLAMATH RIVER 10' D/S S SUBURBAN STP DISCHARGE	1	8.40	8.4	8.4	08/07/90	08/07/90
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	29	8.56	7.6	10	08/07/90	03/23/98
KR25200	421310121472001	2	9.25	9.2	9.3	08/22/88	08/22/88
KR25200	LAKE EWAUNA BETWEEN STPS	1123	8.82	7.7	9.82	06/12/90	03/30/95
KR25250	KLAMATH RIVER 120' D/S KLAMATH FALLS STP	4	9.10	8.6	9.6	08/07/90	08/07/90
KR25271	KLAMATH RIVER 100' U/S KLAMATH FALLS STP	2	9.00	9	9	07/12/88	07/12/88
KR25274	KLAMATH RIVER 120' U/S KLAMATH FALLS STP	1	7.70	7.7	7.7	08/07/90	08/07/90
KR25278	KLAMATH RIVER 150' U/S KLAMATH FALLS STP	3	9.27	9.2	9.3	07/12/88	07/12/88
KR25312	LINK RIVER AT MOUTH	456	8.52	6	10.4	05/12/69	03/13/01
KR25344	421404121480101	48	9.14	7.3	10.5	06/03/92	09/09/92
KR25479	LINK RIVER AT FREMONT ST BRIDGE	29	8.72	7.34	10.18	06/11/90	04/07/98

Table C-2. Summary of temperature data, Klamath River above Iron Gate Dam (°C).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19645	COPCO DAM OUTFLOW	34	16.43	10.4	22.9	4/5/96	10/8/97
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	35	14.91	8.9	21.7	4/5/96	10/8/97
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	65	12.90	2.4	23.5	6/18/86	3/13/01
KR22505	JC BOYLE RESERVOIR AT DEEPEST POINT	12	17.56	11.2	25.8	4/16/84	9/9/84
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	132	13.88	0.5	26	1/21/80	3/13/01
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	21	20.08	4.6	24.5	8/28/90	2/29/00
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	36	20.15	4.6	29.5	4/17/90	3/2/00
KR24013	KLAMATH RIVER 1000' D/S KLAMATH STRAIT	2	29.75	28.5	31	8/8/90	8/8/90
KR24047	KLAMATH RIVER 150' D/S KLAMATH STRAIT	2	30.00	30	30	8/8/90	8/8/90
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	33	20.87	4.6	31	4/17/90	3/2/00
KR24057	KLAMATH RIVER 20' U/S KLAMATH STRAIT	1	27.50	27.5	27.5	8/8/90	8/8/90
KR24077	KLAMATH RIVER 1000' U/S KLAMATH STRAIT	1	28.00	28	28	8/8/90	8/8/90
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	3	21.57	6.2	30	8/8/90	2/29/00
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	31	19.75	4.7	27	4/17/90	3/1/00
KR24171	KLAMATH RIVER AT RIVER MILE 242	4	19.75	15	25	6/13/90	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	32	19.96	4.3	26.5	6/13/90	3/1/00
KR24594	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	37	18.88	2.7	28	6/12/90	3/23/98
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL	22	21.98	17	27.5	8/28/90	8/16/94

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
	SMOKESTACK						
KR24894	KLAMATH RIVER AT HWY 97 BR SE	23	20.63	17	26	4/17/90	8/16/94
KR24901	KLAMATH RIVER AT HWY 97 BR NE	12	15.13	2.7	26.5	4/17/90	3/23/98
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	26	20.98	17	28	6/12/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	5	18.70	17	24.5	6/12/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	25	18.86	2.7	28	6/13/90	3/23/98
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	27	20.11	16.5	26.5	4/17/90	8/16/94
KR25149	KLAMATH RIVER 200' D/S S SUBURBAN STP DISCHARGE	1	26.00	26	26	8/7/90	8/7/90
KR25158	KLAMATH RIVER 100' D/S S SUBURBAN STP DISCHARGE	1	25.00	25	25	8/7/90	8/7/90
KR25164	KLAMATH RIVER 30' D/S S SUBURBAN STP DISCHARGE	1	27.00	27	27	8/7/90	8/7/90
KR25166	KLAMATH RIVER 20' D/S S SUBURBAN STP DISCHARGE	1	28.00	28	28	8/7/90	8/7/90
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	12	15.45	2.8	25.5	8/7/90	3/23/98
KR25200	421310121472001	1	18.50	18.5	18.5	8/22/88	8/22/88
KR25200	LAKE EWAUNA BETWEEN STPS	24	19.88	15	27.5	6/12/90	8/16/94
KR25250	KLAMATH RIVER 120' D/S KLAMATH FALLS STP	2	23.75	23.5	24	8/7/90	8/7/90
KR25271	KLAMATH RIVER 100' U/S KLAMATH FALLS STP	1	22.00	22	22	7/12/88	7/12/88
KR25278	KLAMATH RIVER 150' U/S KLAMATH FALLS STP	1	22.00	22	22	7/12/88	7/12/88
KR25312	LINK RIVER AT MOUTH	134	12.85	-2	25.4	1/21/80	3/13/01
KR25344	421404121480101	46	19.95	14	28	6/3/92	9/9/92
KR25479	LINK RIVER AT FREMONT ST BRIDGE	29	13.13	1.31	23.25	6/11/90	4/7/98

Table C-3. Summary of total ammonia nitrogen data, Klamath River above Iron Gate Dam (mg/L as N).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19198	IRON GATE RESERVOIR 61102	12	0.15	0.03	0.22	3/27/75	10/31/75
KR19645	COPCO DAM OUTFLOW	12	0.16	0.025	0.29	4/17/96	10/8/97
KR19856	KLAMATH RIVER 0611A2	12	0.23	0.045	0.59	11/16/74	11/8/75
KR19874	COPCO LAKE NR COPCO	5	0.19	0.03	0.69	9/22/77	5/11/78
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	12	0.17	0.025	0.42	4/17/96	10/8/97
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	165	0.32	0.01	4.3	7/7/59	9/15/97
KR23334	KLAMATH RIVER D/S OF KENO DAM	2	0.05	0.05	0.05	3/28/95	3/29/95
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	299	0.57	0.01	3.75	7/7/59	9/15/97
KR23503	KLAMATH R.BLW BIG BEND POWER PL	13	0.36	0.04	1.14	10/5/75	1/16/78
KR23519	KENO ELEMENTARY SCHOOL,KENO	1	0.02	0.02	0.02	11/28/89	11/28/89
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	17	0.59	0.04	1.03	8/28/90	8/17/94
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	34	0.37	0.03	0.97	4/17/90	3/29/95
KR24013	KLAMATH RIVER 1000' D/S KLAMATH STRAIT	2	0.13	0.11	0.14	8/8/90	8/8/90
KR24047	KLAMATH RIVER 150' D/S KLAMATH STRAIT	2	0.22	0.21	0.23	8/8/90	8/8/90

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	27	0.43	0.05	1.37	4/17/90	8/17/94
KR24057	KLAMATH RIVER 20' U/S KLAMATH STRAIT	1	0.10	0.1	0.1	8/8/90	8/8/90
KR24077	KLAMATH RIVER 1000' U/S KLAMATH STRAIT	2	0.05	0.05	0.05	8/8/90	8/8/90
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	2	0.04	0.04	0.04	8/8/90	8/8/90
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	26	0.34	0.03	1.09	4/17/90	3/29/95
KR24171	KLAMATH RIVER AT RIVER MILE 242	4	0.05	0.03	0.05	6/13/90	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	22	0.37	0.02	0.98	6/13/90	8/17/94
KR24589	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	38	0.50	0.04	1.01	4/17/90	11/19/97
KR24713	WEYERHAEUSER KLAMATH FALLS /BOX 9	6	6.59	0.59	17.621	6/1/83	6/1/83
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	17	0.57	0.07	1.05	8/28/90	8/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	76	0.73	0.01	4.15	7/7/59	3/29/95
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	111	0.47	0.01	1.7	5/16/72	8/25/93
KR24901	KLAMATH RIVER AT HWY 97 BR NE	23	0.43	0.04	1.38	4/7/70	11/19/97
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	22	0.25	0.08	0.66	6/12/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	7	0.31	0.08	0.51	6/12/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	16	0.32	0.06	1	6/13/90	11/19/97
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	23	0.22	0.08	0.41	4/17/90	8/16/94
KR25141	KLAMATH RIVER 300' D/S S SUBURBAN STP DISCHARGE	1	1.32	1.32	1.32	8/7/90	8/7/90
KR25149	KLAMATH RIVER 200' D/S S SUBURBAN STP DISCHARGE	1	0.90	0.9	0.9	8/7/90	8/7/90
KR25158	KLAMATH RIVER 100' D/S S SUBURBAN STP DISCHARGE	1	2.70	2.7	2.7	8/7/90	8/7/90
KR25164	KLAMATH RIVER 30' D/S S SUBURBAN STP DISCHARGE	2	0.79	0.74	0.83	8/7/90	8/7/90
KR25168	KLAMATH RIVER 10' D/S S SUBURBAN STP DISCHARGE	1	4.80	4.8	4.8	8/7/90	8/7/90
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	15	0.30	0.03	1	8/7/90	11/19/97
KR25200	LAKE EWAUNA BETWEEN STPS	25	0.17	0.02	0.33	6/12/90	3/29/95
KR25250	KLAMATH RIVER 120' D/S KLAMATH FALLS STP	2	0.90	0.19	1.6	8/7/90	8/7/90
KR25263	KLAMATH RIVER 50' U/S KLAMATH FALLS STP	1	4.60	4.6	4.6	8/7/90	8/7/90
KR25271	KLAMATH RIVER 100' U/S KLAMATH FALLS STP	1	1.60	1.6	1.6	7/12/88	7/12/88
KR25274	KLAMATH RIVER 120' U/S KLAMATH FALLS STP	1	4.30	4.3	4.3	8/7/90	8/7/90
KR25278	KLAMATH RIVER 150' U/S KLAMATH FALLS STP	2	0.91	0.88	0.94	7/12/88	7/12/88
KR25312	LINK RIVER AT MOUTH	217	0.35	0.01	18	5/12/69	11/19/97

Table C-4. Summary of biochemical oxygen demand (BOD) data, Klamath River above Iron Gate Dam (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19645	COPCO DAM OUTFLOW	12	2.63	1.5	8	4/17/96	10/8/97
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	12	2.75	1.5	5	4/17/96	10/8/97
KR22127	KLAMATH RIVER D/S OF BIG BEND	227	2.57	0.2	10	7/7/59	3/13/01

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
	POWERHOUSE						
KR23193	KLAMATH RIVER NEAR KENO	83	4.13	1.1	8.6	4/5/61	4/9/69
KR23334	KLAMATH RIVER D/S OF KENO DAM	2	4.60	3.7	5.5	3/28/95	3/29/95
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	334	3.74	0.3	20	7/7/59	3/13/01
KR23503	KLAMATH R.BLW BIG BEND POWER PL	1	0.70	0.7	0.7	7/10/77	7/10/77
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	21	3.45	1.6	10	9/25/90	2/29/00
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	28	4.73	1.8	12	4/17/90	3/2/00
KR23973	KLAMATH RIVER D/S GORR IS @ TEETERS LANDING	3	3.47	2.3	5.7	2/29/00	3/2/00
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	25	4.67	0.1	11.7	4/17/90	3/2/00
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	1	4.30	4.3	4.3	2/29/00	2/29/00
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	22	5.10	1.6	11.7	4/17/90	3/1/00
KR24171	KLAMATH RIVER AT RIVER MILE 242	2	6.40	6.4	6.4	8/17/94	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	13	5.43	2.1	15	9/26/90	3/1/00
KR24589	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	13	5.47	1.4	17	4/17/90	8/17/94
KR24594	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	13	5.50	1.4	17	4/17/90	8/17/94
KR24713	WEYERHAEUSER KLAMATH FALLS /BOX 9	14	43.82	5	156.4	6/1/83	6/1/83
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	18	9.58	1.2	40	9/26/90	8/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	78	4.93	1.4	15	7/7/59	3/29/95
KR24901	KLAMATH RIVER AT HWY 97 BR NE	17	2.90	0.5	7.2	4/7/70	3/28/95
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	14	8.03	2.7	19	9/26/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	9	7.78	2	17	9/26/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	6	3.27	2.9	3.9	8/16/94	8/16/94
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	22	13.35	1.4	46	4/17/90	8/16/94
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	4	3.90	3.5	4.3	8/16/94	8/16/94
KR25200	LAKE EWAUNA BETWEEN STPS	13	9.54	3.6	26	9/26/90	3/29/95
KR25312	LINK RIVER AT MOUTH	287	5.36	0.7	20	5/12/69	3/13/01

Table C-5. Summary of total Kjeldahl nitrogen (TKN) data, Klamath River above Iron Gate Dam (mg/L as N).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19198	IRON GATE RESERVOIR 61102	13	0.98	0.4	1.5	3/27/75	10/31/75
KR19645	COPCO DAM OUTFLOW	12	1.00	0.65	1.35	4/17/96	10/8/97
KR19856	KLAMATH RIVER 0611A2	12	1.37	0.8	2	11/16/74	11/8/75
KR19874	COPCO LAKE NR COPCO	9	1.09	0.8	1.8	6/30/77	9/19/85
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	12	1.10	0.46	2	4/17/96	10/8/97
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	165	1.08	0.3	3.4	1/16/77	3/13/01
KR23193	KLAMATH RIVER NEAR KENO	39	1.57	0.1	7.7	12/6/64	9/29/68
KR23334	KLAMATH RIVER D/S OF KENO DAM	2	1.70	1.5	1.9	3/28/95	3/29/95
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY	326	2.10	0.05	17	2/6/73	3/13/01

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
	66)						
KR23503	KLAMATH R.BLW BIG BEND POWER PL	2	1.23	0.75	1.7	8/1/76	1/16/78
KR23519	KENO ELEMENTARY SCHOOL,KENO	1	0.20	0.2	0.2	11/28/89	11/28/89
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	33	2.51	1	3.9	8/28/90	2/29/00
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	66	2.37	0.9	4.2	4/17/90	3/2/00
KR23973	KLAMATH RIVER D/S GORR IS @ TEETERS LANDING	3	0.87	0.8	1	2/29/00	3/2/00
KR24013	KLAMATH RIVER 1000' D/S KLAMATH STRAIT	4	1.30	1	1.6	8/8/90	8/8/90
KR24047	KLAMATH RIVER 150' D/S KLAMATH STRAIT	4	1.80	1.4	2.2	8/8/90	8/8/90
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	54	2.42	0.8	3.2	4/17/90	3/2/00
KR24057	KLAMATH RIVER 20' U/S KLAMATH STRAIT	2	2.90	2.9	2.9	8/8/90	8/8/90
KR24077	KLAMATH RIVER 1000' U/S KLAMATH STRAIT	3	1.63	1.5	1.7	8/8/90	8/8/90
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	5	2.12	0.9	3.9	8/8/90	2/29/00
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	50	2.28	0.7	5.1	4/17/90	3/1/00
KR24171	KLAMATH RIVER AT RIVER MILE 242	8	1.43	0.9	2	6/13/90	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	44	2.12	0.8	3.6	6/13/90	3/1/00
KR24589	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	37	2.26	0.8	5.1	4/17/90	11/19/97
KR24594	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	34	2.26	0.8	5.1	4/17/90	3/23/98
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	32	2.75	1.9	5.9	8/28/90	8/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	44	2.24	0.8	4	4/17/90	3/29/95
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	70	2.41	0.05	28.7	4/17/73	6/20/01
KR24901	KLAMATH RIVER AT HWY 97 BR NE	23	1.91	0.7	3	4/17/90	3/23/98
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	41	2.13	0.7	4.3	6/12/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	13	2.40	1.1	3.8	6/12/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	31	2.21	0.7	3.4	6/13/90	3/23/98
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	46	2.50	0.7	7.7	4/17/90	8/16/94
KR25149	KLAMATH RIVER 200' D/S S SUBURBAN STP DISCHARGE	2	3.20	3.2	3.2	8/7/90	8/7/90
KR25158	KLAMATH RIVER 100' D/S S SUBURBAN STP DISCHARGE	2	5.80	5.8	5.8	8/7/90	8/7/90
KR25164	KLAMATH RIVER 30' D/S S SUBURBAN STP DISCHARGE	4	2.40	1.6	3.2	8/7/90	8/7/90
KR25166	KLAMATH RIVER 20' D/S S SUBURBAN STP DISCHARGE	1	9.40	9.4	9.4	8/7/90	8/7/90
KR25168	KLAMATH RIVER 10' D/S S SUBURBAN STP DISCHARGE	1	9.40	9.4	9.4	8/7/90	8/7/90
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	28	2.23	0.7	4.1	8/7/90	3/23/98
KR25200	LAKE EWAUNA BETWEEN STPS	43	2.00	0.6	4.7	6/12/90	3/29/95
KR25250	KLAMATH RIVER 120' D/S KLAMATH FALLS STP	4	2.80	2.5	3.1	8/7/90	8/7/90
KR25271	KLAMATH RIVER 100' U/S KLAMATH FALLS STP	2	4.00	4	4	7/12/88	7/12/88
KR25274	KLAMATH RIVER 120' U/S KLAMATH FALLS STP	1	6.00	6	6	8/7/90	8/7/90

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR25278	KLAMATH RIVER 150' U/S KLAMATH FALLS STP	3	2.97	2.9	3	7/12/88	7/12/88
KR25312	LINK RIVER AT MOUTH	306	2.16	0.05	5.6	2/6/73	3/13/01
KR25479	LINK RIVER AT FREMONT ST BRIDGE	4	1.08	0.9	1.3	6/11/90	6/11/90

Table C-6. Summary of total phosphorous (TP) data, Klamath River above Iron Gate Dam (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19198	IRON GATE RESERVOIR 61102	16	0.186	0.096	0.298	3/27/75	10/31/75
KR19621	KLAMATH RIVER BELOW FALL CREEK NEAR COPCO	2	0.115	0.03	0.2	9/3/54	5/12/55
KR19645	COPCO DAM OUTFLOW	12	0.324	0.0735	0.71	4/17/96	10/8/97
KR19856	KLAMATH RIVER 0611A2	12	0.163	0.09	0.23	11/16/74	11/8/75
KR19874	COPCO LAKE NR COPCO	9	0.246	0.1	0.47	6/30/77	9/19/85
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	12	0.342	0.025	1.16	4/17/96	10/8/97
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	165	0.194	0.08	0.5	1/16/77	3/13/01
KR22505	JC BOYLE RESERVOIR AT DEEPEST POINT	8	1.665	0.258	3.3	9/11/81	9/9/84
KR23193	KLAMATH RIVER NEAR KENO	40	0.165	0.04	0.33	12/6/64	9/29/68
KR23334	KLAMATH RIVER D/S OF KENO DAM	2	0.215	0.19	0.24	3/28/95	3/29/95
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	367	0.248	0.09	0.724	2/26/73	3/13/01
KR23503	KLAMATH R.BLW BIG BEND POWER PL	3	0.173	0.141	0.2	6/6/76	1/16/78
KR23519	KENO ELEMENTARY SCHOOL,KENO	1	0.040	0.04	0.04	11/28/89	11/28/89
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	33	0.244	0.13	0.3	8/28/90	2/29/00
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	66	0.294	0.11	0.56	4/17/90	3/2/00
KR23973	KLAMATH RIVER D/S GORR IS @ TEETERS LANDING	3	0.120	0.11	0.13	2/29/00	3/2/00
KR24013	KLAMATH RIVER 1000' D/S KLAMATH STRAIT	4	0.130	0.1	0.16	8/8/90	8/8/90
KR24047	KLAMATH RIVER 150' D/S KLAMATH STRAIT	4	0.225	0.16	0.29	8/8/90	8/8/90
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	54	0.289	0.1	1	4/17/90	3/2/00
KR24057	KLAMATH RIVER 20' U/S KLAMATH STRAIT	2	0.260	0.26	0.26	8/8/90	8/8/90
KR24077	KLAMATH RIVER 1000' U/S KLAMATH STRAIT	3	0.130	0.13	0.13	8/8/90	8/8/90
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	5	0.174	0.08	0.28	8/8/90	2/29/00
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	50	0.230	0.1	0.49	4/17/90	3/1/00
KR24171	KLAMATH RIVER AT RIVER MILE 242	8	0.168	0.16	0.18	6/13/90	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	44	0.203	0.1	0.34	6/13/90	3/1/00
KR24589	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	37	0.226	0.12	0.42	4/17/90	11/19/97
KR24594	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	34	0.226	0.1	0.42	4/17/90	3/23/98
KR24713	WEYERHAEUSER KLAMATH FALLS /BOX 9	4	1.405	0.3	4.405	6/1/83	6/1/83
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	31	0.254	0.2	0.42	8/28/90	8/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	44	0.320	0.12	1.93	4/17/90	3/29/95

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	182	0.231	0.05	1.3	2/26/73	6/20/01
KR24901	KLAMATH RIVER AT HWY 97 BR NE	23	0.187	0.09	0.29	4/17/90	3/23/98
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	41	0.218	0.17	0.34	6/12/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	13	0.230	0.21	0.26	6/12/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	31	0.188	0.08	0.26	6/13/90	3/23/98
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	46	0.237	0.08	0.47	4/17/90	8/16/94
KR25149	KLAMATH RIVER 200' D/S S SUBURBAN STP DISCHARGE	2	0.740	0.74	0.74	8/7/90	8/7/90
KR25158	KLAMATH RIVER 100' D/S S SUBURBAN STP DISCHARGE	2	1.800	1.8	1.8	8/7/90	8/7/90
KR25164	KLAMATH RIVER 30' D/S S SUBURBAN STP DISCHARGE	4	0.550	0.52	0.58	8/7/90	8/7/90
KR25166	KLAMATH RIVER 20' D/S S SUBURBAN STP DISCHARGE	1	3.400	3.4	3.4	8/7/90	8/7/90
KR25168	KLAMATH RIVER 10' D/S S SUBURBAN STP DISCHARGE	1	3.400	3.4	3.4	8/7/90	8/7/90
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	28	0.189	0.07	0.28	8/7/90	3/23/98
KR25200	LAKE EWAUNA BETWEEN STPS	43	0.173	0.01	0.3	6/12/90	3/29/95
KR25250	KLAMATH RIVER 120' D/S KLAMATH FALLS STP	4	0.535	0.1	0.97	8/7/90	8/7/90
KR25263	KLAMATH RIVER 50' U/S KLAMATH FALLS STP	2	3.200	3.2	3.2	8/7/90	8/7/90
KR25271	KLAMATH RIVER 100' U/S KLAMATH FALLS STP	2	2.100	2.1	2.1	7/12/88	7/12/88
KR25274	KLAMATH RIVER 120' U/S KLAMATH FALLS STP	1	3.000	3	3	8/7/90	8/7/90
KR25278	KLAMATH RIVER 150' U/S KLAMATH FALLS STP	3	0.990	0.97	1	7/12/88	7/12/88
KR25312	LINK RIVER AT MOUTH	305	0.170	0.036	0.516	6/6/76	3/13/01
KR25479	LINK RIVER AT FREMONT ST BRIDGE	68	0.085	0.019	0.322	6/11/90	5/15/00

Table C-7. Summary of dissolved orthophosphate data, Klamath River above Iron Gate Dam (mg/L as P).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19198	IRON GATE RESERVOIR 61102	16	0.128	0.066	0.278	3/27/75	10/31/75
KR19621	KLAMATH RIVER BELOW FALL CREEK NEAR COPCO	6	0.158	0.05	0.24	5/17/59	9/11/61
KR19856	KLAMATH RIVER 0611A2	12	0.123	0.055	0.185	11/16/74	11/8/75
KR19874	COPCO LAKE NR COPCO	9	0.171	0.06	0.44	6/30/77	9/19/85
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	165	0.113	0.014	0.244	1/16/77	3/13/01
KR22505	JC BOYLE RESERVOIR AT DEEPEST POINT	12	1.383	0.6	2.4	4/16/84	9/9/84
KR23334	KLAMATH RIVER D/S OF KENO DAM	2	0.009	0.009	0.009	3/28/95	3/29/95
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	351	0.134	0.008	1.01	2/26/73	3/13/01
KR23503	KLAMATH R.BLW BIG BEND POWER PL	2	0.150	0.14	0.16	6/6/76	8/1/76
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	33	0.125	0.023	0.173	8/28/90	2/29/00
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	60	0.152	0.011	0.292	6/13/90	3/2/00
KR23973	KLAMATH RIVER D/S GORR IS @ TEETERS LANDING	3	0.019	0.016	0.023	2/29/00	3/2/00

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR24013	KLAMATH RIVER 1000' D/S KLAMATH STRAIT	4	0.069	0.067	0.071	8/8/90	8/8/90
KR24047	KLAMATH RIVER 150' D/S KLAMATH STRAIT	4	0.219	0.193	0.245	8/8/90	8/8/90
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	48	0.147	0.015	0.326	6/13/90	3/2/00
KR24057	KLAMATH RIVER 20' U/S KLAMATH STRAIT	2	0.056	0.056	0.056	8/8/90	8/8/90
KR24077	KLAMATH RIVER 1000' U/S KLAMATH STRAIT	3	0.045	0.044	0.045	8/8/90	8/8/90
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	5	0.044	0.017	0.051	8/8/90	2/29/00
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	48	0.096	0.003	0.247	6/13/90	3/1/00
KR24171	KLAMATH RIVER AT RIVER MILE 242	8	0.056	0.002	0.094	6/13/90	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	45	0.096	0.001	0.142	6/13/90	3/1/00
KR24589	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	27	0.102	0.006	0.168	6/12/90	4/8/97
KR24594	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	25	0.101	0.006	0.168	6/12/90	4/8/97
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	32	0.106	0.015	0.2	8/28/90	8/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	38	0.106	0.005	0.157	6/12/90	3/29/95
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	133	0.128	0.04	0.57	2/26/73	6/20/01
KR24901	KLAMATH RIVER AT HWY 97 BR NE	7	0.018	0.008	0.022	8/16/94	4/8/97
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	41	0.093	0.006	0.123	6/12/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	12	0.093	0.012	0.149	6/12/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	16	0.038	0.007	0.079	6/13/90	4/8/97
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	44	0.091	0.006	0.236	6/12/90	8/16/94
KR25141	KLAMATH RIVER 300' D/S S SUBURBAN STP DISCHARGE	2	0.165	0.165	0.165	8/7/90	8/7/90
KR25149	KLAMATH RIVER 200' D/S S SUBURBAN STP DISCHARGE	2	0.310	0.31	0.31	8/7/90	8/7/90
KR25158	KLAMATH RIVER 100' D/S S SUBURBAN STP DISCHARGE	2	1.290	1.29	1.29	8/7/90	8/7/90
KR25164	KLAMATH RIVER 30' D/S S SUBURBAN STP DISCHARGE	4	0.473	0.411	0.535	8/7/90	8/7/90
KR25166	KLAMATH RIVER 20' D/S S SUBURBAN STP DISCHARGE	1	2.960	2.96	2.96	8/7/90	8/7/90
KR25168	KLAMATH RIVER 10' D/S S SUBURBAN STP DISCHARGE	1	2.960	2.96	2.96	8/7/90	8/7/90
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	10	0.065	0.008	0.15	8/7/90	4/8/97
KR25200	LAKE EWAUNA BETWEEN STPS	43	0.059	0.005	0.15	6/12/90	3/29/95
KR25250	KLAMATH RIVER 120' D/S KLAMATH FALLS STP	4	0.453	0.067	0.839	8/7/90	8/7/90
KR25271	KLAMATH RIVER 100' U/S KLAMATH FALLS STP	2	1.260	1.26	1.26	7/12/88	7/12/88
KR25274	KLAMATH RIVER 120' U/S KLAMATH FALLS STP	1	2.860	2.86	2.86	8/7/90	8/7/90
KR25278	KLAMATH RIVER 150' U/S KLAMATH FALLS STP	3	0.970	0.97	0.97	7/12/88	7/12/88
KR25312	LINK RIVER AT MOUTH	270	0.039	0.003	0.342	6/6/76	3/13/01
KR25479	LINK RIVER AT FREMONT ST BRIDGE	60	0.019	0.003	0.083	6/11/90	5/15/00

Table C-8. Summary of total nitrate nitrogen data, Klamath River above Iron Gate Dam (mg/L as N).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19856	KLAMATH RIVER 0611A2	2	0.148	0.04	0.256	11/16/74	12/7/74
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	102	0.273	0.01	6.2	7/7/59	9/10/79
KR22505	JC BOYLE RESERVOIR AT DEEPEST POINT	24	1.801	0.04	6.8	4/16/84	9/9/84
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	190	0.182	0.01	8.5	7/7/59	9/16/82
KR23503	KLAMATH R.BLW BIG BEND POWER PL	13	0.131	0.02	0.34	10/5/75	1/16/78
KR24894	KLAMATH RIVER AT HWY 97 BR SE	50	0.170	0.03	0.56	7/7/59	7/1/75
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	133	0.338	0.01	15	5/16/72	6/20/01
KR24901	KLAMATH RIVER AT HWY 97 BR NE	10	0.192	0.05	0.56	4/7/70	11/26/74
KR25312	LINK RIVER AT MOUTH	102	0.052	0.02	0.3	5/12/69	9/16/82
KR25479	LINK RIVER AT FREMONT ST BRIDGE	59	0.047	0.005	0.27	5/10/94	5/15/00

Table C-9. Summary of dissolved nitrate nitrogen data, Klamath River above Iron Gate Dam (mg/L as N).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19198	IRON GATE RESERVOIR 61102	12	0.383	0.02	0.58	3/27/75	10/31/75
KR19621	KLAMATH RIVER BELOW FALL CREEK NEAR COPCO	25	2.588	1.1	5.4	5/7/51	9/11/61
KR19645	COPCO DAM OUTFLOW	12	0.279	0.04	0.55	4/17/96	10/8/97
KR19856	KLAMATH RIVER 0611A2	12	0.395	0.05	0.77	11/16/74	11/8/75
KR19874	COPCO LAKE NR COPCO	3	0.560	0.3	0.7	5/21/85	9/19/85
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	12	0.370	0.04	0.8	4/17/96	10/8/97
KR21970	KLAMATH R BL JOHN C BOYLE PP NR KENO,OREG.	8	1.088	0.2	1.9	9/12/61	6/12/63
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	178	0.423	0.02	2.3	2/17/76	3/13/01
KR23193	KLAMATH RIVER NEAR KENO	42	1.437	0.1	21	12/12/61	9/29/68
KR23334	KLAMATH RIVER D/S OF KENO DAM	2	0.080	0.07	0.09	3/28/95	3/29/95
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	356	0.126	0.01	0.86	5/16/72	3/13/01
KR23503	KLAMATH R.BLW BIG BEND POWER PL	6	0.297	0.11	0.93	4/4/76	1/16/78
KR23519	KENO ELEMENTARY SCHOOL,KENO	1	2.400	2.4	2.4	11/28/89	11/28/89
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	32	0.045	0.02	0.283	8/28/90	2/29/00
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	66	0.103	0.02	0.33	4/17/90	3/2/00
KR23973	KLAMATH RIVER D/S GORR IS @ TEETERS LANDING	3	0.230	0.202	0.248	2/29/00	3/2/00
KR24013	KLAMATH RIVER 1000' D/S KLAMATH STRAIT	4	0.020	0.02	0.02	8/8/90	8/8/90
KR24047	KLAMATH RIVER 150' D/S KLAMATH STRAIT	4	0.030	0.02	0.04	8/8/90	8/8/90
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	53	0.065	0.02	0.34	4/17/90	3/2/00
KR24057	KLAMATH RIVER 20' U/S KLAMATH STRAIT	2	0.020	0.02	0.02	8/8/90	8/8/90
KR24077	KLAMATH RIVER 1000' U/S KLAMATH STRAIT	3	0.020	0.02	0.02	8/8/90	8/8/90
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	5	0.056	0.02	0.202	8/8/90	2/29/00
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	49	0.054	0.02	0.32	4/17/90	3/1/00
KR24171	KLAMATH RIVER AT RIVER MILE 242	8	0.020	0.02	0.02	6/13/90	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL	43	0.033	0.02	0.246	6/13/90	3/1/00

	(MIDLAND)						
KR24589	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	38	0.046	0.02	0.25	4/17/90	11/19/97
KR24594	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	35	0.049	0.02	0.25	4/17/90	3/23/98
KR24713	WEYERHAEUSER KLAMATH FALLS /BOX 9	2	0.660	0.57	0.75	6/1/83	6/1/83
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	32	0.032	0.02	0.06	8/28/90	8/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	44	0.059	0.02	0.12	4/17/90	3/29/95
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	103	0.207	0.01	1.04	5/16/72	8/25/93
KR24901	KLAMATH RIVER AT HWY 97 BR NE	31	0.299	0.02	2.5	10/12/60	3/23/98
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	41	0.068	0.02	0.16	6/12/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	13	0.058	0.03	0.12	6/12/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	33	0.068	0.02	0.23	6/13/90	3/23/98
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	46	0.067	0.02	0.2	4/17/90	8/16/94
KR25149	KLAMATH RIVER 200' D/S S SUBURBAN STP DISCHARGE	2	0.190	0.19	0.19	8/7/90	8/7/90
KR25158	KLAMATH RIVER 100' D/S S SUBURBAN STP DISCHARGE	2	0.170	0.17	0.17	8/7/90	8/7/90
KR25164	KLAMATH RIVER 30' D/S S SUBURBAN STP DISCHARGE	4	0.185	0.16	0.21	8/7/90	8/7/90
KR25166	KLAMATH RIVER 20' D/S S SUBURBAN STP DISCHARGE	1	0.100	0.1	0.1	8/7/90	8/7/90
KR25168	KLAMATH RIVER 10' D/S S SUBURBAN STP DISCHARGE	1	0.100	0.1	0.1	8/7/90	8/7/90
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	30	0.101	0.02	0.32	8/7/90	3/23/98
KR25200	LAKE EWAUNA BETWEEN STPS	43	0.054	0.02	0.16	6/12/90	3/29/95
KR25250	KLAMATH RIVER 120' D/S KLAMATH FALLS STP	4	0.280	0.04	0.52	8/7/90	8/7/90
KR25271	KLAMATH RIVER 100' U/S KLAMATH FALLS STP	2	2.500	2.5	2.5	7/12/88	7/12/88
KR25274	KLAMATH RIVER 120' U/S KLAMATH FALLS STP	1	2.500	2.5	2.5	8/7/90	8/7/90
KR25278	KLAMATH RIVER 150' U/S KLAMATH FALLS STP	3	1.167	1.1	1.2	7/12/88	7/12/88
KR25312	LINK RIVER AT MOUTH	319	0.101	0.005	0.76	2/6/74	3/13/01
KR25479	LINK RIVER AT FREMONT ST BRIDGE	4	0.038	0.02	0.06	6/11/90	6/11/90

Table C-10. Summary of total ammonia nitrogen data, Klamath River above Iron Gate Dam (mg/L as N).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19198	IRON GATE RESERVOIR 61102	12	0.153	0.03	0.22	3/27/75	10/31/75
KR19645	COPCO DAM OUTFLOW	12	0.155	0.025	0.29	4/17/96	10/8/97
KR19856	KLAMATH RIVER 0611A2	12	0.231	0.045	0.59	11/16/74	11/8/75
KR19874	COPCO LAKE NR COPCO	5	0.190	0.03	0.69	9/22/77	5/11/78
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	12	0.166	0.025	0.42	4/17/96	10/8/97
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	165	0.321	0.01	4.3	7/7/59	9/15/97
KR23334	KLAMATH RIVER D/S OF KENO DAM	2	0.050	0.05	0.05	3/28/95	3/29/95
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	299	0.573	0.01	3.75	7/7/59	9/15/97
KR23503	KLAMATH R.BLW BIG BEND POWER PL	13	0.359	0.04	1.14	10/5/75	1/16/78
KR23519	KENO ELEMENTARY SCHOOL,KENO	1	0.020	0.02	0.02	11/28/89	11/28/89
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF	17	0.585	0.04	1.03	8/28/90	8/17/94

	HILL 4315						
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	34	0.373	0.03	0.97	4/17/90	3/29/95
KR24013	KLAMATH RIVER 1000' D/S KLAMATH STRAIT	2	0.125	0.11	0.14	8/8/90	8/8/90
KR24047	KLAMATH RIVER 150' D/S KLAMATH STRAIT	2	0.220	0.21	0.23	8/8/90	8/8/90
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	27	0.433	0.05	1.37	4/17/90	8/17/94
KR24057	KLAMATH RIVER 20' U/S KLAMATH STRAIT	1	0.100	0.1	0.1	8/8/90	8/8/90
KR24077	KLAMATH RIVER 1000' U/S KLAMATH STRAIT	2	0.050	0.05	0.05	8/8/90	8/8/90
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	2	0.040	0.04	0.04	8/8/90	8/8/90
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	26	0.344	0.03	1.09	4/17/90	3/29/95
KR24171	KLAMATH RIVER AT RIVER MILE 242	4	0.045	0.03	0.05	6/13/90	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	22	0.369	0.02	0.98	6/13/90	8/17/94
KR24589	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	38	0.500	0.04	1.01	4/17/90	11/19/97
KR24713	WEYERHAEUSER KLAMATH FALLS /BOX 9	6	6.588	0.59	17.621	6/1/83	6/1/83
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	17	0.572	0.07	1.05	8/28/90	8/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	76	0.727	0.01	4.15	7/7/59	3/29/95
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	111	0.468	0.01	1.7	5/16/72	8/25/93
KR24901	KLAMATH RIVER AT HWY 97 BR NE	23	0.426	0.04	1.38	4/7/70	11/19/97
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	22	0.245	0.08	0.66	6/12/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	7	0.313	0.08	0.51	6/12/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	16	0.321	0.06	1	6/13/90	11/19/97
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	23	0.222	0.08	0.41	4/17/90	8/16/94
KR25149	KLAMATH RIVER 200' D/S S SUBURBAN STP DISCHARGE	1	0.900	0.9	0.9	8/7/90	8/7/90
KR25158	KLAMATH RIVER 100' D/S S SUBURBAN STP DISCHARGE	1	2.700	2.7	2.7	8/7/90	8/7/90
KR25164	KLAMATH RIVER 30' D/S S SUBURBAN STP DISCHARGE	2	0.785	0.74	0.83	8/7/90	8/7/90
KR25168	KLAMATH RIVER 10' D/S S SUBURBAN STP DISCHARGE	1	4.800	4.8	4.8	8/7/90	8/7/90
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	15	0.301	0.03	1	8/7/90	11/19/97
KR25200	LAKE EWAUNA BETWEEN STPS	25	0.175	0.02	0.33	6/12/90	3/29/95
KR25250	KLAMATH RIVER 120' D/S KLAMATH FALLS STP	2	0.895	0.19	1.6	8/7/90	8/7/90
KR25271	KLAMATH RIVER 100' U/S KLAMATH FALLS STP	1	1.600	1.6	1.6	7/12/88	7/12/88
KR25274	KLAMATH RIVER 120' U/S KLAMATH FALLS STP	1	4.300	4.3	4.3	8/7/90	8/7/90
KR25278	KLAMATH RIVER 150' U/S KLAMATH FALLS STP	2	0.910	0.88	0.94	7/12/88	7/12/88
KR25312	LINK RIVER AT MOUTH	217	0.345	0.01	18	5/12/69	11/19/97

Table C-11. Summary of dissolved ammonia nitrogen data, Klamath River above Iron Gate Dam (mg/L as N).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19645	COPCO DAM OUTFLOW	12	0.157	0.025	0.23	4/17/96	10/8/97

KR19874	COPCO LAKE NR COPCO	2	0.510	0.33	0.69	5/21/85	9/19/85
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	12	0.100	0.025	0.17	4/17/96	10/8/97

Table C-12. Summary of ammonia nitrogen data, Klamath River above Iron Gate Dam (?).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR22505	JC BOYLE RESERVOIR AT DEEPEST POINT	12	1.342	0.3	3.5	4/16/84	9/9/84
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	36	0.484	0.05	3.36	5/21/91	6/20/01
KR25479	LINK RIVER AT FREMONT ST BRIDGE	61	0.158	0.005	1.02	5/10/94	5/15/00

Table C-13. Summary of dissolved oxygen (DO) data, Klamath River above Iron Gate Dam (mg/L).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19198	IRON GATE RESERVOIR 61102	11	7.32	1.4	11.4	3/27/75	10/31/75
KR19621	KLAMATH RIVER BELOW FALL CREEK NEAR COPCO	15	7.19	4.7	9	10/10/52	9/11/61
KR19645	COPCO DAM OUTFLOW	35	8.11	5.6	10.2	4/5/96	10/8/97
KR19874	COPCO LAKE NR COPCO	16	5.89	0	12	8/8/73	9/19/85
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	36	9.46	8.2	10.8	4/5/96	10/8/97
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	243	9.43	3.4	12.8	7/7/59	3/13/01
KR22505	JC BOYLE RESERVOIR AT DEEPEST POINT	12	8.09	1.8	12.2	4/16/84	9/9/84
KR23193	KLAMATH RIVER NEAR KENO	81	9.55	4.5	14	4/5/61	8/4/68
KR23334	KLAMATH RIVER D/S OF KENO DAM	2	10.95	10.6	11.3	3/28/95	3/29/95
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	2024	7.58	0.3	22	7/7/59	3/13/01
KR23503	KLAMATH R.BLW BIG BEND POWER PL	45	9.91	7	15	10/5/75	6/13/78
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	49	4.45	0.1	13	8/28/90	2/29/00
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	269	7.25	0	18.5	4/17/90	3/2/00
KR23973	KLAMATH RIVER D/S GORR IS @ TEETERS LANDING	3	10.50	10.3	10.6	2/29/00	3/2/00
KR24013	KLAMATH RIVER 1000' D/S KLAMATH STRAIT	4	9.00	8.2	9.8	8/8/90	8/8/90
KR24047	KLAMATH RIVER 150' D/S KLAMATH STRAIT	4	8.35	7.2	9.5	8/8/90	8/8/90
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	69	6.78	0.1	15.8	4/17/90	3/2/00
KR24057	KLAMATH RIVER 20' U/S KLAMATH STRAIT	2	13.60	13.6	13.6	8/8/90	8/8/90
KR24077	KLAMATH RIVER 1000' U/S KLAMATH STRAIT	3	13.20	13.2	13.2	8/8/90	8/8/90
KR24099	KLAMATH RIVER 1500' U/S KLAMATH STRAIT	4	13.28	9.6	22.7	8/8/90	2/29/00
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	523	9.48	0.3	19.1	4/17/90	3/1/00
KR24171	KLAMATH RIVER AT RIVER MILE 242	8	8.90	6.4	11.4	6/13/90	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	239	8.07	1.4	16.5	6/13/90	3/1/00
KR24589	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	43	4.06	0.2	10.2	4/17/90	11/19/97
KR24594	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	46	4.83	0.2	14	4/17/90	3/23/98
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	54	3.19	0.1	17	8/28/90	8/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	904	2.15	0	13	7/7/59	3/29/95

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR24898	KLAMATH RIVER AT HWY 97 BRIDGE	208	7.79	0.6	16.4	5/16/72	6/20/01
KR24901	KLAMATH RIVER AT HWY 97 BR NE	36	5.74	0.5	13	4/7/70	3/23/98
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	572	6.60	2	13.9	6/12/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	13	6.55	4.2	9.1	6/12/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	831	9.03	2.3	19.9	6/11/90	3/23/98
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	57	7.19	3.3	19.1	4/17/90	8/16/94
KR25149	KLAMATH RIVER 200' D/S S SUBURBAN STP DISCHARGE	2	8.90	8.9	8.9	8/7/90	8/7/90
KR25158	KLAMATH RIVER 100' D/S S SUBURBAN STP DISCHARGE	2	8.20	8.2	8.2	8/7/90	8/7/90
KR25164	KLAMATH RIVER 30' D/S S SUBURBAN STP DISCHARGE	4	6.90	6.7	7.1	8/7/90	8/7/90
KR25166	KLAMATH RIVER 20' D/S S SUBURBAN STP DISCHARGE	1	5.20	5.2	5.2	8/7/90	8/7/90
KR25168	KLAMATH RIVER 10' D/S S SUBURBAN STP DISCHARGE	1	5.20	5.2	5.2	8/7/90	8/7/90
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	26	6.55	2.4	13.3	8/7/90	3/23/98
KR25200	421310121472001	1	5.40	5.4	5.4	8/22/88	8/22/88
KR25200	LAKE EWAUNA BETWEEN STPS	860	6.78	2.4	13	6/12/90	3/29/95
KR25250	KLAMATH RIVER 120' D/S KLAMATH FALLS STP	4	7.50	5.6	9.4	8/7/90	8/7/90
KR25271	KLAMATH RIVER 100' U/S KLAMATH FALLS STP	2	5.90	5.9	5.9	7/12/88	7/12/88
KR25274	KLAMATH RIVER 120' U/S KLAMATH FALLS STP	1	5.50	5.5	5.5	8/7/90	8/7/90
KR25278	KLAMATH RIVER 150' U/S KLAMATH FALLS STP	3	5.73	5.6	6	7/12/88	7/12/88
KR25312	LINK RIVER AT MOUTH	376	9.27	5.5	16	5/12/69	3/13/01
KR25344	421404121480101	46	7.03	3.3	13.8	6/3/92	9/9/92
KR25479	LINK RIVER AT FREMONT ST BRIDGE	29	9.47	5.37	12.77	6/11/90	4/7/98

Table C-14. Summary of chlorophyll a data, Klamath River above Iron Gate Dam (?).

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR19645	COPCO DAM OUTFLOW	11	6.2	1.9	11	4/17/96	10/8/97
KR20642	KLAMATH RIVER U/S SHOVEL CREEK	11	7.2	1.6	24	4/17/96	10/8/97
KR22127	KLAMATH RIVER D/S OF BIG BEND POWERHOUSE	36	6.5	0.1	40	6/18/86	7/19/00
KR22505	JC BOYLE RESERVOIR AT DEEPEST POINT	6	5.6	1.4	9	4/16/84	9/9/84
KR23490	KLAMATH RIVER AT KENO BRIDGE (HWY 66)	74	24.1	0.1	160	6/23/80	7/19/00
KR23828	KLAMATH RIVER DIRECTLY SOUTH OF HILL 4315	8	26.7	3.1	64	8/28/90	8/17/94
KR23932	KLAMATH RIVER AT POWERLINE CROSSING (D/S STRAIT)	18	29.0	0.2	100	6/13/90	8/17/94
KR24050	KLAMATH RIVER AT EAST SIDE OF GORR ISLAND	15	34.3	0.2	150	6/13/90	8/17/94
KR24148	KLAMATH RIVER U/S OF KLAMATH STRAIT	14	35.4	0.1	150	6/13/90	8/17/94
KR24171	KLAMATH RIVER AT RIVER MILE 242	4	16.6	0.1	63	6/13/90	8/17/94
KR24408	KLAMATH RIVER D/S OF NORTH CANAL (MIDLAND)	15	20.9	0.1	110	6/13/90	8/17/94
KR24594	KLAMATH RIVER AT MILLER ISLAND BOAT RAMP	21	36.5	0.3	240	6/12/90	10/22/97

Site ID	Site Name	Count	Average	Min	Max	Min Date	Max Date
KR24781	KLAMATH RIVER AT WEYERHAEUSER MILL SMOKESTACK	9	78.7	11	320	8/28/90	8/16/94
KR24894	KLAMATH RIVER AT HWY 97 BR SE	13	25.6	0.1	92	6/12/90	8/16/94
KR24901	KLAMATH RIVER AT HWY 97 BR NE	7	18.3	7.4	42	8/16/94	10/22/97
KR25015	KLAMATH RIVER AT SOUTH END OF DOG POUND ISLAND	13	31.8	0.1	140	6/12/90	8/16/94
KR25066	KLAMATH RIVER AT NORTH END OF DOG POUND ISLAND	5	53.5	1.5	130	6/12/90	8/16/94
KR25079	KLAMATH RIVER AT SOUTH-SIDE BYPASS BRIDGE	12	29.3	0.1	84	6/13/90	10/22/97
KR25127	KLAMATH RIVER AT KLAD RADIO TOWER	14	65.9	0.9	160	6/12/90	8/16/94
KR25173	LAKE EWAUNA AT RAILROAD BRIDGE DRAWSPAN	6	26.7	7.4	59	8/16/94	10/22/97
KR25200	LAKE EWAUNA BETWEEN STPS	13	23.6	0.1	110	6/12/90	8/21/91
KR25312	LINK RIVER AT MOUTH	76	48.5	0.1	440	5/19/80	7/19/00
KR25479	LINK RIVER AT FREMONT ST BRIDGE	41	67.5	3.7	299	6/11/90	2/18/97

APPENDIX D: Lost River Model Configuration and Model Review

A preliminary evaluation of existing data and data needs was conducted to support TMDL model development for the Lost River. It was focused on the availability and needs for water quality and quantity data in the Lost River (primarily from Malone Dam to Tule Lake, although Tule Lake, Tule Lake Sump, Lower Klamath Lake, and Klamath Straits Drain will also be included in the modeling effort) and water entering the Klamath Project. Overall, the evaluation of data compiled to date identified substantial data/information gaps. Many of these gaps may be easily filled with existing data that have simply not yet been accessed. The rest of the data gaps may be filled with future data collection and/or estimations based on surrogate data sets.

Flow data are available at the following locations: downstream of Malone Dam, Keller Bridge, and downstream of Harpold Dam for the Lost River, as well as within the Lost River Diversion Channel. In order to develop the Lost River model, flow data for incoming tributaries, pumping records, canals, and irrigation returns are needed. The summary of data needs for each segment is presented in tabular format on the following pages (after presentation of the critical model inputs that will be represented in the proposed or alternative modeling frameworks). The locations discussed in the tables are presented graphically on a modified version of a figure obtained from Woods and Orlob, 1963. Water quality data (nutrients, temperature, DO, etc.) are also needed for the water entering into the Lost River through canals, tributaries, and irrigation drains. Due to the presence of a large number of hydraulic structures, the Lost River system likely exhibits organic enrichment and oxygen depletion related to sediment diagenesis. However, there is currently no information to understand these in-stream processes. More detailed data for water quality are essential to successfully developing a model of the Lost River system.

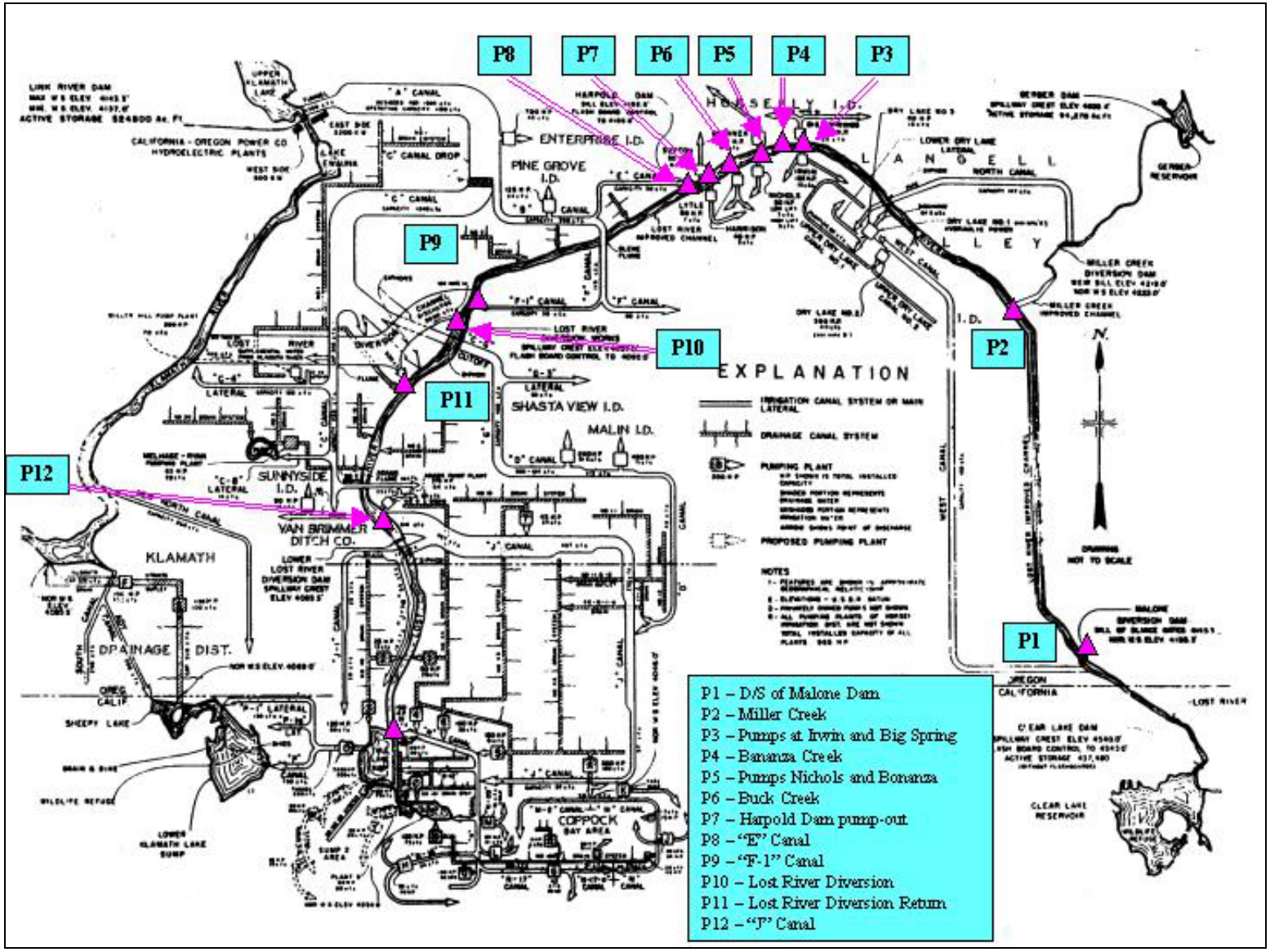
Lost River Major Sources and Sink for Modeling		
Model Component	**ID**	**Source/Sink**
Lost River Main Channel	1	Inflow at Malone Dam
Lost River Main Channel	2	Miller Creek
Lost River Main Channel	3	Irwin and Big Springs pumps
Lost River Main Channel	4	Bonanza creek
Lost River Main Channel	5	Nichols and Bonanza pumps
Lost River Main Channel	6	Buck Creek
Lost River Main Channel	7	Harpold dam pump-out (including Sutton, Lytle, and Harrison pumps)
Lost River Main Channel	8	"E" canal inflow
Lost River Main Channel	9	"F-1" canal inflow
Lost River Main Channel	10	Lost River diversion outflow to Klamath River
Lost River Main Channel	11	Lost River diversion inflow from Klamath River
Lost River Main Channel	12	"J" canal irrigation flow
Lost River Main Channel	13	Return flows from irrigation (number and locations unidentified yet)
Lost River Main Channel	14	Boundary condition at Tule Lake
Tule Lake	1	Inflow from Lost River
Tule Lake	2	Return flows from irrigation
Tule Lake	3	Pump-out flow at Sump
"P" canal	1	Inflow from Tule Lake
"P" canal	2	Outflow at Lower Klamath Lake
Lower Klamath Lake	1	Inflow from "P" canal
Lower Klamath Lake	2	irrigation return flow
Lower Klamath Lake	3	Inflow from ADY canal
Lower Klamath Lake	4	Pump-out flow from pumps E and F
Lower Klamath Lake	5	Flows from Cottonwood, Sheepy, and Willow Creeks
Klamath Straits Drains	1	Return flow from irrigation land
Klamath Straits Drains	2	Flow pumped from Lower Klamath Lake
Klamath Straits Drains	3	Flow discharge back to Klamath River (Ewauna Reservoir)

Segment	Location		Flow Data	Water Quality Data			Discussion on Data Requirements
	Description	Points		DO	Temperature	Nutrients	
1	From Malone Dam to Miller Creek Influence	P1 - P2	Flow Data is available d/s of Malone Dam. Data appears to reflect flow control by Malone Dam. Median flow is high in March and steadily decreases till the beginning of winter. In the winter, median flow is very low till the end when the flow increases rapidly. Mean and Median flows vary substantially from winter to early summer.	High DO in Winter and LOW DO in Summer. In general, the segment meets the DO standard.	No abnormal trend.	No data available.	• Need data on nutrients in the segment • Need data on quality and quantity of water entering the Malone Dam (Baseline information or Background data) • Flow data needs clarification on standing water vs running water
2	From Miller Creek Influence to Pumps Irwin and Big Spring	P2 - P3	Flow Data is available at Keller Bridge. Median Flow is low in winter and high in summer. Large difference between mean and median in late winter and spring flow indicates that during these periods flow may have been primarily influenced by natural extreme events or dam releases. During these periods the flow is slightly higher than that of Malone dam. The difference is due to the flow from Miller creek. However, in the summer, the flow is about 5 - 10 higher than that of Malone dam. It indicates a substantial return of irrigation flow at this location.	High DO in Winter and LOW DO in Summer. In general, the segment meets the DO standard.	No abnormal trend.	Overall nutrient data indicate high values in August and low values in May.	• Need data on quantity and quality entering Lost River from Miller Creek, and irrigation returns fed by North and West Canals
3	From Pumps Irwin and Big Spring to Bonanza Creek	P3 - P4	No Data	No Data	No Data	No Data	• Need data on quantity of water pumped by Irwin and Big Spring pumps • In-stream water quality and quantity in the segment

4	From Bonanza Creek to Pumps Nichols and Bonanza	P4 - P5	No Data	No Data	No Data	No Data	• Need data on quantity and quality entering Lost River from Bonanza Creek • In-stream water quality and quantity in the segment
5	From Pumps Nichols and Bonanza to Buck Creek	P5 - P6	No Data	High DO in Winter and LOW DO in Summer. In general, the segment meets the DO standard.	No abnormal trend.	Overall nutrient data indicate high values in August and low values in May.	• Need data on quantity and quality entering Lost River from Buck Creek • Need data on quantity of water pumped by Nichols and Bonanza pumps • Need data on quantity and quality on return flows (irrigation returns) • In-stream water flow in the segment (It could be estimated through water balance if the rest were known.)
6	From Buck Creek to Harpold Dam	P6 - P7	No Data	High DO in Winter and LOW DO in Summer. In general, the segment meets the DO standard.	No abnormal trend.	This segment has two sites, Harpold dam and Harpold dam bridge. In Harpold dam, the observations were similar to other upstream sites that are high in August and low in May. At Harpold dam bridge, low nutrient values were observed in May, but the highs were observed in December.	• Need data on quantity of water pumped by Harpold Dam pump • Need data on quantity and quality on return flows (irrigation returns) • In-stream water flow in the segment (It could be estimated through water balance if the rest were known)
7	From Harpold Dam to E Canal	P7 - P8	Flow data is available d/s of the Harplod dam. The data indicates high flow in summer and low flow in winter. Overall flow is gained at this location compared to the u/s flow data.	No Data	No Data	No Data	• Need data on quantity and quality entering Lost River from E canal • Need data on quantity and quality on return flows (irrigation returns)

							• In-stream water quality in the segment
8	From E Canal to F-1 Canal	P8 - P9	No Data	High DO in Winter and LOW DO in Summer. In summer, the segment fails to meet the DO standard.	No abnormal trend.	This segment has two sites, at Olene Gap and Wilson Reservoir at Crystal Spring Road. At Wilson Reservoir site, the minimum value was observed in February and Maximum was observed in August. But at the Olene Gap, minimum was in June and maximum in December.	• Need data on quantity and quality entering Lost River from F1 canal • Need data on quantity and quality on return flows (irrigation returns) • In-stream water flow in the segment (It could be estimated through water balance if the rest were known)
9	From F-1 Canal to LR Diversion Dam	P9 - P10	No Data on Lost River flow. Data available on flow through diversion channel.	No Data on in-stream DO. However, WQ at station 48 indicates the flow entering Lost River through station 48 has low DO in summer and high in winter. In general, it meets the DO standard.	No abnormal trend.	No Data	• In-stream water flow in the segment (It could be estimated through water balance if the rest were known) • Need data on nutrients in the segment
10	From LR Diversion Dam to Klamath Return point	P10 - P11	No Data on Lost River flow. Data available to estimate the flow from Klamath.	High DO in Winter and LOW DO in Summer. In general, the segment meets the DO standard.	No abnormal trend.	Overall nutrient data indicate high values in September and low values in May.	• In-stream water flow in the segment (It could be estimated through water balance if the rest were know.)

11	From Klamath Return point to J Canal	P11 - P12	No Data	High DO in Winter and Low DO in Summer. DO values decrease along the LS from u/s to d/s within this segment. D/S sites fail to meet the standard.	Though the temperature follows the seasonal pattern, large error bars were observed at many sites in November. Also the observations substantially vary among the sites.	The nutrient observations vary substantially among the sites in the segment.	• Need data on quantity and quality entering Lost River from VAN BRIMMER DITCH CO. • Need data on quantity of water pumped by ADAMS PUMP PLANT and water transported by J Canal • Need data on quantity and quality on return flows (irrigation returns) • In-stream water flow in the segment (It could be estimated through water balance if the rest were known)
12	From J Canal to Tule Lake	P12 - Tule Lake	No Data	High DO in Winter and LOW DO in Summer. In general, the segment meets the DO standard.	No abnormal trend.	The nutrient observations vary substantially among the sites in the segment.	• Need data on quantity and quality on return flows (irrigation returns) • In-stream water flow in the segment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P7
P6
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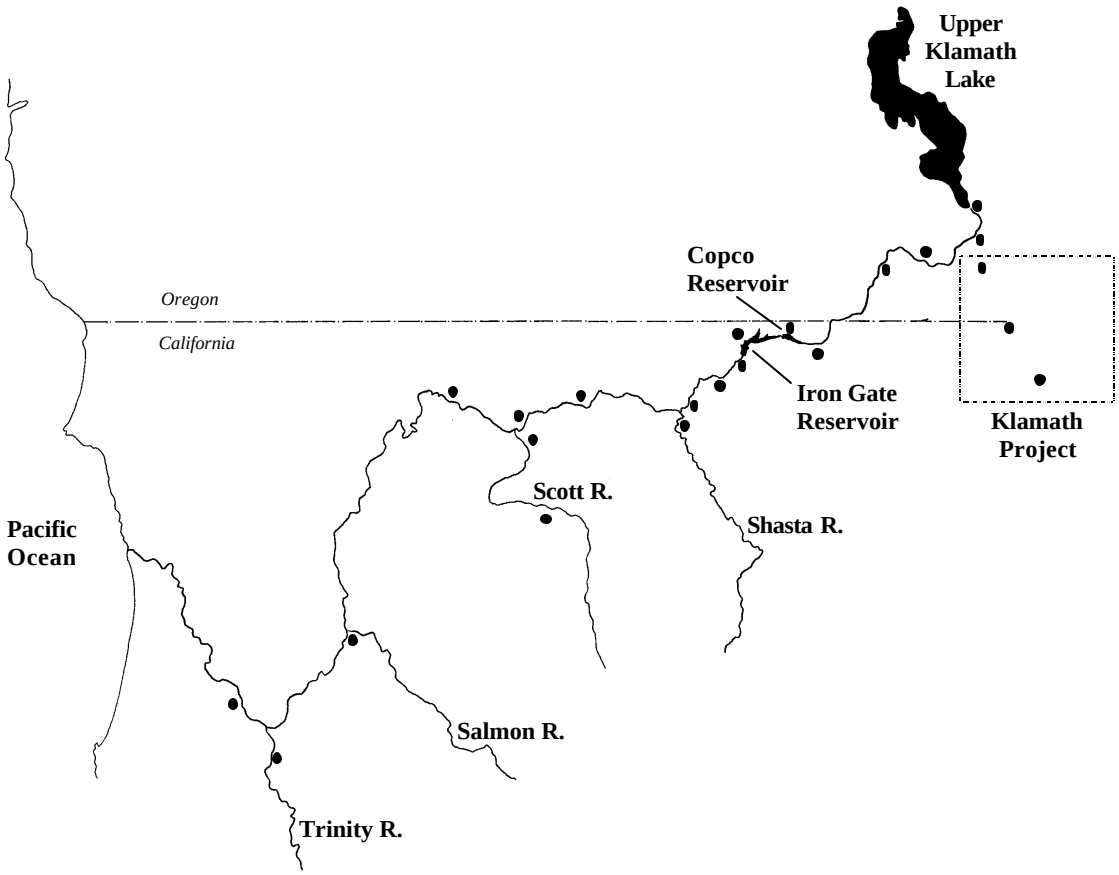
HOSELY I.D.
LANGELL VALLEY I.D.
SHASTA VIEW I.D.
MALIN I.D.
SUNNYSIDE I.D.
VAN BRIMMER DITCH CO.
KLAMATH DRAINAGE DIST.
COPPOCK BAY AREA
EXPLANATION
N.
P1 – D/S of Malone Dam
P2 – Miller Creek
P3 – Pumps at Irwin and Big Spring
P4 – Bananza Creek
P5 – Pumps Nichols and Bonanza
P6 – Buck Creek
P7 – Harpold Dam pump-out
P8 – "E" Canal
P9 – "F-1" Canal
P10 – Lost River Diversion
P11 – Lost River Diversion Return
P12 – "J" Canal

APPENDIX E: Klamath Model Configuration

Model component	ID	Source/Sink
Link River	1	Link Dam discharge
Link River	2	East Side turbine discharge
Link River	3	West Side turbine discharge
Link River	4	downstream open boundary at Lake Ewauna
Lake Ewauna	1	inflow from Link River
Lake Ewauna	2	Klamath Falls WTP
Lake Ewauna	3	South Suburban WTP
Lake Ewauna	4	Lost River Diversion
Lake Ewauna	5	Columbia Plywood
Lake Ewauna	6	Storm water runoff #1
Lake Ewauna	7	North Canal diversion
Lake Ewauna	8	Storm water runoff #2
Lake Ewauna	9	Collins Forest Products #1 and #2
Lake Ewauna	10	Irrigator #2
Lake Ewauna	11	Storm water runoff #3
Lake Ewauna	12	Irrigator #3
Lake Ewauna	13	Storm water runoff #4
Lake Ewauna	14	Storm water runoff #5
Lake Ewauna	15	Irrigator #4
Lake Ewauna	16	ADY Canal diversion
Lake Ewauna	17	Storm water runoff #6
Lake Ewauna	18	Klamath Straits Drain
Lake Ewauna	19	Storm water runoff #7
Lake Ewauna	20	Storm water runoff #8
Lake Ewauna	21	Storm water runoff #9
Lake Ewauna	22	Irrigator #7
Lake Ewauna	23	Storm water runoff #10
Lake Ewauna	24	Storm water runoff #11
Lake Ewauna	25	Keno Dam outflow
Keno Reach	1	Keno dam discharge
Keno Reach	2	A insignificant lateral flow
Keno Reach	3	Open boundary condition at downstream
J.C. Boyle Reservoir	1	Inflow from Keno Reach
J.C. Boyle Reservoir	2	Spencer Creek inflow
J.C. Boyle Reservoir	3	J.C Boyle dam outflow
Bypass/Fullflow Reach	1	Inflow from J.C. Boyle dam
Bypass/Fullflow Reach	2	A/D bypass #1
Bypass/Fullflow Reach	3	A/D bypass #2
Bypass/Fullflow Reach	4	A/D bypass #3
Bypass/Fullflow Reach	5	Power house return flow
Bypass/Fullflow Reach	6	A/D at stateline
Copco Reservoir	1	Inflow from the Bypass/Fullflow reach
Copco Reservoir	2	Copco Dam outflow
Iron Gate Reservoir	1	Inflow from Copco Dam

Model component	ID	Source/Sink
Iron Gate Reservoir	2	Branch 2 inflow
Iron Gate Reservoir	3	Fall creek inflow
Iron Gate Reservoir	4	Jenny creek inflow
Iron Gate Reservoir	5	Iron Gate dam outflow
Lower Klamath River (to Turwar)	1	Inflow from Iron Gate dam
Lower Klamath River (to Turwar)	1	Bogus Creek
Lower Klamath River (to Turwar)	2	Willow Creek
Lower Klamath River (to Turwar)	3	Cottonwood Creek
Lower Klamath River (to Turwar)	4	Shasta River
Lower Klamath River (to Turwar)	5	Humbug Creek
Lower Klamath River (to Turwar)	6	Beaver Creek
Lower Klamath River (to Turwar)	7	Horse Creek
Lower Klamath River (to Turwar)	8	Seiad Creek
Lower Klamath River (to Turwar)	9	Scott River
Lower Klamath River (to Turwar)	10	Grider Creek
Lower Klamath River (to Turwar)	11	Thompson Creek
Lower Klamath River (to Turwar)	12	Indian Creek
Lower Klamath River (to Turwar)	13	Elk Creek
Lower Klamath River (to Turwar)	14	Clear Creek
Lower Klamath River (to Turwar)	15	Ukonom Creek
Lower Klamath River (to Turwar)	16	Dillon Creek
Lower Klamath River (to Turwar)	17	Salmon River
Lower Klamath River (to Turwar)	18	Rock Creek
Lower Klamath River (to Turwar)	19	Camp Creek
Lower Klamath River (to Turwar)	20	Red Cap
Lower Klamath River (to Turwar)	21	Bluff Creek
Lower Klamath River (to Turwar)	22	Trinity River
Lower Klamath River (to Turwar)	23	Pine Creek
Lower Klamath River (to Turwar)	24	Roach Creek
Lower Klamath River (to Turwar)	25	Tully Creek
Lower Klamath River (to Turwar)	26	Tectah Creek
Lower Klamath River (to Turwar)	27	Blue Creek
Lower Klamath River (to Turwar)	28	Turwar Creek
Bottom Klamath River (Turwar to Pacific Ocean)	1	Inflow from Lower Klamath River
Bottom Klamath River (Turwar to Pacific Ocean)	2	Lateral storm runoff
Bottom Klamath River (Turwar to Pacific Ocean)	3	Hunter Creek
Bottom Klamath River (Turwar to Pacific Ocean)	4	Open boundary condition at the mouth

KLAMATH RIVER WATER QUALITY 2000
– DATA APPENDIX –



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January 25, 2003

This document accompanies the *Klamath River Water Quality Monitoring Program: 2000* report and its associated appendices. An electronic data set containing the water quality data addressed herein is an integral part of this report. The data listing is included in the main report.

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A SEMI-MONTHLY DATA BY SAMPLING SITE

Table A-1 Tule Lake Outlet Channel (TLO) semi-monthly water quality data

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	uS/cm		mV	NTU
TLO	05/01/00	15:00	<0.05	4.9	2.62	0.82	0.41	23	1.34j	-	-	-	-	-	-	-	-	-	61.2
TLO	05/09/00	10:59	0.41	2.2	<0.05	0.51	0.22	5.0	19.0j	378	10.0	246	256	12.33	8.31	470	8.93	-	-
TLO	05/23/00	08:10	0.74	2.2	0.15	0.64	0.25	6.0	17.0j	536	36	321	357	17.33	7.40	732	9.04	-	44.97
TLO	06/06/00	12:30	0.17	2.2	0.6	0.38	0.24	4.0	10j	484	48	290	338	18.69	8.86	691	9.34	412	23.37
TLO	06/20/00	14:40	0.13	2.5	<0.05	0.43	0.25	4.0	10j	448	48	207	255	19.98	9.43	635	9.54	411	21.13
TLO	07/11/00	12:00	0.31	2.0	0.44	0.45	0.43	6.0	16	365	60	119	179	-	-	-	-	-	11.13
TLO	07/25/00	11:45	0.08	2.6	0.45	0.35	0.15	7.0	21j	373	59	109	168	20.68	6.80	489	9.67	412	10.47
TLO	08/08/00	13:15	0.14	2.0	0.72	0.23	0.17	5.0	11j	337	50	101	150	22.02	5.74	438	9.80	96	8.48
TLO	08/22/00	10:30	0.22	3.9	0.07	0.18	0.17	5.0	15j	336	69.1	79	148	17.42	6.40	427	9.90	104	8.81
TLO	09/12/00	10:45	0.11	2.4	1.28	0.30	0.08	9.0	57	380	49.9	129	179	18.08	8.62	517	9.60	332	18.27
TLO	09/26/00	13:00	0.06	4.2	<0.05	0.29	0.11	13.0	40j	377	65.3	130	195	14.20	10.43	495	9.54	173	26.53
TLO	10/17/00	08:00	0.06	3.9	<0.05	0.42	<0.05	11.0	74	356	17.3	181	198	9.96	9.49	500	9.17	158	55.4
TLO	10/31/00	13:30	0.55	2.7	0.17	0.24	0.07	9.0	28j	253	<1.4	205	205	7.19	10.30	368	8.77	203	67.3
TLO	11/14/00	13:00	0.12	3.6	0.06	0.27	0.06	12	38j	350	24	197	222	1.87	12.17	452	9.18	252	57.1

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table A-2 Klamath Straits Drain at Headworks (KSDH) semi-monthly water quality data

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KSDH	05/01/00	14:15	0.09	2.3	1.00	0.52	0.51	5.0	0.80j	-	-	-	-	-	-	-	-	-	6.77
KSDH	05/09/00	11:56	0.55	2.4	<0.05	0.47	0.37	4.0	22	527	<1.4	348	348	14.16	8.95	663	8.54	304	-
KSDH	05/23/00	12:50	0.51	2.3	<0.05	0.69	0.59	3.0	3.40j	592	10	400	410	21.74	9.18	829	9.08	-	14.57
KSDH	06/06/00	11:30	0.19	2.7	0.55	0.36	0.33	4.0	3.48j	596	<1.4	342	342	19.95	8.37	819	9.22	495	12.1
KSDH	06/20/00	13:45	0.26	5.4	<0.05	0.63	0.46	<3.0	1j	1150	<1.4	439	439	23.79	7.24	1495	9.09	411	6.28
KSDH	07/11/00	11:20	0.31	2.0	0.56	0.51	0.51	<3.0	5j	390	48	132	180	22.20	8.02	504	9.31	351	4.59
KSDH	07/25/00	11:05	0.15	2.4	<0.05	0.91	0.27	<3.0	2j	365	40	131	171	22.97	5.24	487	9.30	432	5.52
KSDH	08/08/00	12:10	0.09	2.4	0.58	0.24	0.24	6.0	18j	342	29	127	156	23.73	7.03	419	9.37	108	6.39
KSDH	08/22/00	11:30	0.1	3.9	<0.05	0.17	0.17	<3.0	2j	463	51.8	172	224	19.71	8.29	623	9.40	111	5.44
KSDH	09/12/00	11:30	<0.05	3.8	<0.05	0.33	<0.05	16.0	95	370	54.7	139	193	19.58	11.67	570	9.73	317	30.4
KSDH	09/26/00	12:10	5.58	8.6	<0.05	0.64	0.22	12.0	51	477	<1.4	336	336	14.53	1.46	698	7.77	197	289.67
KSDH	10/17/00	09:15	2.24	5.0	0.07	0.83	0.15	19.0	136	470	<1.4	420	420	5.39	7.85	720	8.01	201	112.33
KSDH	10/31/00	12:30	<0.05	3.7	<0.05	0.40	0.11	4.0	74	453	24.0	351	376	5.85	11.33	638	9.11	210	24.3
KSDH	11/14/00	11:45	0.43	2.0	0.21	0.24	0.09	5	30j	369	<1.4	264	264	2.97	11.98	568	7.67	196	14.37

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table A-3 Klamath Straits Drain at Highway 97 (KSD97) semi-monthly water quality data

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KSD97	05/01/00	11:45	0.19	2.3	1.29	0.61	0.56	8.0	6.99j	-	-	-	-	-	-	-	-	-	18
KSD97	05/09/00	08:00	0.67	2.3	0.37	0.57	0.40	4.0	<0.01j	369	<1.4	236	236	14.23	6.62	460	8.38	311	-
KSD97	05/23/00	11:30	0.80	<0.2	0.08	0.62	0.49	5.0	7.12j	510	10	324	334	20.82	6.80	707	8.94	-	-
KSD97	06/06/00	10:00	0.34	2.2	0.68	0.48	0.36	4.0	4.11j	409	<1.4	262	262	19.81	5.79	561	8.95	575	16.37
KSD97	06/20/00	11:00	0.72	3.9	0.06	0.90	0.62	6.0	13j	491	<1.4	230	230	21.19	2.18	663	8.02	487	-
KSD97	07/11/00	09:30	0.80	2.1	1.00	0.76	0.66	3.0	2j	368	<1.4	187	187	21.63	3.14	516	8.57	374	8.99
KSD97	07/25/00	09:15	0.22	2.4	0.64	0.66	0.35	8.0	9j	279	<1.4	142	142	22.86	1.69	340	7.75	542	13.37
KSD97	08/08/00	07:50	0.82	2.8	1.12	0.27	0.25	<3.0	5j	347	<1.4	180	180	23.23	2.26	475	8.46	335	8.49
KSD97	08/22/00	08:45	0.24	5.0	1.22	0.31	0.29	7.0	15j	395	<1.4	207	207	19.83	1.62	522	7.89	91	6.27
KSD97	09/12/00	08:30	0.29	2.5	1.35	0.28	0.11	8.0	49	386	24	171	195	17.55	4.98	528	9.20	230	16.33
KSD97	09/26/00	10:00	1.73	4.8	2.29	0.27	0.23	7.0	0j	382	<1.4	248	248	12.97	2.76	525	7.65	208	8.34
KSD97	10/17/00	10:30	2.47	4.0	0.21	0.29	0.14	4.0	4j	472	<1.4	349	349	9.91	3.20	740	7.60	198	14.87
KSD97	10/31/00	09:00	0.57	1.8	0.53	0.10	0.09	4.0	28j	396	<1.4	234	234	6.74	7.09	565	7.92	216	7.89
KSD97	11/14/00	09:00	0.07	2.1	0.14	0.14	<0.05	7	75	430	<1.4	244	244	4.14	10.01	590	8.51	450	13.5

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table A-4 Klamath River at Miller Island (KRMI) semi-monthly water quality data

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KRMI	05/01/00	10:30	<0.05	0.9	<0.05	0.22	0.16	4.0	11.0j	-	-	-	-	-	-	-	-	-	7.22
KRMI	05/09/00	14:36	0.29	0.8	<0.05	0.34	0.27	<3.0	17.0j	31	<1.4	61	61	14.76	8.66	104	7.86	362	-
KRMI	05/23/00	09:15	0.27	0.8	<0.05	0.28	0.28	4.0	19j	74	<1.4	60	60	18.26	9.13	108	8.43	-	8.12
KRMI	06/06/00	07:30	0.12	2.0	1.69	0.37	0.15	8.0	288	90	<1.4	51	51	18.77	10.63	102	9.33	564	50.57
KRMI	06/20/00	08:40	0.30	4.0	0.19	0.71	0.38	6.0	96	80	<1.4	55	55	19.11	3.10	103	9.33	510	37.73
KRMI	07/11/00	07:30	0.63	2.4	1.79	0.56	0.52	8.0	81	115	9	51	59	19.54	2.38	107	9.01	470	48.27
KRMI	07/25/00	08:00	0.84	3.7	2.05	0.44	0.22	10.0	22j	106	<1.4	21	21	22.77	0.29	117	8.54	428	7.11
KRMI	08/08/00	06:50	1.53	3.2	2.30	0.24	0.24	7.0	6j	123	<1.4	73	73	23.56	1.20	121	7.59	-47	6.45
KRMI	08/22/00	13:30	0.91	2.8	0.18	0.08	0.06	<3.0	6j	138	<1.4	74	74	20.00	3.03	126	7.17	186	3.98
KRMI	09/12/00	13:15	0.36	0.8	0.70	0.25	0.14	5.0	25j	144	<1.4	128	128	16.95	2.03	205	7.21	393	24.1
KRMI	09/26/00	07:45	0.35	1.6	0.26	0.19	0.15	4.0	11j	151	<1.4	120	120	14.50	3.09	202	7.54	54	28.83
KRMI	10/17/00	13:30	0.47	2.1	0.10	0.15	0.05	5.0	33j	140	<1.4	76	76	11.46	5.26	134	7.39	169	15.7
KRMI	10/31/00	08:30	0.40	1.7	0.13	0.08	<0.05	5.0	14j	102	<1.4	71	71	7.48	5.45	118	7.34	178	9.22
KRMI	11/14/00	08:00	0.43	1.4	0.42	0.09	0.07	<3	4j	107	<1.4	82	82	4.19	6.32	156	7.34	448	13.6

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table A-5 Klamath River at Keno (KRK) semi-monthly water quality data

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KRK	05/01/00	13:00	<0.05	0.9	0.34	0.23	0.17	5.0	7.01j	-	-	-	-	13.54	8.90	133	7.66	419	6.59
KRK	05/09/00	12:58	0.36	0.8	0.07	0.61	0.12	<3.0	2.34j	100	<1.4	75	75	13.99	7.80	129	7.58	354	-
KRK	05/23/00	13:30	0.35	1.2	0.05	0.36	0.34	5.0	18j	227	<1.4	156	156	19.10	8.52	315	9.00	-	7.72
KRK	06/06/00	08:45	0.12	1.4	0.39	0.27	0.33	<3.0	20j	182	<1.4	119	119	18.19	8.57	237	8.96	604	10.05
KRK	06/20/00	09:45	0.68	2.2	0.07	0.46	0.38	4.0	6j	130	<1.4	68	68	19.41	3.32	152	8.95	548	4.98
KRK	07/11/00	08:50	0.71	1.8	1.31	0.62	0.62	4.0	15j	138	<1.4	72	72	18.97	1.72	165	7.89	444	3.5
KRK	07/25/00	13:15	0.46	2.6	1.08	0.40	0.24	8.0	20j	184	1.9	53	55	23.12	2.87	220	8.41	408	4.7
KRK	08/08/00	10:45	1.11	3.0	1.89	0.24	0.25	8.0	22j	145	<1.4	82	82	23.08	0.53	155	7.71	-185	5.02
KRK	08/22/00	12:30	1.47	3.5	0.10	0.14	0.16	<3.0	17j	168	<1.4	89	89	20.36	3.02	176	7.28	177	2.64
KRK	09/12/00	12:30	0.41	2.0	1.06	0.24	0.11	8.0	35j	202	<1.4	135	135	16.72	5.80	272	7.94	364	12.93
KRK	09/26/00	09:00	0.43	1.5	0.13	0.17	0.17	<3.0	0j	178	<1.4	139	139	15.19	2.50	231	7.51	185	13
KRK	10/17/00	12:30	0.53	1.7	0.23	0.13	0.07	<3.0	4j	94	<1.4	84.9	84.9	11.61	2.80	150	7.22	202	9.8
KRK	10/31/00	11:30	0.26	1.2	0.31	0.05	<0.05	3.0	1j	110	<1.4	69	69	7.98	6.10	131	7.17	265	10.09
KRK	11/14/00	11:00	0.27	1.0	0.48	0.08	0.06	<3	2j	102	<1.4	80	80	4.39	5.46	149	7.13	480	7.77

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table A-6 Klamath River above Copco Reservoir (KRCR) semi-monthly water quality data

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KRCR	05/09/00	13:50	0.10	<0.2	0.19	0.24	0.23	3.0	2.67j	102	<1.4	70	70	-	-	-	-	-	-
KRCR	05/23/00	16:10	0.23	0.3	0.25	0.25	0.13	<3.0	0.80j	183	<1.4	127	127	19.97	8.65	251	8.31	317	8.47
KRCR	06/06/00	13:10	0.10	1.0	0.30	0.30	0.26	<3.0	5.72j	176	<1.4	113	113	18.81	7.96	231	8.45	281	6.48
KRCR	06/20/00	16:35	0.21	1.8	0.57	0.43	0.39	<3.0	6j	96	<1.4	70	70	18.27	7.86	144	8.45	304	5.43
KRCR	07/11/00	14:15	<0.05	0.5	0.41	0.42	0.16	<3.0	2j	104	<1.4	75	75	17.02	8.04	143	8.44	289	0.69
KRCR	07/25/00	13:40	0.08	0.3	0.42	0.33	0.25	<3.0	2j	144	<1.4	78	78	21.02	9.49	169	8.75	298	2.86
KRCR	08/07/00	15:13	<0.05	1.0	0.61	0.16	0.17	<3.0	23j	129	<1.4	76	76	19.62	8.11	145	8.41	322	4.01
KRCR	08/22/00	14:55	<0.05	0.8	0.36	0.08	<0.05	<3.0	2j	136	9.6	74	84	17.86	9.53	145	8.71	327	2.57
KRCR	09/12/00	14:35	<0.05	0.6	0.38	0.14	0.10	2.0	20j	164	9.6	103	112	18.15	9.71	232	8.23	152	1.42
KRCR	09/26/00	13:45	<0.05	0.6	0.31	0.11	0.12	<3.0	1j	115	<1.4	108	108	13.91	10.97	182	8.76	-	2.13
KRCR	10/17/00	14:00	0.05	0.9	0.68	0.17	0.09	<3.0	1j	156	<1.4	83	83	10.00	-	-	-	-	-
KRCR	10/31/00	12:30	<0.05	0.5	0.49	0.06	0.05	3.0	1j	109	<1.4	75	75	9.02	10.75	127	8.57	332	6.09
KRCR	11/14/00	13:15	<0.05	<0.2	0.43	0.07	0.08	<3	1j	122	<1.4	79	79	5.76	11.38	135	8.34	381	3.58

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table A-7 Klamath River below Iron Gate Reservoir (KRIG) semi-monthly water quality data

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KRIG	05/09/00	13:00	0.30	<0.2	0.15	0.29	0.18	<3.0	1.34j	76	<1.4	70	70	-	-	-	-	-	-
KRIG	05/23/00	14:22	0.26	<0.2	0.10	0.26	0.26	<3.0	4.50j	86	<1.4	83	83	15.42	9.76	155	8.32	307	4.67
KRIG	06/06/00	12:18	0.10	0.7	0.06	0.21	0.29	<3.0	5.07j	153	<1.4	106	106	17.99	8.57	207	8.28	298	-
KRIG	06/20/00	15:42	0.05	1.6	0.18	0.41	0.34	<3.0	1j	159	<1.4	107	107	19.81	7.69	211	7.92	322	2.01
KRIG	07/11/00	13:00	0.30	4.5	0.28	0.32	0.12	<3.0	3j	129	<1.4	90	90	20.50	7.31	180	7.74	305	1.36
KRIG	07/25/00	12:30	0.09	0.8	0.36	0.11	0.19	<3.0	2j	129	<1.4	87	87	21.54	8.06	168	8.44	301	1.37
KRIG	08/07/00	12:15	<0.05	1.8	0.24	0.11	0.15	<3.0	11j	132	3.8	80	84	23.00	7.98	171	8.51	371	-
KRIG	08/22/00	13:35	<0.05	1.3	0.24	0.13	0.17	<3.0	6j	146	<1.4	84	84	21.29	6.63	171	8.45	330	2.39
KRIG	09/12/00	13:30	0.06	0.9	0.58	0.20	0.17	3.0	6j	131	<1.4	87	87	19.35	5.91	188	7.01	179	1.03
KRIG	09/26/00	12:20	<0.05	0.7	0.57	0.13	0.15	<3.0	1j	131	<1.4	81	81	17.35	6.00	165	7.61	-	1.8
KRIG	10/17/00	12:50	0.07	0.7	0.52	0.19	0.15	<3.0	2j	136	<1.4	102	102	13.00	-	-	-	-	-
KRIG	10/31/00	11:30	<0.05	0.7	0.63	0.10	0.13	14.0	0j	133	<1.4	93	93	12.59	6.34	171	7.47	356	5.42
KRIG	11/14/00	12:05	0.09	0.6	0.65	0.12	0.12	<3	1j	122	<1.4	84	84	9.81	6.46	152	7.30	404	3.88

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table A-8 Klamath River near Seiad Valley (KRSV) semi-monthly water quality data

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (°C)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KRSV	05/09/00	10:30	0.64	<0.2	<0.05	0.29	0.19	<3.0	0.53j	85	<1.4	90	90	-	-	-	-	-	-
KRSV	05/23/00	12:01	0.19	<0.2	0.05	0.17	0.17	3.0	2.40j	92	<1.4	78	78	16.42	9.57	138	8.24	312	10.53
KRSV	06/06/00	09:50	0.05	0.4	<0.05	0.12	0.16	<3.0	0.53j	114	<1.4	93	93	15.91	8.80	125	8.07	298	-
KRSV	06/20/00	11:47	0.18	1.2	0.09	0.37	0.23	<3.0	0j	140	<1.4	107	107	19.30	8.85	202	8.22	326	2.47
KRSV	07/11/00	10:00	0.26	0.2	<0.05	0.32	0.32	<3.0	0j	134	<1.4	111	111	20.88	7.55	212	8.23	328	2.54
KRSV	07/25/00	09:55	0.22	1.4	0.09	0.26	0.14	<3.0	2j	155	<1.4	45	45	21.87	8.39	197	8.23	320	1.54
KRSV	08/07/00	11:45	0.05	1.2	0.10	0.11	0.13	<3.0	9j	138	<1.4	96	96	-	-	-	-	-	-
KRSV	08/22/00	10:30	<0.05	1.6	0.11	0.12	0.14	<3.0	7j	153	<1.4	99	99	21.06	8.27	190	8.44	320	4.23
KRSV	09/12/00	10:30	0.07	0.7	0.39	0.17	0.15	<3.0	0j	149	<1.4	108	108	19.73	7.50	219	7.58	130	2.14
KRSV	09/26/00	10:30	<0.05	0.9	0.42	0.12	0.14	<3.0	3j	149	<1.4	104	104	15.60	9.48	197	8.22	-	2.27
KRSV	10/17/00	10:10	<0.05	0.6	0.44	0.16	0.13	<3.0	0j	165	<1.4	132	132	11.00	-	-	-	-	-
KRSV	10/31/00	08:45	<0.05	0.5	0.48	0.09	0.11	3.0	2j	160	<1.4	139	139	11.20	9.87	213	7.97	342	5.29
KRSV	11/14/00	09:20	0.05	0.3	0.53	0.09	0.11	<3	1j	156	<1.4	110	110	6.86	10.83	202	7.96	395	3.59

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table A-9 Shasta River near mouth (SHR) semi-monthly water quality data

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (°C)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
SHR	05/09/00	12:15	0.48	0.2	<0.05	0.45	0.39	<3.0	1.34j	316	<1.4	339	339	-	-	-	-	-	-
SHR	05/23/00	13:35	0.22	<0.2	<0.05	0.52	0.57	<3.0	0.50j	379	29	329	358	23.00	8.48	545	8.63	308	1.87
SHR	06/06/00	11:42	0.08	0.8	<0.05	0.31	0.48	<3.0	1.07j	335	34	319	353	17.95	9.34	509	8.57	284	-
SHR	06/20/00	13:45	0.27	1.5	<0.05	0.60	0.46	<3.0	3j	326	<1.4	311	311	22.93	7.91	491	8.59	305	8.97
SHR	07/11/00	12:00	0.32	0.3	<0.05	0.58	0.53	<3.0	2j	313	<1.4	287	287	21.71	8.32	481	8.57	286	5.45
SHR	07/25/00	11:25	<0.05	0.5	<0.05	0.33	0.25	<3.0	1j	314	<1.4	295	295	22.39	8.51	496	8.61	309	2.08
SHR	08/07/00	10:45	0.05	1.0	<0.05	0.17	0.2	<3.0	3j	351	<1.4	311	311	21.75	8.38	525	8.35	369	-
SHR	08/22/00	12:35	<0.05	0.6	<0.05	0.14	0.19	<3.0	0j	356	8	318	326	21.31	8.21	529	8.70	302	3.29
SHR	09/12/00	12:30	0.05	1.0	<0.05	0.21	0.18	<3.0	6j	399	<1.4	435	435	20.22	8.69	685	8.17	156	2.14
SHR	09/26/00	15:15	0.17	0.5	<0.05	0.13	0.16	<3.0	0j	343	24.0	352	376	16.46	9.14	516	8.73	-	3.1
SHR	10/17/00	12:00	<0.05	0.4	0.26	0.24	0.16	<3.0	1j	299	<1.4	276	276	10.00	-	-	-	-	-
SHR	10/31/00	10:30	<0.05	0.4	0.24	0.21	0.16	<3.0	0j	287	<1.4	268	268	9.01	10.80	425	8.47	326	4.29
SHR	11/14/00	11:20	<0.05	<0.2	0.24	0.13	0.17	<3	1j	309	<1.4	266	266	5.81	11.47	434	8.51	384	1.9

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table A-10 Scott River ne ar Ft. Jones (SCR) semi-monthly water quality data

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
SCR	05/09/00	09:40	0.52	<0.2	0.15	0.21	0.08	<3.0	1.60j	73	<1.4	73	73	-	-	-	-	-	-
SCR	05/23/00	10:02	0.21	0.2	<0.05	0.16	0.16	5.0	1.10j	56	<1.4	49	49	11.85	9.48	77	7.64	351	24.8
SCR	06/06/00	07:45	0.06	0.4	0.08	0.08	0.09	<3.0	0.27j	76	<1.4	75	75	13.34	8.49	113	7.53	318	6.02
SCR	06/20/00	09:46	0.09	0.9	0.27	0.21	0.16	<3.0	2j	100	<1.4	88	88	15.64	8.31	144	7.73	332	4.45
SCR	07/11/00	08:00	0.36	0.4	0.20	0.09	0.17	<3.0	2j	144	<1.4	142	142	17.02	7.31	229	7.76	312	1.25
SCR	07/25/00	08:00	<0.05	<0.2	0.34	0.16	<0.05	<3.0	1j	178	<1.4	164	164	16.19	9.17	270	7.83	295	1
SCR	08/07/00	08:47	<0.05	0.5	0.25	0.05	<0.05	<3.0	46	164	<1.4	154	154	17.13	7.77	250	7.76	333	2.22
SCR	08/22/00	07:55	<0.05	0.5	0.12	<0.05	<0.05	<3.0	3j	92	16.3	76	92	15.14	6.89	215	7.73	315	4.87
SCR	09/12/00	08:30	0.08	<0.2	0.14	<0.05	<0.05	<3.0	13j	156	<1.4	152	152	15.60	7.59	287	7.55	148	1.13
SCR	09/26/00	07:45	<0.05	0.2	0.30	<0.05	<0.05	<3.0	2j	161	<1.4	165	165	11.91	7.86	277	7.85	-	1.77
SCR	10/17/00	08:20	<0.05	<0.2	0.39	<0.05	<0.05	<3.0	1j	178	<1.4	190	190	9.00	-	-	-	-	-
SCR	10/31/00	07:15	<0.05	<0.2	0.40	<0.05	<0.05	4.0	3j	169	<1.4	175	175	9.26	9.00	273	7.74	355	2.62
SCR	11/14/00	08:10	<0.05	<0.2	0.47	<0.05	<0.05	<3	5j	173	<1.4	170	170	6.13	9.70	272	7.79	401	0.94

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

B SEMI-MONTHLY DATA BY SAMPLING DATE

Table B-1 Semi-monthly water quality data: May 1, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	5/1/00	15:00	<0.05	4.9	2.62	0.82	0.41	23	1.34j	-	-	-	-	-	-	-	-	-	61.2
KSDH	5/1/00	14:15	0.09	2.3	1.00	0.52	0.51	5.0	0.80j	-	-	-	-	-	-	-	-	-	6.77
KSD97	5/1/00	11:45	0.19	2.3	1.29	0.61	0.56	8.0	6.99j	-	-	-	-	-	-	-	-	-	18
KRMI	5/1/00	10:30	<0.05	0.9	<0.05	0.22	0.16	4.0	11.0j	-	-	-	-	-	-	-	-	-	7.22
KRK	5/1/00	13:00	<0.05	0.9	0.34	0.23	0.17	5.0	7.01j	-	-	-	-	13.54	8.90	133	7.66	419	6.59

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-2 Semi-monthly water quality data: May 9, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	5/9/00	10:59	0.41	2.2	<0.05	0.51	0.22	5.0	19.0j	378	10.0	246	256	12.33	8.31	470	8.93	-	-
KSDH	5/9/00	11:56	0.55	2.4	<0.05	0.47	0.37	4.0	22j	527	<1.4	348	348	14.16	8.95	663	8.54	304	-
KSD97	5/9/00	8:00	0.67	2.3	0.37	0.57	0.40	4.0	<0.01j	369	<1.4	236	236	14.23	6.62	460	8.38	311	-
KRMI	5/9/00	14:36	0.29	0.8	<0.05	0.34	0.27	<3.0	17.0j	31	<1.4	61	61	14.76	8.66	104	7.86	362	-
KRK	5/9/00	12:58	0.36	0.8	0.07	0.61	0.12	<3.0	2.34j	100	<1.4	75	75	13.99	7.80	129	7.58	354	-
KRCR	5/9/00	13:50	0.10	<0.2	0.19	0.24	0.23	3.0	2.67j	102	<1.4	70	70	-	-	-	-	-	-
KRIG	5/9/00	13:00	0.30	<0.2	0.15	0.29	0.18	<3.0	1.34j	76	<1.4	70	70	-	-	-	-	-	-
KRSV	5/9/00	10:30	0.64	<0.2	<0.05	0.29	0.19	<3.0	0.53j	85	<1.4	90	90	-	-	-	-	-	-
SHR	5/9/00	12:15	0.48	0.2	<0.05	0.45	0.39	<3.0	1.34j	316	<1.4	339	339	-	-	-	-	-	-
SCR	5/9/00	9:40	0.52	<0.2	0.15	0.21	0.08	<3.0	1.60j	73	<1.4	73	73	-	-	-	-	-	-

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-3 Semi-monthly water quality data: May 23, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	5/23/00	8:10	0.74	2.2	0.15	0.64	0.25	6.0	17.0j	536	36	321	357	17.33	7.40	732	9.04	-	44.97
KSDH	5/23/00	12:50	0.51	2.3	<0.05	0.69	0.59	3.0	3.40j	592	10	400	410	21.74	9.18	829	9.08	-	14.57
KSD97	5/23/00	11:30	0.80	<0.2	0.08	0.62	0.49	5.0	7.12j	510	10	324	334	20.82	6.80	707	8.94	-	-
KRMI	5/23/00	9:15	0.27	0.8	<0.05	0.28	0.28	4.0	19j	74	<1.4	60	60	18.26	9.13	108	8.43	-	8.12
KRK	5/23/00	13:30	0.35	1.2	0.05	0.36	0.34	5.0	18j	227	<1.4	156	156	19.10	8.52	315	9.00	-	7.72
KRCR	5/23/00	16:10	0.23	0.3	0.25	0.25	0.13	<3.0	0.80j	183	<1.4	127	127	19.97	8.65	251	8.31	317	8.47
KRIG	5/23/00	14:22	0.26	<0.2	0.10	0.26	0.26	<3.0	4.50j	86	<1.4	83	83	15.42	9.76	155	8.32	307	4.67
KRSV	5/23/00	12:01	0.19	<0.2	0.05	0.17	0.17	3.0	2.40j	92	<1.4	78	78	16.42	9.57	138	8.24	312	10.53
SHR	5/23/00	13:35	0.22	<0.2	<0.05	0.52	0.57	<3.0	0.50j	379	29	329	358	23.00	8.48	545	8.63	308	1.87
SCR	5/23/00	10:02	0.21	0.2	<0.05	0.16	0.16	5.0	1.10j	56	<1.4	49	49	11.85	9.48	77	7.64	351	24.8

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-4 Semi-monthly water quality data: June 6, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	6/6/00	12:30	0.17	2.2	0.6	0.38	0.24	4.0	10j	484	48	290	338	18.69	8.86	691	9.34	412	23.37
KSDH	6/6/00	11:30	0.19	2.7	0.55	0.36	0.33	4.0	3.48j	596	<1.4	342	342	19.95	8.37	819	9.22	495	12.1
KSD97	6/6/00	10:00	0.34	2.2	0.68	0.48	0.36	4.0	4.11j	409	<1.4	262	262	19.81	5.79	561	8.95	575	16.37
KRMI	6/6/00	7:30	0.12	2.0	1.69	0.37	0.15	8.0	288	90	<1.4	51	51	18.77	10.63	102	9.33	564	50.57
KRK	6/6/00	8:45	0.12	1.4	0.39	0.27	0.33	<3.0	20j	182	<1.4	119	119	18.19	8.57	237	8.96	604	10.05
KRCR	6/6/00	13:10	0.10	1.0	0.30	0.30	0.26	<3.0	5.72j	176	<1.4	113	113	18.81	7.96	231	8.45	281	6.48
KRIG	6/6/00	12:18	0.10	0.7	0.06	0.21	0.29	<3.0	5.07j	153	<1.4	106	106	17.99	8.57	207	8.28	298	-
KRSV	6/6/00	9:50	0.05	0.4	<0.05	0.12	0.16	<3.0	0.53j	114	<1.4	93	93	15.91	8.80	125	8.07	298	-
SHR	6/6/00	11:42	0.08	0.8	<0.05	0.31	0.48	<3.0	1.07j	335	34	319	353	17.95	9.34	509	8.57	284	-
SCR	6/6/00	7:45	0.06	0.4	0.08	0.08	0.09	<3.0	0.27j	76	<1.4	75	75	13.34	8.49	113	7.53	318	6.02

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-5 Semi-monthly water quality data: June 20, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	6/20/00	14:40	0.13	2.5	<0.05	0.43	0.25	4.0	10j	448	48	207	255	19.98	9.43	635	9.54	411	21.13
KSDH	6/20/00	13:45	0.26	5.4	<0.05	0.63	0.46	<3.0	1j	1150	<1.4	439	439	23.79	7.24	1495	9.09	411	6.28
KSD97	6/20/00	11:00	0.72	3.9	0.06	0.90	0.62	6.0	13j	491	<1.4	230	230	21.19	2.18	663	8.02	487	-
KRMI	6/20/00	8:40	0.30	4.0	0.19	0.71	0.38	6.0	96	80	<1.4	55	55	19.11	3.10	103	9.33	510	37.73
KRK	6/20/00	9:45	0.68	2.2	0.07	0.46	0.38	4.0	6j	130	<1.4	68	68	19.41	3.32	152	8.95	548	4.98
KRCR	6/20/00	16:35	0.21	1.8	0.57	0.43	0.39	<3.0	6j	96	<1.4	70	70	18.27	7.86	144	8.45	304	5.43
KRIG	6/20/00	15:42	0.05	1.6	0.18	0.41	0.34	<3.0	1j	159	<1.4	107	107	19.81	7.69	211	7.92	322	2.01
KRSV	6/20/00	11:47	0.18	1.2	0.09	0.37	0.23	<3.0	0j	140	<1.4	107	107	19.30	8.85	202	8.22	326	2.47
SHR	6/20/00	13:45	0.27	1.5	<0.05	0.60	0.46	<3.0	3j	326	<1.4	311	311	22.93	7.91	491	8.59	305	8.97
SCR	6/20/00	9:46	0.09	0.9	0.27	0.21	0.16	<3.0	2j	100	<1.4	88	88	15.64	8.31	144	7.73	332	4.45

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-6 Semi-monthly water quality data: July 11, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	7/11/00	12:00	0.31	2.0	0.44	0.45	0.43	6.0	16j	365	60	119	179	-	-	-	-	-	11.13
KSDH	7/11/00	11:20	0.31	2.0	0.56	0.51	0.51	<3.0	5j	390	48	132	180	22.20	8.02	504	9.31	351	4.59
KSD97	7/11/00	9:30	0.80	2.1	1.00	0.76	0.66	3.0	2j	368	<1.4	187	187	21.63	3.14	516	8.57	374	8.99
KRMI	7/11/00	7:30	0.63	2.4	1.79	0.56	0.52	8.0	81	115	9	51	59	19.54	2.38	107	9.01	470	48.27
KRK	7/11/00	8:50	0.71	1.8	1.31	0.62	0.62	4.0	15j	138	<1.4	72	72	18.97	1.72	165	7.89	444	3.5
KRCR	7/11/00	14:15	<0.05	0.5	0.41	0.42	0.16	<3.0	2j	104	<1.4	75	75	17.02	8.04	143	8.44	289	0.69
KRIG	7/11/00	13:00	0.30	4.5	0.28	0.32	0.12	<3.0	3j	129	<1.4	90	90	20.50	7.31	180	7.74	305	1.36
KRSV	7/11/00	10:00	0.26	0.2	<0.05	0.32	0.32	<3.0	0j	134	<1.4	111	111	20.88	7.55	212	8.23	328	2.54
SHR	7/11/00	12:00	0.32	0.3	<0.05	0.58	0.53	<3.0	2j	313	<1.4	287	287	21.71	8.32	481	8.57	286	5.45
SCR	7/11/00	8:00	0.36	0.4	0.20	0.09	0.17	<3.0	2j	144	<1.4	142	142	17.02	7.31	229	7.76	312	1.25

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-7 Semi-monthly water quality data: July 25, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	7/25/00	11:45	0.08	2.6	0.45	0.35	0.15	7.0	21j	373	59	109	168	20.68	6.80	489	9.67	412	10.47
KSDH	7/25/00	11:05	0.15	2.4	<0.05	0.91	0.27	<3.0	2j	365	40	131	171	22.97	5.24	487	9.30	432	5.52
KSD97	7/25/00	9:15	0.22	2.4	0.64	0.66	0.35	8.0	9j	279	<1.4	142	142	22.86	1.69	340	7.75	542	13.37
KRMI	7/25/00	8:00	0.84	3.7	2.05	0.44	0.22	10.0	22j	106	<1.4	21	21	22.77	0.29	117	8.54	428	7.11
KRK	7/25/00	13:15	0.46	2.6	1.08	0.40	0.24	8.0	20j	184	1.9	53	55	23.12	2.87	220	8.41	408	4.7
KRCR	7/25/00	13:40	0.08	0.3	0.42	0.33	0.25	<3.0	2j	144	<1.4	78	78	21.02	9.49	169	8.75	298	2.86
KRIG	7/25/00	12:30	0.09	0.8	0.36	0.11	0.19	<3.0	2j	129	<1.4	87	87	21.54	8.06	168	8.44	301	1.37
KRSV	7/25/00	9:55	0.22	1.4	0.09	0.26	0.14	<3.0	2j	155	<1.4	45	45	21.87	8.39	197	8.23	320	1.54
SHR	7/25/00	11:25	<0.05	0.5	<0.05	0.33	0.25	<3.0	1j	314	<1.4	295	295	22.39	8.51	496	8.61	309	2.08
SCR	7/25/00	8:00	<0.05	<0.2	0.34	0.16	<0.05	<3.0	1j	178	<1.4	164	164	16.19	9.17	270	7.83	295	1

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-8 Semi-monthly water quality data: August 8, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
KRCR	8/7/00	15:13	<0.05	1.0	0.61	0.16	0.17	<3.0	23j	129	<1.4	76	76	19.62	8.11	145	8.41	322	4.01
KRIG	8/7/00	12:15	<0.05	1.8	0.24	0.11	0.15	<3.0	11j	132	3.8	80	84	23.00	7.98	171	8.51	371	-
KRSV	8/7/00	11:45	0.05	1.2	0.10	0.11	0.13	<3.0	9j	138	<1.4	96	96	-	-	-	-	-	-
SHR	8/7/00	10:45	0.05	1.0	<0.05	0.17	0.2	<3.0	3j	351	<1.4	311	311	21.75	8.38	525	8.35	369	-
SCR	8/7/00	8:47	<0.05	0.5	0.25	0.05	<0.05	<3.0	46	164	<1.4	154	154	17.13	7.77	250	7.76	333	2.22
TLO	8/8/00	13:15	0.14	2.0	0.72	0.23	0.17	5.0	11j	337	50	101	150	22.02	5.74	438	9.80	96	8.48
KSDH	8/8/00	12:10	0.09	2.4	0.58	0.24	0.24	6.0	18j	342	29	127	156	23.73	7.03	419	9.37	108	6.39
KSD97	8/8/00	7:50	0.82	2.8	1.12	0.27	0.25	<3.0	5j	347	<1.4	180	180	23.23	2.26	475	8.46	335	8.49
KRMI	8/8/00	6:50	1.53	3.2	2.30	0.24	0.24	7.0	6j	123	<1.4	73	73	23.56	1.20	121	7.59	-47	6.45
KRK	8/8/00	10:45	1.11	3.0	1.89	0.24	0.25	8.0	22j	145	<1.4	82	82	23.08	0.53	155	7.71	-185	5.02

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-9 Semi-monthly water quality data: August 22, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	8/22/00	10:30	0.22	3.9	0.07	0.18	0.17	5.0	15j	336	69.1	79	148	17.42	6.40	427	9.90	104	8.81
KSDH	8/22/00	11:30	0.1	3.9	<0.05	0.17	0.17	<3.0	2j	463	51.8	172	224	19.71	8.29	623	9.40	111	5.44
KSD97	8/22/00	8:45	0.24	5.0	1.22	0.31	0.29	7.0	15j	395	<1.4	207	207	19.83	1.62	522	7.89	91	6.27
KRMI	8/22/00	13:30	0.91	2.8	0.18	0.08	0.06	<3.0	6j	138	<1.4	74	74	20.00	3.03	126	7.17	186	3.98
KRK	8/22/00	12:30	1.47	3.5	0.10	0.14	0.16	<3.0	17j	168	<1.4	89	89	20.36	3.02	176	7.28	177	2.64
KRCR	8/22/00	14:55	<0.05	0.8	0.36	0.08	<0.05	<3.0	2j	136	9.6	74	84	17.86	9.53	145	8.71	327	2.57
KRIG	8/22/00	13:35	<0.05	1.3	0.24	0.13	0.17	<3.0	6j	146	<1.4	84	84	21.29	6.63	171	8.45	330	2.39
KRSV	8/22/00	10:30	<0.05	1.6	0.11	0.12	0.14	<3.0	7j	153	<1.4	99	99	21.06	8.27	190	8.44	320	4.23
SHR	8/22/00	12:35	<0.05	0.6	<0.05	0.14	0.19	<3.0	0j	356	8	318	326	21.31	8.21	529	8.70	302	3.29
SCR	8/22/00	7:55	<0.05	0.5	0.12	<0.05	<0.05	<3.0	3j	92	16.3	76	92	15.14	6.89	215	7.73	315	4.87

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-10 Semi-monthly water quality data: September 12, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	9/12/00	10:45	0.11	2.4	1.28	0.30	0.08	9.0	57	380	49.9	129	179	18.08	8.62	517	9.60	332	18.27
KSDH	9/12/00	11:30	<0.05	3.8	<0.05	0.33	<0.05	16.0	95	370	54.7	139	193	19.58	11.67	570	9.73	317	30.4
KSD97	9/12/00	8:30	0.29	2.5	1.35	0.28	0.11	8.0	49	386	24	171	195	17.55	4.98	528	9.20	230	16.33
KRMI	9/12/00	13:15	0.36	0.8	0.70	0.25	0.14	5.0	25j	144	<1.4	128	128	16.95	2.03	205	7.21	393	24.1
KRK	9/12/00	12:30	0.41	2.0	1.06	0.24	0.11	8.0	35j	202	<1.4	135	135	16.72	5.80	272	7.94	364	12.93
KRCR	9/12/00	14:35	<0.05	0.6	0.38	0.14	0.10	2.0	20j	164	9.6	103	112	18.15	9.71	232	8.23	152	1.42
KRIG	9/12/00	13:30	0.06	0.9	0.58	0.20	0.17	3.0	6j	131	<1.4	87	87	19.35	5.91	188	7.01	179	1.03
KRSV	9/12/00	10:30	0.07	0.7	0.39	0.17	0.15	<3.0	0j	149	<1.4	108	108	19.73	7.50	219	7.58	130	2.14
SHR	9/12/00	12:30	0.05	1.0	<0.05	0.21	0.18	<3.0	6j	399	<1.4	435	435	20.22	8.69	685	8.17	156	2.14
SCR	9/12/00	8:30	0.08	<0.2	0.14	<0.05	<0.05	<3.0	13j	156	<1.4	152	152	15.60	7.59	287	7.55	148	1.13

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-11 Semi-monthly water quality data: September 26, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	9/26/00	13:00	0.06	4.2	<0.05	0.29	0.11	13.0	40j	377	65.3	130	195	14.20	10.43	495	9.54	173	26.53
KSDH	9/26/00	12:10	5.58	8.6	<0.05	0.64	0.22	12.0	51	477	<1.4	336	336	14.53	1.46	698	7.77	197	289.67
KSD97	9/26/00	10:00	1.73	4.8	2.29	0.27	0.23	7.0	0j	382	<1.4	248	248	12.97	2.76	525	7.65	208	8.34
KRMI	9/26/00	7:45	0.35	1.6	0.26	0.19	0.15	4.0	11j	151	<1.4	120	120	14.50	3.09	202	7.54	54	28.83
KRK	9/26/00	9:00	0.43	1.5	0.13	0.17	0.17	<3.0	0j	178	<1.4	139	139	15.19	2.50	231	7.51	185	13
KRCR	9/26/00	13:45	<0.05	0.6	0.31	0.11	0.12	<3.0	1j	115	<1.4	108	108	13.91	10.97	182	8.76	-	2.13
KRIG	9/26/00	12:20	<0.05	0.7	0.57	0.13	0.15	<3.0	1j	131	<1.4	81	81	17.35	6.00	165	7.61	-	1.8
KRSV	9/26/00	10:30	<0.05	0.9	0.42	0.12	0.14	<3.0	3j	149	<1.4	104	104	15.60	9.48	197	8.22	-	2.27
SHR	9/26/00	15:15	0.17	0.5	<0.05	0.13	0.16	<3.0	0j	343	24.0	352	376	16.46	9.14	516	8.73	-	3.1
SCR	9/26/00	7:45	<0.05	0.2	0.30	<0.05	<0.05	<3.0	2j	161	<1.4	165	165	11.91	7.86	277	7.85	-	1.77

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-12 Semi-monthly water quality data: October 17, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	10/17/00	8:00	0.06	3.9	<0.05	0.42	<0.05	11.0	74	356	17.3	181	198	9.96	9.49	500	9.17	158	55.4
KSDH	10/17/00	9:15	2.24	5.0	0.07	0.83	0.15	19.0	136	470	<1.4	420	420	5.39	7.85	720	8.01	201	112.33
KSD97	10/17/00	10:30	2.47	4.0	0.21	0.29	0.14	4.0	4j	472	<1.4	349	349	9.91	3.20	740	7.60	198	14.87
KRMI	10/17/00	13:30	0.47	2.1	0.10	0.15	0.05	5.0	33j	140	<1.4	76	76	11.46	5.26	134	7.39	169	15.7
KRK	10/17/00	12:30	0.53	1.7	0.23	0.13	0.07	<3.0	4j	94	<1.4	84.9	84.9	11.61	2.80	150	7.22	202	9.8
KRCR	10/17/00	14:00	0.05	0.9	0.68	0.17	0.09	<3.0	1j	156	<1.4	83	83	10.00	-	-	-	-	-
KRIG	10/17/00	12:50	0.07	0.7	0.52	0.19	0.15	<3.0	2j	136	<1.4	102	102	13.00	-	-	-	-	-
KRSV	10/17/00	10:10	<0.05	0.6	0.44	0.16	0.13	<3.0	0j	165	<1.4	132	132	11.00	-	-	-	-	-
SHR	10/17/00	12:00	<0.05	0.4	0.26	0.24	0.16	<3.0	1j	299	<1.4	276	276	10.00	-	-	-	-	-
SCR	10/17/00	8:20	<0.05	<0.2	0.39	<0.05	<0.05	<3.0	1j	178	<1.4	190	190	9.00	-	-	-	-	-

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-13 Semi-monthly water quality data: October 31, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	10/31/00	13:30	0.55	2.7	0.17	0.24	0.07	9.0	28j	253	<1.4	205	205	7.19	10.30	368	8.77	203	67.3
KSDH	10/31/00	12:30	<0.05	3.7	<0.05	0.40	0.11	4.0	74	453	24.0	351	376	5.85	11.33	638	9.11	210	24.3
KSD97	10/31/00	9:00	0.57	1.8	0.53	0.10	0.09	4.0	28j	396	<1.4	234	234	6.74	7.09	565	7.92	216	7.89
KRMI	10/31/00	8:30	0.40	1.7	0.13	0.08	<0.05	5.0	14j	102	<1.4	71	71	7.48	5.45	118	7.34	178	9.22
KRK	10/31/00	11:30	0.26	1.2	0.31	0.05	<0.05	3.0	1j	110	<1.4	69	69	7.98	6.10	131	7.17	265	10.09
KRCR	10/31/00	12:30	<0.05	0.5	0.49	0.06	0.05	3.0	1j	109	<1.4	75	75	9.02	10.75	127	8.57	332	6.09
KRIG	10/31/00	11:30	<0.05	0.7	0.63	0.10	0.13	14.0	0j	133	<1.4	93	93	12.59	6.34	171	7.47	356	5.42
KRSV	10/31/00	8:45	<0.05	0.5	0.48	0.09	0.11	3.0	2j	160	<1.4	139	139	11.20	9.87	213	7.97	342	5.29
SHR	10/31/00	10:30	<0.05	0.4	0.24	0.21	0.16	<3.0	0j	287	<1.4	268	268	9.01	10.80	425	8.47	326	4.29
SCR	10/31/00	7:15	<0.05	<0.2	0.40	<0.05	<0.05	4.0	3j	169	<1.4	175	175	9.26	9.00	273	7.74	355	2.62

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table B-14 Semi-monthly water quality data: November 14, 2000

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
TLO	11/14/00	13:00	0.12	3.6	0.06	0.27	0.06	12	38j	350	24	197	222	1.87	12.17	452	9.18	252	57.1
KSDH	11/14/00	11:45	0.43	2.0	0.21	0.24	0.09	5	30j	369	<1.4	264	264	2.97	11.98	568	7.67	196	14.37
KSD97	11/14/00	9:00	0.07	2.1	0.14	0.14	<0.05	7	75	430	<1.4	244	244	4.14	10.01	590	8.51	450	13.5
KRMI	11/14/00	8:00	0.43	1.4	0.42	0.09	0.07	<3	4j	107	<1.4	82	82	4.19	6.32	156	7.34	448	13.6
KRK	11/14/00	11:00	0.27	1.0	0.48	0.08	0.06	<3	2j	102	<1.4	80	80	4.39	5.46	149	7.13	480	7.77
KRCR	11/14/00	13:15	<0.05	<0.2	0.43	0.07	0.08	<3	1j	122	<1.4	79	79	5.76	11.38	135	8.34	381	3.58
KRIG	11/14/00	12:05	0.09	0.6	0.65	0.12	0.12	<3	1j	122	<1.4	84	84	9.81	6.46	152	7.30	404	3.88
KRSV	11/14/00	9:20	0.05	0.3	0.53	0.09	0.11	<3	1j	156	<1.4	110	110	6.86	10.83	202	7.96	395	3.59
SHR	11/14/00	11:20	<0.05	<0.2	0.24	0.13	0.17	<3	1j	309	<1.4	266	266	5.81	11.47	434	8.51	384	1.9
SCR	11/14/00	8:10	<0.05	<0.2	0.47	<0.05	<0.05	<3	5j	173	<1.4	170	170	6.13	9.70	272	7.79	401	0.94

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

C SEMI-MONTHLY DATA BY SAMPLING SITE: SUMMARY STATISTICS

Table C-1 Tule Lake Outlet Channel (TLO) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
TLO	05/01/00	15:00	**0.04**	4.9	2.62	0.82	0.41	23	1.34j	-	-	-	-	-	-	-	-	-	61.2
TLO	05/09/00	10:59	0.41	2.2	**0.01**	0.51	0.22	5.0	19.0j	378	10.0	246	256	12.33	8.31	470	8.93	-	-
TLO	05/23/00	08:10	0.74	2.2	0.15	0.64	0.25	6.0	17.0j	536	36	321	357	17.33	7.40	732	9.04	-	44.97
TLO	06/06/00	12:30	0.17	2.2	0.6	0.38	0.24	4.0	10j	484	48	290	338	18.69	8.86	691	9.34	412	23.37
TLO	06/20/00	14:40	0.13	2.5	**0.02**	0.43	0.25	4.0	10j	448	48	207	255	19.98	9.43	635	9.54	411	21.13
TLO	07/11/00	12:00	0.31	2.0	0.44	0.45	0.43	6.0	16	365	60	119	179	-	-	-	-	-	11.13
TLO	07/25/00	11:45	0.08	2.6	0.45	0.35	0.15	7.0	21j	373	59	109	168	20.68	6.80	489	9.67	412	10.47
TLO	08/08/00	13:15	0.14	2.0	0.72	0.23	0.17	5.0	11j	337	50	101	150	22.02	5.74	438	9.80	96	8.48
TLO	08/22/00	10:30	0.22	3.9	0.07	0.18	0.17	5.0	15j	336	69.1	79	148	17.42	6.40	427	9.90	104	8.81
TLO	09/12/00	10:45	0.11	2.4	1.28	0.30	0.08	9.0	57	380	49.9	129	179	18.08	8.62	517	9.60	332	18.27
TLO	09/26/00	13:00	0.06	4.2	**0.03**	0.29	0.11	13.0	40j	377	65.3	130	195	14.20	10.43	495	9.54	173	26.53
TLO	10/17/00	08:00	0.06	3.9	**0.04**	0.42	**0.05**	11.0	74	356	17.3	181	198	9.96	9.49	500	9.17	158	55.4
TLO	10/31/00	13:30	0.55	2.7	0.17	0.24	0.07	9.0	28j	253	<1.4	205	205	7.19	10.30	368	8.77	203	67.3
TLO	11/14/00	13:00	0.12	3.6	0.06	0.27	0.06	12	38j	350	24	197	222	1.87	12.17	452	9.18	252	57.1
		average	0.22	3.0	0.48	0.39	0.19	8.5	-	383	-	178	219	14.98	8.66	518	-	255	31.9
		minimum	0.04	2.0	0.01	0.18	0.05	4.0	-	253	<1.4	79	148	1.87	5.74	368	8.77	96	8.5
		maximum	0.74	4.9	2.62	0.82	0.43	23.0	74	536	69.1	321	357	22.02	12.17	732	9.90	412	67.3
		median	0.14	2.6	0.16	0.37	0.17	6.5	-	373	-	181	198	17.38	8.74	492	-	228	23.4
		std. dev	0.209	0.95	0.716	0.174	0.120	5.13	-	71.5	-	75.4	66.2	6.085	1.865	110.8	-	127.6	22.07
		X_{25}	0.08	2.2	0.04	0.27	0.08	5.0	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	0.31	3.9	0.60	0.45	0.25	11.0	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)
If more than 50% of the data are censored, values below the detection limit are not estimated.

Table C-2 Klamath Straits Drain at Headworks (KSDH) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KSDH	05/01/00	14:15	0.09	2.3	1.00	0.52	0.51	5.0	0.80j	-	-	-	-	-	-	-	-	-	6.77
KSDH	05/09/00	11:56	0.55	2.4	<0.05	0.47	0.37	4.0	22j	527	<1.4	348	348	14.16	8.95	663	8.54	304	-
KSDH	05/23/00	12:50	0.51	2.3	<0.05	0.69	0.59	3.0	3.40j	592	10	400	410	21.74	9.18	829	9.08	-	14.57
KSDH	06/06/00	11:30	0.19	2.7	0.55	0.36	0.33	4.0	3.48j	596	<1.4	342	342	19.95	8.37	819	9.22	495	12.1
KSDH	06/20/00	13:45	0.26	5.4	<0.05	0.63	0.46	**1.2**	1j	1150	<1.4	439	439	23.79	7.24	1495	9.09	411	6.28
KSDH	07/11/00	11:20	0.31	2.0	0.56	0.51	0.51	**1.4**	5j	390	48	132	180	22.20	8.02	504	9.31	351	4.59
KSDH	07/25/00	11:05	0.15	2.4	<0.05	0.91	0.27	**1.7**	2j	365	40	131	171	22.97	5.24	487	9.30	432	5.52
KSDH	08/08/00	12:10	0.09	2.4	0.58	0.24	0.24	6.0	18j	342	29	127	156	23.73	7.03	419	9.37	108	6.39
KSDH	08/22/00	11:30	0.1	3.9	<0.05	0.17	0.17	**2.1**	2j	463	51.8	172	224	19.71	8.29	623	9.40	111	5.44
KSDH	09/12/00	11:30	**0.03**	3.8	<0.05	0.33	**0.05**	16.0	95	370	54.7	139	193	19.58	11.67	570	9.73	317	30.4
KSDH	09/26/00	12:10	5.58	8.6	<0.05	0.64	0.22	12.0	51	477	<1.4	336	336	14.53	1.46	698	7.77	197	289.67
KSDH	10/17/00	09:15	2.24	5.0	0.07	0.83	0.15	19.0	136	470	<1.4	420	420	5.39	7.85	720	8.01	201	112.33
KSDH	10/31/00	12:30	**0.04**	3.7	<0.05	0.40	0.11	4.0	74	453	24.0	351	376	5.85	11.33	638	9.11	210	24.3
KSDH	11/14/00	11:45	0.43	2.0	0.21	0.24	0.09	5	30j	369	<1.4	264	264	2.97	11.98	568	7.67	196	14.37
		average	0.76	3.5	-	0.50	0.29	6.0	-	505	-	277	297	16.66	8.20	695	-	278	41.0
		minimum	0.03	2.0	<0.05	0.17	0.05	1.2	-	342	<1.4	127	156	2.97	1.46	419	7.67	108	4.6
		maximum	5.58	8.6	1.00	0.91	0.59	19.0	136	1150	54.7	439	439	23.79	11.98	1495	9.73	495	289.7
		median	0.23	2.6	-	0.49	0.26	4.0	-	463	-	336	336	19.71	8.29	638	-	257	12.1
		std. dev	1.498	1.84	-	0.224	0.174	5.59	-	211.1	-	120.8	102.9	7.460	2.804	269.4	-	126.7	80.10
		X_{25}	0.09	2.3	-	0.33	0.15	2.1	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	0.51	3.9	-	0.64	0.46	6.0	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table C-3 Klamath Straits Drain at Highway 97(KSD97) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KSD97	05/01/00	11:45	0.19	2.3	1.29	0.61	0.56	8.0	6.99j	-	-	-	-	-	-	-	-	-	18
KSD97	05/09/00	08:00	0.67	2.3	0.37	0.57	0.40	4.0	<0.01j	369	<1.4	236	236	14.23	6.62	460	8.38	311	-
KSD97	05/23/00	11:30	0.80	**1.6**	0.08	0.62	0.49	5.0	7.12j	510	10	324	334	20.82	6.80	707	8.94	-	-
KSD97	06/06/00	10:00	0.34	2.2	0.68	0.48	0.36	4.0	4.11j	409	<1.4	262	262	19.81	5.79	561	8.95	575	16.37
KSD97	06/20/00	11:00	0.72	3.9	0.06	0.90	0.62	6.0	13j	491	<1.4	230	230	21.19	2.18	663	8.02	487	-
KSD97	07/11/00	09:30	0.80	2.1	1.00	0.76	0.66	3.0	2j	368	<1.4	187	187	21.63	3.14	516	8.57	374	8.99
KSD97	07/25/00	09:15	0.22	2.4	0.64	0.66	0.35	8.0	9j	279	<1.4	142	142	22.86	1.69	340	7.75	542	13.37
KSD97	08/08/00	07:50	0.82	2.8	1.12	0.27	0.25	**3.0**	5j	347	<1.4	180	180	23.23	2.26	475	8.46	335	8.49
KSD97	08/22/00	08:45	0.24	5.0	1.22	0.31	0.29	7.0	15j	395	<1.4	207	207	19.83	1.62	522	7.89	91	6.27
KSD97	09/12/00	08:30	0.29	2.5	1.35	0.28	0.11	8.0	49	386	24	171	195	17.55	4.98	528	9.20	230	16.33
KSD97	09/26/00	10:00	1.73	4.8	2.29	0.27	0.23	7.0	0j	382	<1.4	248	248	12.97	2.76	525	7.65	208	8.34
KSD97	10/17/00	10:30	2.47	4.0	0.21	0.29	0.14	4.0	4j	472	<1.4	349	349	9.91	3.20	740	7.60	198	14.87
KSD97	10/31/00	09:00	0.57	1.8	0.53	0.10	0.09	4.0	28j	396	<1.4	234	234	6.74	7.09	565	7.92	216	7.89
KSD97	11/14/00	09:00	0.07	2.1	0.14	0.14	**0.05**	7	75	430	<1.4	244	244	4.14	10.01	590	8.51	450	13.5
		average	0.71	2.8	0.78	0.45	0.33	5.6	-	403	-	232	234	16.53	4.47	553	-	335	12.0
		minimum	0.07	1.6	0.06	0.10	0.05	3.0	-	279	<1.4	142	142	4.14	1.62	340	7.60	91	6.3
		maximum	2.47	5.0	2.29	0.90	0.66	8.0	75	510	24.0	349	349	23.23	10.01	740	9.20	575	18.0
		median	0.62	2.4	0.66	0.40	0.32	5.5	-	395	-	234	234	19.81	3.20	528	-	323	13.4
		std. dev	0.659	1.11	0.634	0.243	0.199	1.91	-	62.2	-	58.4	58.0	6.357	2.612	106.5	-	153.3	4.13
		X_{25}	0.24	2.1	0.21	0.27	0.14	4.0	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	0.80	3.9	1.22	0.62	0.49	7.0	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table C-4 Klamath River at Miller Island (KRMI) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KRMI	05/01/00	10:30	**0.05**	0.9	**0.03**	0.22	0.16	4.0	11.0j	-	-	-	-	-	-	-	-	-	7.22
KRMI	05/09/00	14:36	0.29	0.8	**0.04**	0.34	0.27	**2.7**	17.0j	31	<1.4	61	61	14.76	8.66	104	7.86	362	-
KRMI	05/23/00	09:15	0.27	0.8	**0.05**	0.28	0.28	4.0	19j	74	<1.4	60	60	18.26	9.13	108	8.43	-	8.12
KRMI	06/06/00	07:30	0.12	2.0	1.69	0.37	0.15	8.0	288	90	<1.4	51	51	18.77	10.63	102	9.33	564	50.57
KRMI	06/20/00	08:40	0.30	4.0	0.19	0.71	0.38	6.0	96	80	<1.4	55	55	19.11	3.10	103	9.33	510	37.73
KRMI	07/11/00	07:30	0.63	2.4	1.79	0.56	0.52	8.0	81	115	9	51	59	19.54	2.38	107	9.01	470	48.27
KRMI	07/25/00	08:00	0.84	3.7	2.05	0.44	0.22	10.0	22j	106	<1.4	21	21	22.77	0.29	117	8.54	428	7.11
KRMI	08/08/00	06:50	1.53	3.2	2.30	0.24	0.24	7.0	6j	123	<1.4	73	73	23.56	1.20	121	7.59	-47	6.45
KRMI	08/22/00	13:30	0.91	2.8	0.18	0.08	0.06	**3.0**	6j	138	<1.4	74	74	20.00	3.03	126	7.17	186	3.98
KRMI	09/12/00	13:15	0.36	0.8	0.70	0.25	0.14	5.0	25j	144	<1.4	128	128	16.95	2.03	205	7.21	393	24.1
KRMI	09/26/00	07:45	0.35	1.6	0.26	0.19	0.15	4.0	11j	151	<1.4	120	120	14.50	3.09	202	7.54	54	28.83
KRMI	10/17/00	13:30	0.47	2.1	0.10	0.15	0.05	5.0	33j	140	<1.4	76	76	11.46	5.26	134	7.39	169	15.7
KRMI	10/31/00	08:30	0.40	1.7	0.13	0.08	**0.05**	5.0	14j	102	<1.4	71	71	7.48	5.45	118	7.34	178	9.22
KRMI	11/14/00	08:00	0.43	1.4	0.42	0.09	0.07	**3.0**	4j	107	<1.4	82	82	4.19	6.32	156	7.34	448	13.6
		average	0.50	2.0	0.71	0.29	0.20	5.3	-	108	-	71	72	16.26	4.66	131	-	310	20.1
		minimum	0.05	0.8	0.03	0.08	0.05	2.7	-	31	<1.4	21	21	4.19	0.29	102	7.17	-47	4.0
		maximum	1.53	4.0	2.30	0.71	0.52	10.0	288	151	9.0	128	128	23.56	10.63	205	9.33	564	50.6
		median	0.38	1.9	0.23	0.25	0.16	5.0	-	107	-	71	71	18.26	3.10	118	-	378	13.6
		std. dev	0.383	1.08	0.848	0.186	0.136	2.20	-	33.6	-	28.3	28.0	5.704	3.242	35.5	-	195.0	16.40
		X_{25}	0.29	0.9	0.10	0.15	0.07	4.0	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	0.63	2.8	1.69	0.37	0.27	7.0	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table C-5 Klamath River at Keno (KRK) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
KRK	05/01/00	13:00	**0.05**	0.9	0.34	0.23	0.17	5.0	7.01j	-	-	-	-	13.54	8.90	133	7.66	419	6.59
KRK	05/09/00	12:58	0.36	0.8	0.07	0.61	0.12	**1.3**	2.34j	100	<1.4	75	75	13.99	7.80	129	7.58	354	-
KRK	05/23/00	13:30	0.35	1.2	0.05	0.36	0.34	5.0	18j	227	<1.4	156	156	19.10	8.52	315	9.00	-	7.72
KRK	06/06/00	08:45	0.12	1.4	0.39	0.27	0.33	**1.5**	20j	182	<1.4	119	119	18.19	8.57	237	8.96	604	10.05
KRK	06/20/00	09:45	0.68	2.2	0.07	0.46	0.38	4.0	6j	130	<1.4	68	68	19.41	3.32	152	8.95	548	4.98
KRK	07/11/00	08:50	0.71	1.8	1.31	0.62	0.62	4.0	15j	138	<1.4	72	72	18.97	1.72	165	7.89	444	3.5
KRK	07/25/00	13:15	0.46	2.6	1.08	0.40	0.24	8.0	20j	184	1.9	53	55	23.12	2.87	220	8.41	408	4.7
KRK	08/08/00	10:45	1.11	3.0	1.89	0.24	0.25	8.0	22j	145	<1.4	82	82	23.08	0.53	155	7.71	-185	5.02
KRK	08/22/00	12:30	1.47	3.5	0.10	0.14	0.16	**1.8**	17j	168	<1.4	89	89	20.36	3.02	176	7.28	177	2.64
KRK	09/12/00	12:30	0.41	2.0	1.06	0.24	0.11	8.0	35j	202	<1.4	135	135	16.72	5.80	272	7.94	364	12.93
KRK	09/26/00	09:00	0.43	1.5	0.13	0.17	0.17	**2.0**	0j	178	<1.4	139	139	15.19	2.50	231	7.51	185	13
KRK	10/17/00	12:30	0.53	1.7	0.23	0.13	0.07	**2.4**	4j	94	<1.4	84.9	84.9	11.61	2.80	150	7.22	202	9.8
KRK	10/31/00	11:30	0.26	1.2	0.31	0.05	**0.05**	3.0	1j	110	<1.4	69	69	7.98	6.10	131	7.17	265	10.09
KRK	11/14/00	11:00	0.27	1.0	0.48	0.08	0.06	**2.7**	2j	102	<1.4	80	80	4.39	5.46	149	7.13	480	7.77
		average	0.52	1.8	0.54	0.29	0.22	4.0	-	151	-	94	94	16.12	4.85	187	-	328	7.6
		minimum	0.05	0.8	0.05	0.05	0.05	1.3	-	94	<1.4	53	55	4.39	0.53	129	7.13	-185	2.6
		maximum	1.47	3.5	1.89	0.62	0.62	8.0	-	227	1.9	156	156	23.12	8.90	315	9.00	604	13.0
		median	0.42	1.6	0.33	0.24	0.17	3.5	-	145	-	82	82	17.46	4.39	160	-	364	7.7
		std. dev	0.382	0.81	0.571	0.182	0.157	2.45	-	42.8	-	32.2	32.0	5.436	2.815	58.3	-	204.9	3.40
		X_{25}	0.27	1.2	0.10	0.14	0.11	2.0	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	0.68	2.2	1.06	0.40	0.33	5.0	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table C-6 Klamath River above Copco Reservoir (KRCR) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
KRCR	05/09/00	13:50	0.10	**0.2**	0.19	0.24	0.23	3.0	2.67j	102	<1.4	70	70	-	-	-	-	-	-
KRCR	05/23/00	16:10	0.23	0.3	0.25	0.25	0.13	<3.0	0.80j	183	<1.4	127	127	19.97	8.65	251	8.31	317	8.47
KRCR	06/06/00	13:10	0.10	1.0	0.30	0.30	0.26	<3.0	5.72j	176	<1.4	113	113	18.81	7.96	231	8.45	281	6.48
KRCR	06/20/00	16:35	0.21	1.8	0.57	0.43	0.39	<3.0	6j	96	<1.4	70	70	18.27	7.86	144	8.45	304	5.43
KRCR	07/11/00	14:15	<0.05	0.5	0.41	0.42	0.16	<3.0	2j	104	<1.4	75	75	17.02	8.04	143	8.44	289	0.69
KRCR	07/25/00	13:40	0.08	0.3	0.42	0.33	0.25	<3.0	2j	144	<1.4	78	78	21.02	9.49	169	8.75	298	2.86
KRCR	08/07/00	15:13	<0.05	1.0	0.61	0.16	0.17	<3.0	23j	129	<1.4	76	76	19.62	8.11	145	8.41	322	4.01
KRCR	08/22/00	14:55	<0.05	0.8	0.36	0.08	**0.05**	<3.0	2j	136	9.6	74	84	17.86	9.53	145	8.71	327	2.57
KRCR	09/12/00	14:35	<0.05	0.6	0.38	0.14	0.10	2.0	20j	164	9.6	103	112	18.15	9.71	232	8.23	152	1.42
KRCR	09/26/00	13:45	<0.05	0.6	0.31	0.11	0.12	<3.0	1j	115	<1.4	108	108	13.91	10.97	182	8.76	-	2.13
KRCR	10/17/00	14:00	0.05	0.9	0.68	0.17	0.09	<3.0	1j	156	<1.4	83	83	10.00	-	-	-	-	-
KRCR	10/31/00	12:30	<0.05	0.5	0.49	0.06	0.05	3.0	1j	109	<1.4	75	75	9.02	10.75	127	8.57	332	6.09
KRCR	11/14/00	13:15	<0.05	**0.2**	0.43	0.07	0.08	<3	1j	122	<1.4	79	79	5.76	11.38	135	8.34	381	3.58
		average	-	0.7	0.42	0.21	0.16	-	-	134	-	87	89	15.78	9.31	173	-	300	4.0
		minimum	<0.05	0.2	0.19	0.06	0.05	2.0	-	96	<1.4	70	70	5.76	7.86	127	8.23	152	0.7
		maximum	0.23	1.8	0.68	0.43	0.39	3.0	-	183	9.6	127	127	21.02	11.38	251	8.76	381	8.5
		median	-	0.6	0.41	0.17	0.13	-	-	129	-	78	79	18.01	9.49	145	-	311	3.6
		std. dev	-	0.44	0.143	0.128	0.099	-	-	29.1	-	18.9	19.3	4.951	1.295	44.6	-	59.2	2.39
		X_{25}	-	0.3	0.31	0.11	0.09	-	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	-	0.9	0.49	0.30	0.23	-	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)
If more than 50% of the data are censored, values below the detection limit are not estimated.

Table C-7 Klamath River below Iron Gate Reservoir (KRIG) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
KRIG	05/09/00	13:00	0.30	**0.2**	0.15	0.29	0.18	<3.0	1.34j	76	<1.4	70	70	-	-	-	-	-	-
KRIG	05/23/00	14:22	0.26	**0.2**	0.10	0.26	0.26	<3.0	4.50j	86	<1.4	83	83	15.42	9.76	155	8.32	307	4.67
KRIG	06/06/00	12:18	0.10	0.7	0.06	0.21	0.29	<3.0	5.07j	153	<1.4	106	106	17.99	8.57	207	8.28	298	-
KRIG	06/20/00	15:42	0.05	1.6	0.18	0.41	0.34	<3.0	1j	159	<1.4	107	107	19.81	7.69	211	7.92	322	2.01
KRIG	07/11/00	13:00	0.30	4.5	0.28	0.32	0.12	<3.0	3j	129	<1.4	90	90	20.50	7.31	180	7.74	305	1.36
KRIG	07/25/00	12:30	0.09	0.8	0.36	0.11	0.19	<3.0	2j	129	<1.4	87	87	21.54	8.06	168	8.44	301	1.37
KRIG	08/07/00	12:15	**0.02**	1.8	0.24	0.11	0.15	<3.0	11j	132	3.8	80	84	23.00	7.98	171	8.51	371	-
KRIG	08/22/00	13:35	**0.02**	1.3	0.24	0.13	0.17	<3.0	6j	146	<1.4	84	84	21.29	6.63	171	8.45	330	2.39
KRIG	09/12/00	13:30	0.06	0.9	0.58	0.20	0.17	3.0	6j	131	<1.4	87	87	19.35	5.91	188	7.01	179	1.03
KRIG	09/26/00	12:20	**0.03**	0.7	0.57	0.13	0.15	<3.0	1j	131	<1.4	81	81	17.35	6.00	165	7.61	-	1.8
KRIG	10/17/00	12:50	0.07	0.7	0.52	0.19	0.15	<3.0	2j	136	<1.4	102	102	13.00	-	-	-	-	-
KRIG	10/31/00	11:30	**0.03**	0.7	0.63	0.10	0.13	14.0	0j	133	<1.4	93	93	12.59	6.34	171	7.47	356	5.42
KRIG	11/14/00	12:05	0.09	0.6	0.65	0.12	0.12	<3	1j	122	<1.4	84	84	9.81	6.46	152	7.30	404	3.88
		average	0.11	1.1	0.35	0.20	0.19	-	-	128	-	89	89	17.64	7.34	176	-	317	2.7
		minimum	0.02	0.2	0.06	0.10	0.12	<3.0	-	76	<1.4	70	70	9.81	5.91	152	7.01	179	1.0
		maximum	0.30	4.5	0.65	0.41	0.34	14.0	-	159	3.8	107	107	23.00	9.76	211	8.51	404	5.4
		median	0.07	0.7	0.28	0.19	0.17	-	-	131	-	87	87	18.67	7.31	171	-	315	2.0
		std. dev	0.105	1.12	0.213	0.097	0.069	-	-	23.3	-	10.7	10.5	4.118	1.206	19.0	-	59.7	1.60
		X_{25}	0.03	0.7	0.18	0.12	0.15	-	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	0.10	1.3	0.57	0.26	0.19	-	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table C-8 Klamath River near Seiad Valley (KRSV) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (°C)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
KRSV	05/09/00	10:30	0.64	**0.17**	**0.02**	0.29	0.19	<3.0	0.53j	85	<1.4	90	90	-	-	-	-	-	-
KRSV	05/23/00	12:01	0.19	**0.2**	0.05	0.17	0.17	3.0	2.40j	92	<1.4	78	78	16.42	9.57	138	8.24	312	10.53
KRSV	06/06/00	09:50	0.05	0.4	**0.03**	0.12	0.16	<3.0	0.53j	114	<1.4	93	93	15.91	8.80	125	8.07	298	-
KRSV	06/20/00	11:47	0.18	1.2	0.09	0.37	0.23	<3.0	0j	140	<1.4	107	107	19.30	8.85	202	8.22	326	2.47
KRSV	07/11/00	10:00	0.26	0.2	**0.04**	0.32	0.32	<3.0	0j	134	<1.4	111	111	20.88	7.55	212	8.23	328	2.54
KRSV	07/25/00	09:55	0.22	1.4	0.09	0.26	0.14	<3.0	2j	155	<1.4	45	45	21.87	8.39	197	8.23	320	1.54
KRSV	08/07/00	11:45	0.05	1.2	0.10	0.11	0.13	<3.0	9j	138	<1.4	96	96	-	-	-	-	-	-
KRSV	08/22/00	10:30	**0.01**	1.6	0.11	0.12	0.14	<3.0	7j	153	<1.4	99	99	21.06	8.27	190	8.44	320	4.23
KRSV	09/12/00	10:30	0.07	0.7	0.39	0.17	0.15	<3.0	0j	149	<1.4	108	108	19.73	7.50	219	7.58	130	2.14
KRSV	09/26/00	10:30	**0.01**	0.9	0.42	0.12	0.14	<3.0	3j	149	<1.4	104	104	15.60	9.48	197	8.22	-	2.27
KRSV	10/17/00	10:10	**0.02**	0.6	0.44	0.16	0.13	<3.0	0j	165	<1.4	132	132	11.00	-	-	-	-	-
KRSV	10/31/00	08:45	**0.03**	0.5	0.48	0.09	0.11	3.0	2j	160	<1.4	139	139	11.20	9.87	213	7.97	342	5.29
KRSV	11/14/00	09:20	0.05	0.3	0.53	0.09	0.11	<3	1j	156	<1.4	110	110	6.86	10.83	202	7.96	395	3.59
		average	0.14	0.7	0.21	0.18	0.16	-	-	138	-	101	101	16.35	8.91	190	-	308	3.8
		minimum	0.01	0.17	0.02	0.09	0.11	<3.0	-	85	<1.4	45	45	6.86	7.50	125	7.58	130	1.5
		maximum	0.64	1.6	0.53	0.37	0.32	3.0	-	165	-	139	139	21.87	10.83	219	8.44	395	10.5
		median	0.05	0.6	0.10	0.16	0.14	-	-	149	-	104	104	16.42	8.83	200	-	320	2.5
		std. dev	0.174	0.49	0.200	0.094	0.057	-	-	25.5	-	23.4	23.4	4.892	1.049	31.9	-	72.1	2.77
		X_{25}	0.03	0.3	0.05	0.12	0.13	-	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	0.19	1.2	0.42	0.26	0.17	-	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)
If more than 50% of the data are censored, values below the detection limit are not estimated.

Table C-9 Shasta River near Mouth (SHR) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+	TKN	$NO_3^- + NO_2^-$	TP	PO_4^{3-}	BOD	Chlor_a	TDS	CO_3^{2-}	HCO_3^-	Total Alk.	Tw	DO	EC	pH	Redox	Turb. (avg.)
			(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(^oC)	(mg/l)	US/cm		mV	NTU
SHR	05/09/00	12:15	0.48	0.2	<0.05	0.45	0.39	<3.0	1.34j	316	<1.4	339	339	-	-	-	-	-	-
SHR	05/23/00	13:35	0.22	**0.17**	<0.05	0.52	0.57	<3.0	0.50j	379	29	329	358	23.00	8.48	545	8.63	308	1.87
SHR	06/06/00	11:42	0.08	0.8	<0.05	0.31	0.48	<3.0	1.07j	335	34	319	353	17.95	9.34	509	8.57	284	-
SHR	06/20/00	13:45	0.27	1.5	<0.05	0.60	0.46	<3.0	3j	326	<1.4	311	311	22.93	7.91	491	8.59	305	8.97
SHR	07/11/00	12:00	0.32	0.3	<0.05	0.58	0.53	<3.0	2j	313	<1.4	287	287	21.71	8.32	481	8.57	286	5.45
SHR	07/25/00	11:25	**0.01**	0.5	<0.05	0.33	0.25	<3.0	1j	314	<1.4	295	295	22.39	8.51	496	8.61	309	2.08
SHR	08/07/00	10:45	0.05	1.0	<0.05	0.17	0.2	<3.0	3j	351	<1.4	311	311	21.75	8.38	525	8.35	369	-
SHR	08/22/00	12:35	**0.01**	0.6	<0.05	0.14	0.19	<3.0	0j	356	8	318	326	21.31	8.21	529	8.70	302	3.29
SHR	09/12/00	12:30	0.05	1.0	<0.05	0.21	0.18	<3.0	6j	399	<1.4	435	435	20.22	8.69	685	8.17	156	2.14
SHR	09/26/00	15:15	0.17	0.5	<0.05	0.13	0.16	<3.0	0j	343	24.0	352	376	16.46	9.14	516	8.73	-	3.1
SHR	10/17/00	12:00	**0.02**	0.4	0.26	0.24	0.16	<3.0	1j	299	<1.4	276	276	10.00	-	-	-	-	-
SHR	10/31/00	10:30	**0.02**	0.4	0.24	0.21	0.16	<3.0	0j	287	<1.4	268	268	9.01	10.80	425	8.47	326	4.29
SHR	11/14/00	11:20	**0.03**	**0.2**	0.24	0.13	0.17	<3	1j	309	<1.4	266	266	5.81	11.47	434	8.51	384	1.9
		average	0.13	0.6	-	0.31	0.30	-	-	333	-	316	323	17.71	9.02	512	-	303	3.7
		minimum	0.01	0.17	0.05	0.13	0.16	<3.0	-	287	<1.4	266	266	5.81	7.91	425	8.17	156	1.9
		maximum	0.48	1.5	0.26	0.60	0.57	-	-	399	34.0	435	435	23.00	11.47	685	8.73	384	9.0
		median	0.05	0.5	-	0.24	0.20	-	-	326	-	311	311	20.77	8.51	509	-	307	3.1
		std. dev	0.149	0.39	-	0.173	0.160	-	-	32.1	-	44.7	48.9	6.083	1.129	68.4	-	61.3	2.33
		X_{25}	0.02	0.3	-	0.17	0.17	-	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	0.22	0.8	-	0.45	0.46	-	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)
If more than 50% of the data are censored, values below the detection limit are not estimated.

Table C-10 Scott River near Ft. Jones (SCR) semi-monthly water quality data: summary statistics

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor_a (ug/l)	TDS (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Total Alk. (mg/l)	Tw (^oC)	DO (mg/l)	EC US/cm	pH	Redox mV	Turb. (avg.) NTU
SCR	05/09/00	09:40	0.52	**0.05**	0.15	0.21	0.08	<3.0	1.60j	73	<1.4	73	73	-	-	-	-	-	-
SCR	05/23/00	10:02	0.21	0.2	**0.05**	0.16	0.16	5.0	1.10j	56	<1.4	49	49	11.85	9.48	77	7.64	351	24.8
SCR	06/06/00	07:45	0.06	0.4	0.08	0.08	0.09	<3.0	0.27j	76	<1.4	75	75	13.34	8.49	113	7.53	318	6.02
SCR	06/20/00	09:46	0.09	0.9	0.27	0.21	0.16	<3.0	2j	100	<1.4	88	88	15.64	8.31	144	7.73	332	4.45
SCR	07/11/00	08:00	0.36	0.4	0.20	0.09	0.17	<3.0	2j	144	<1.4	142	142	17.02	7.31	229	7.76	312	1.25
SCR	07/25/00	08:00	<0.05	**0.06**	0.34	0.16	<0.05	<3.0	1j	178	<1.4	164	164	16.19	9.17	270	7.83	295	1
SCR	08/07/00	08:47	<0.05	0.5	0.25	0.05	<0.05	<3.0	46	164	<1.4	154	154	17.13	7.77	250	7.76	333	2.22
SCR	08/22/00	07:55	<0.05	0.5	0.12	**0.01**	<0.05	<3.0	3j	92	16.3	76	92	15.14	6.89	215	7.73	315	4.87
SCR	09/12/00	08:30	0.08	**0.08**	0.14	**0.02**	<0.05	<3.0	13j	156	<1.4	152	152	15.60	7.59	287	7.55	148	1.13
SCR	09/26/00	07:45	<0.05	0.2	0.30	**0.02**	<0.05	<3.0	2j	161	<1.4	165	165	11.91	7.86	277	7.85	-	1.77
SCR	10/17/00	08:20	<0.05	**0.10**	0.39	**0.03**	<0.05	<3.0	1j	178	<1.4	190	190	9.00	-	-	-	-	-
SCR	10/31/00	07:15	<0.05	**0.12**	0.40	**0.04**	<0.05	4.0	3j	169	<1.4	175	175	9.26	9.00	273	7.74	355	2.62
SCR	11/14/00	08:10	<0.05	**0.15**	0.47	**0.05**	<0.05	<3	5j	173	<1.4	170	170	6.13	9.70	272	7.79	401	0.94
		average	-	0.3	0.24	0.09	-	-	-	132	-	129	130	13.18	8.32	219	-	316	4.6
		minimum	<0.05	0.05	0.05	0.01	<0.05	<3.0	-	56	<1.4	49	49	6.13	6.89	77	7.53	148	0.9
		maximum	0.52	0.9	0.47	0.21	0.17	5.0	46.0	178	16.3	190	190	17.13	9.70	287	7.85	401	24.8
		median	-	0.2	0.25	0.05	-	-	-	156	-	152	152	14.24	8.31	250	-	325	2.2
		std. dev	-	0.25	0.133	0.073	-	-	-	45.5	-	48.6	47.3	3.582	0.926	73.7	-	66.0	6.91
		X_{25}	-	0.1	0.27	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
		X_{75}	-	0.4	0.30	0.16	-	-	-	-	-	-	-	-	-	-	-	-	-

Values in bold are estimated at or below the reporting limit (for nutrients and BOD only)
If more than 50% of the data are censored, values below the detection limit are not estimated.

D SEMI-MONTHLY DATA: GRAPHICAL PRESENTATION BY SITE

D.1 Tule Lake Outlet Channel

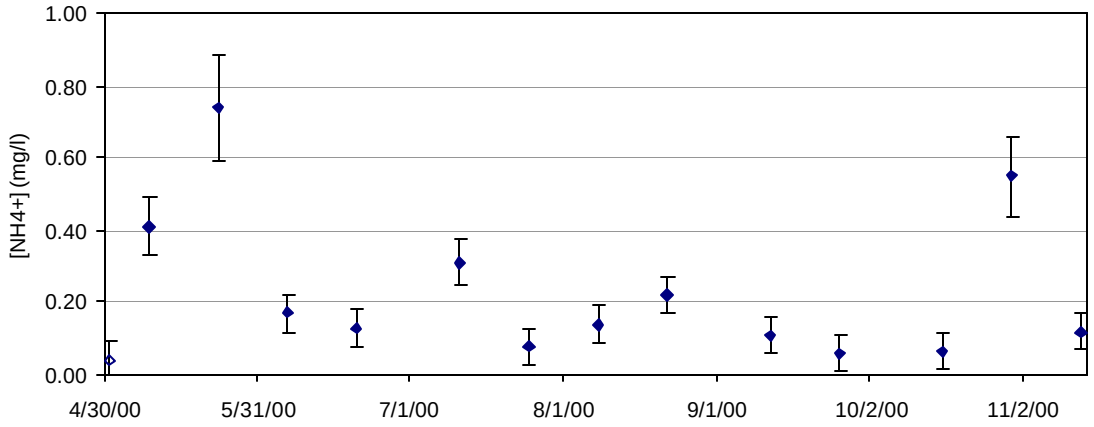


Figure D-1 Tule Lake outlet channel, ammonia concentration, May – November 2000

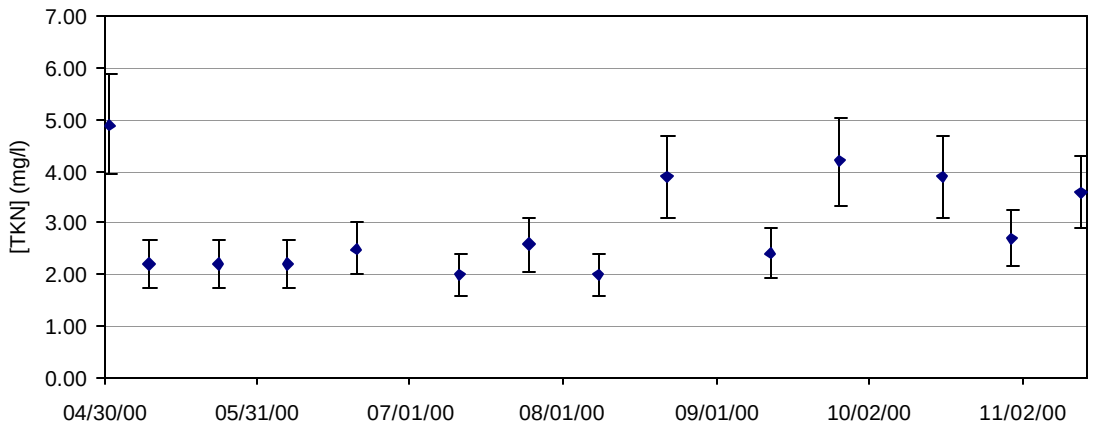


Figure D-2 Tule Lake outlet channel, total Kjeldahl nitrogen concentration, May – November 2000

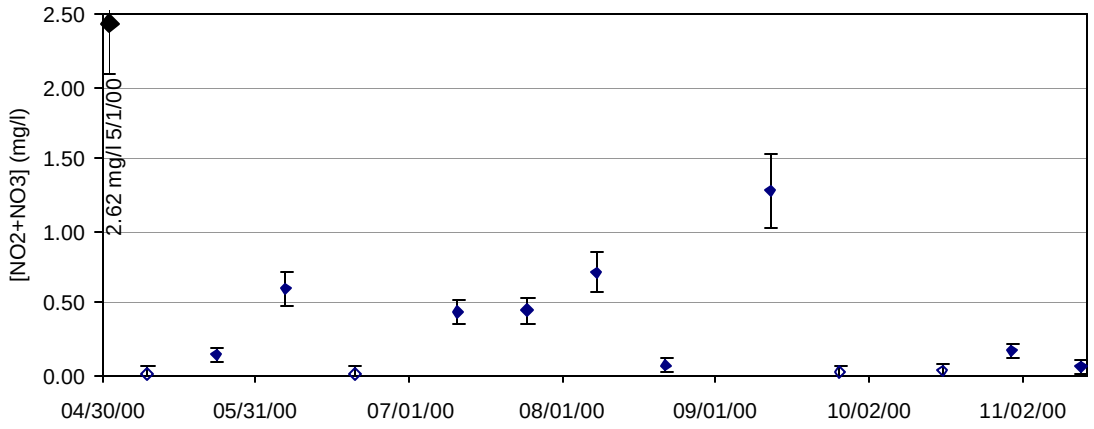


Figure D-3 Tule Lake outlet channel, nitrite plus nitrate concentration, May – November 2000

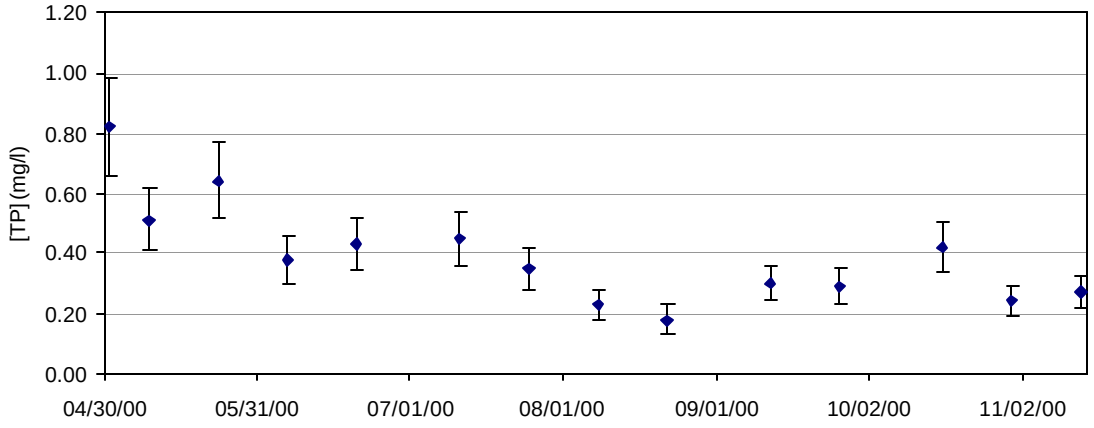


Figure D-4 Tule Lake outlet channel, total phosphorus concentration, May – November 2000

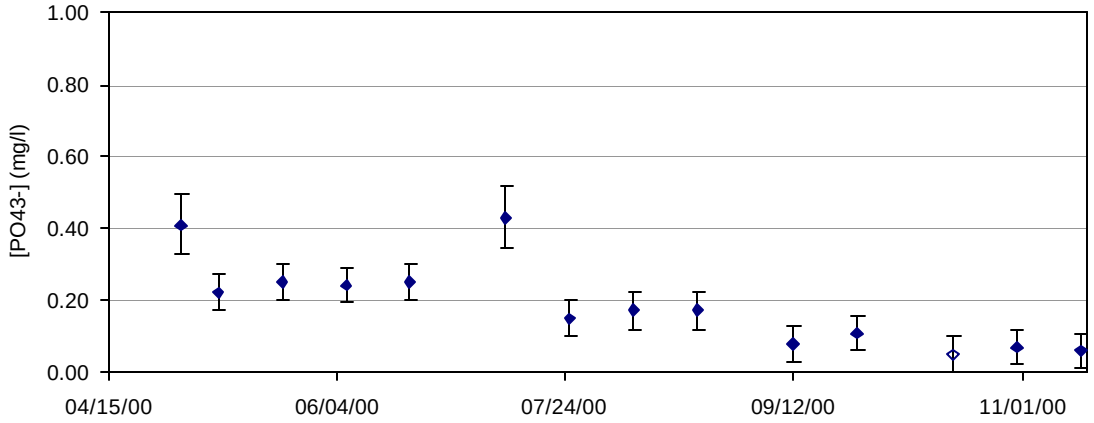


Figure D-5 Tule Lake outlet channel, orthophosphate concentration, May – November 2000

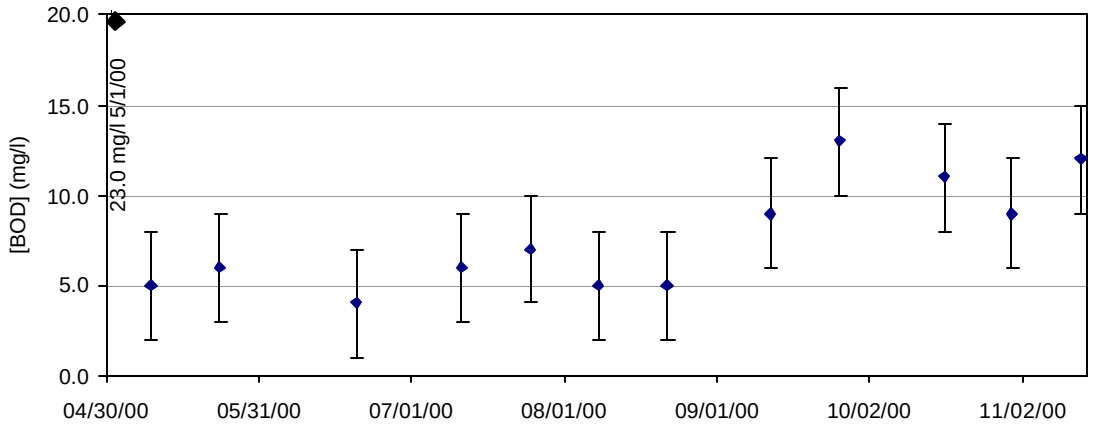


Figure D-6 Tule Lake outlet channel, BOD concentration, May – November 2000

D.2 Klamath Straits Drain at Headworks

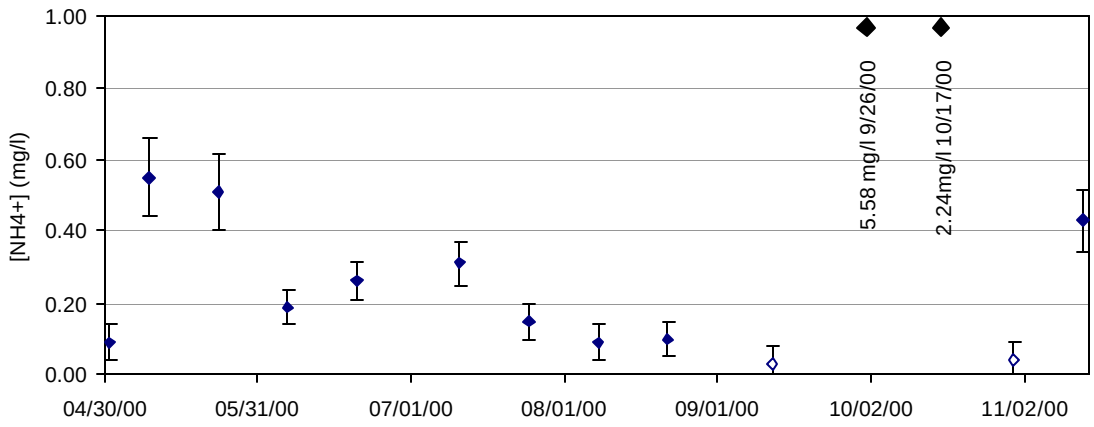


Figure D-7 Figure D?7 Klamath Straits Drain at ammonia, BOD concentration, May – November 2000

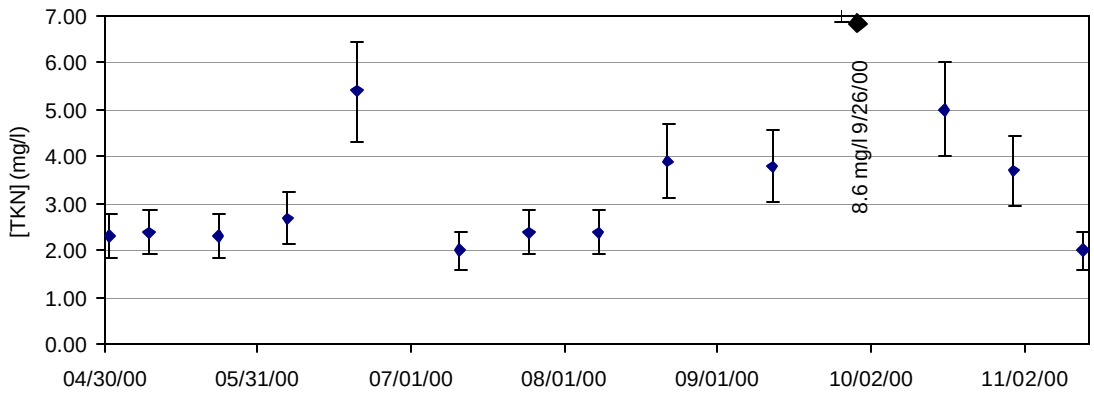


Figure D-8 Klamath Straits Drain at headworks, total Kjeldahl concentration, May – November 2000

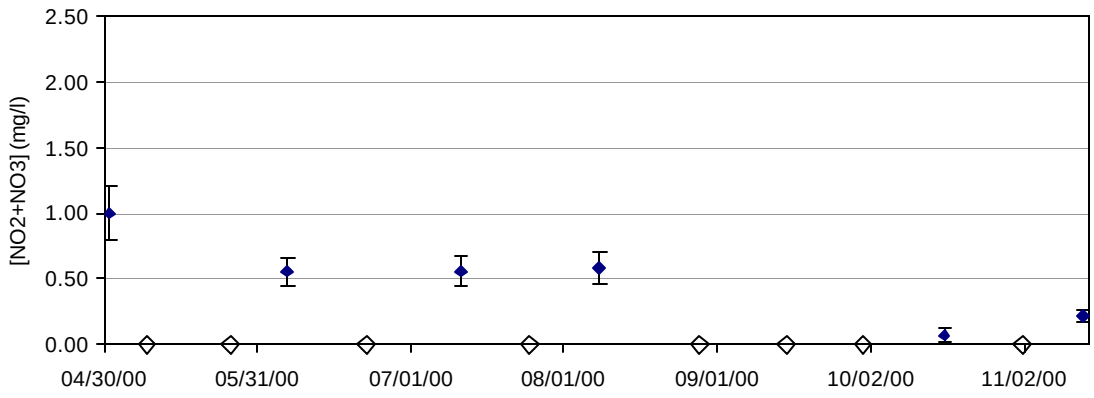


Figure D-9 Klamath Straits Drain at headworks, nitrate plus nitrite concentration, May – November 2000

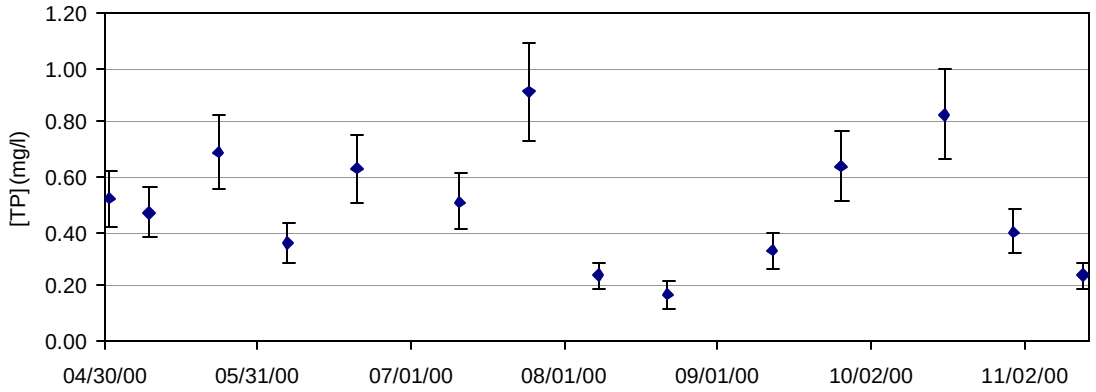


Figure D-10 Klamath Straits Drain at headworks, total phosphorous concentration, May – November 2000

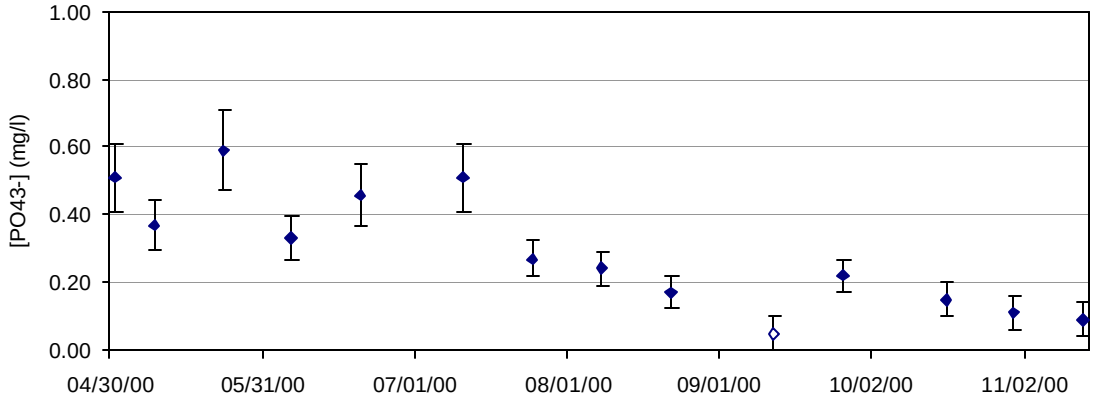


Figure D-11 Klamath Straits Drain at headworks, orthophosphate concentration, May – November 2000

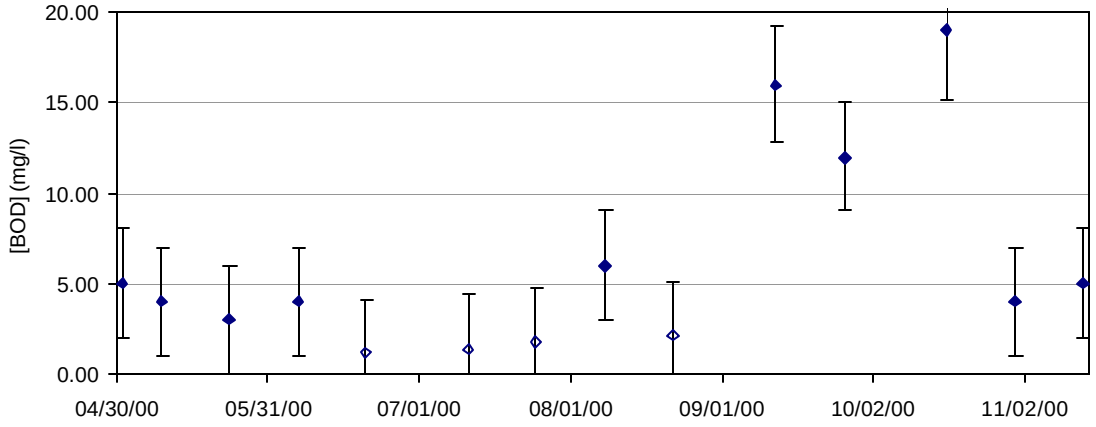


Figure D-12 Klamath Straits Drain at headworks, BOD concentration, May – November 2000

D.3 Klamath Straits Drain at Highway 97

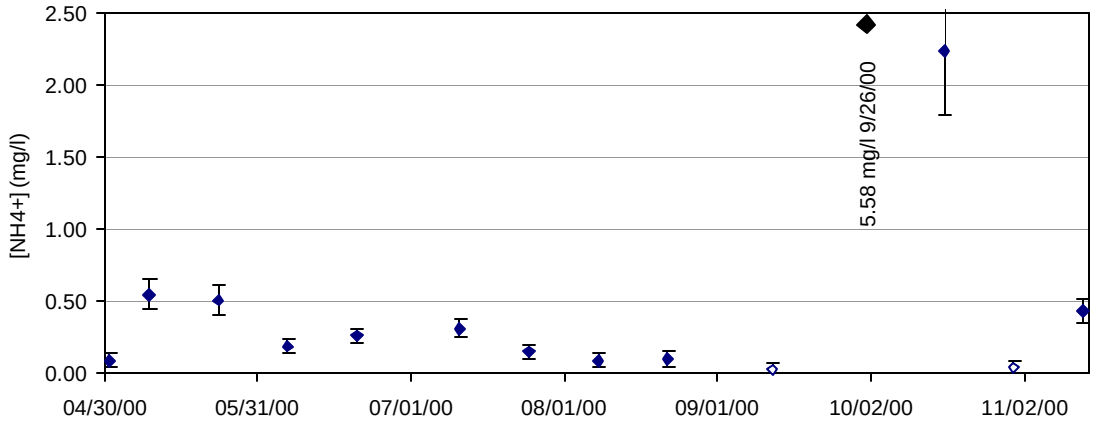


Figure D-13 Klamath Straits Drain at Highway 97, ammonia concentration, May – November 2000

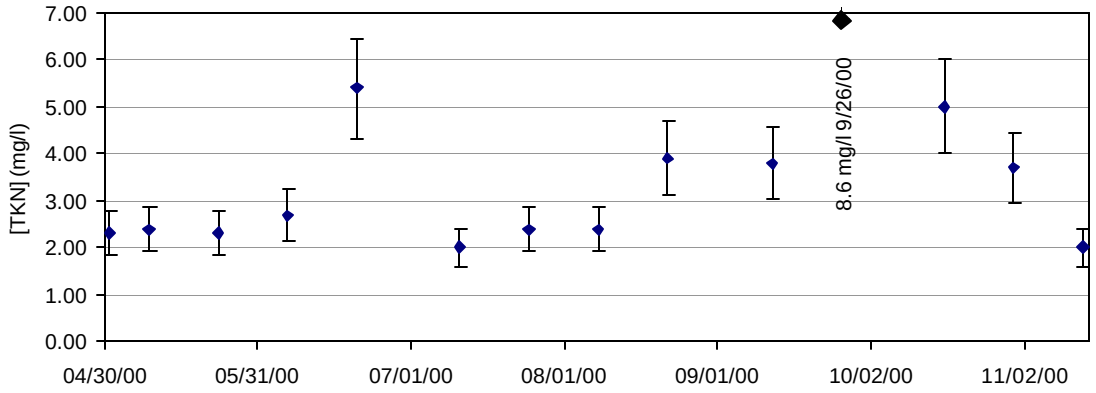


Figure D-14 Klamath Straits Drain at Highway 97, total Kjeldahl nitrogen concentration, May – November 2000

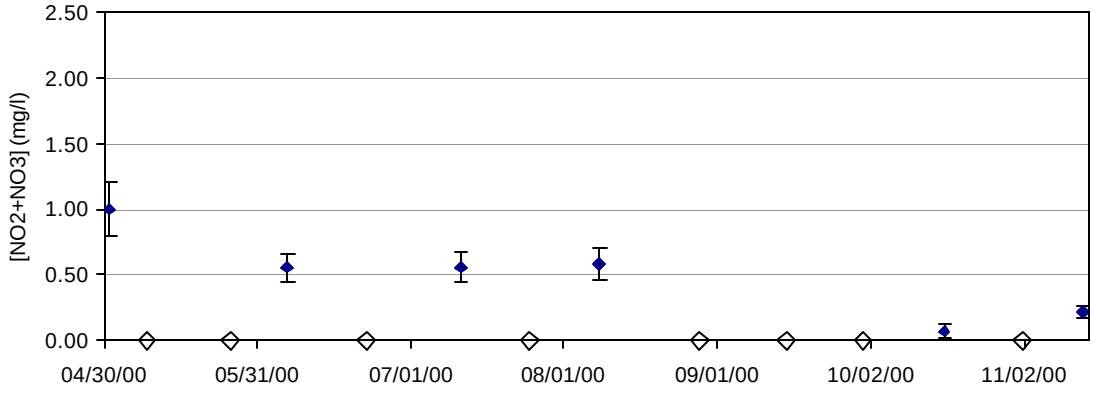


Figure D-15 Klamath Straits Drain at Highway 97, nitrate plus nitrite concentration, May – November 2000

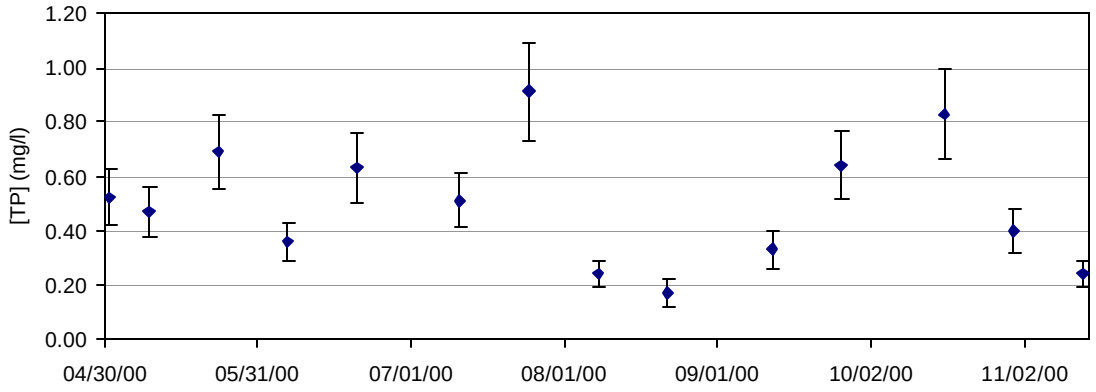


Figure D-16 Klamath Straits Drain at Highway 97, total phosphorous concentration, May – November 2000

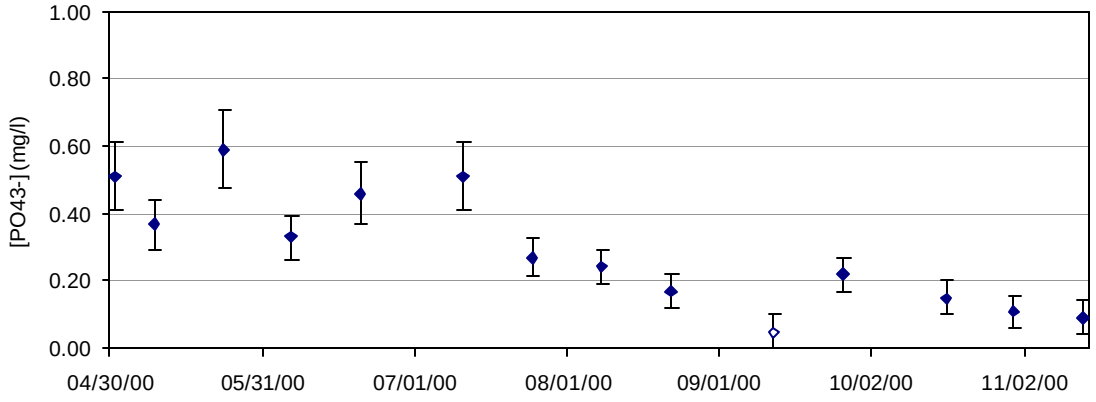


Figure D-17 Klamath Straits Drain at Highway 97, orthophosphate concentration, May – November 2000

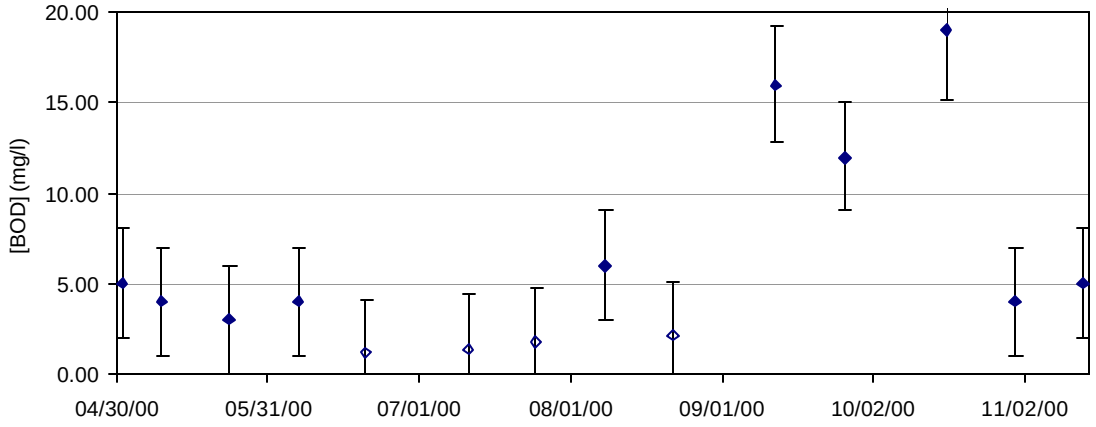


Figure D-18 Klamath Straits Drain at Highway 97, BOD concentration, May – November 2000

D.4 Klamath River at Miller Island

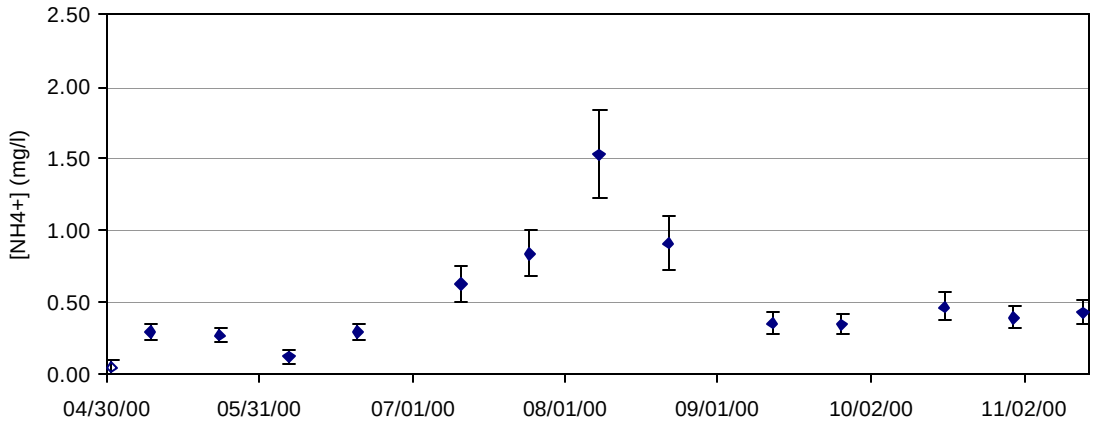


Figure D-19 Klamath River at Miller Island, ammonia concentration, May – November 2000

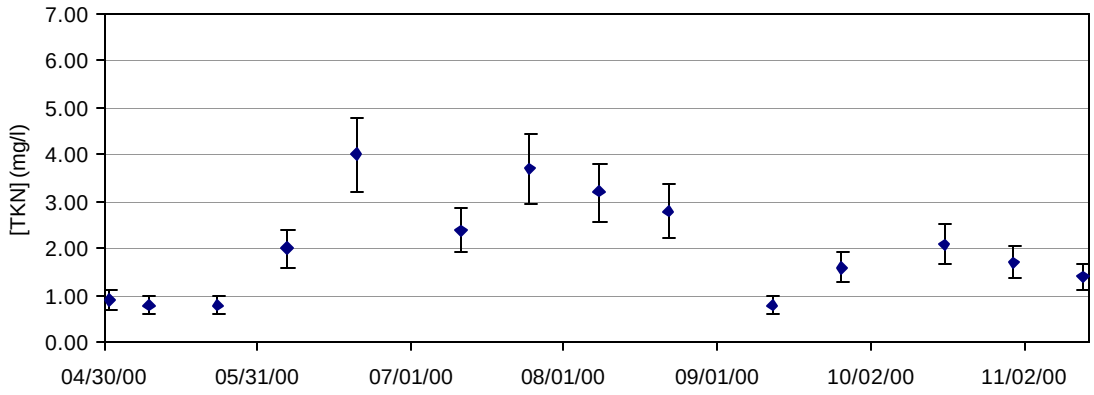


Figure D-20 Klamath River at Miller Island, total Kjeldahl nitrogen concentration, May – November 2000

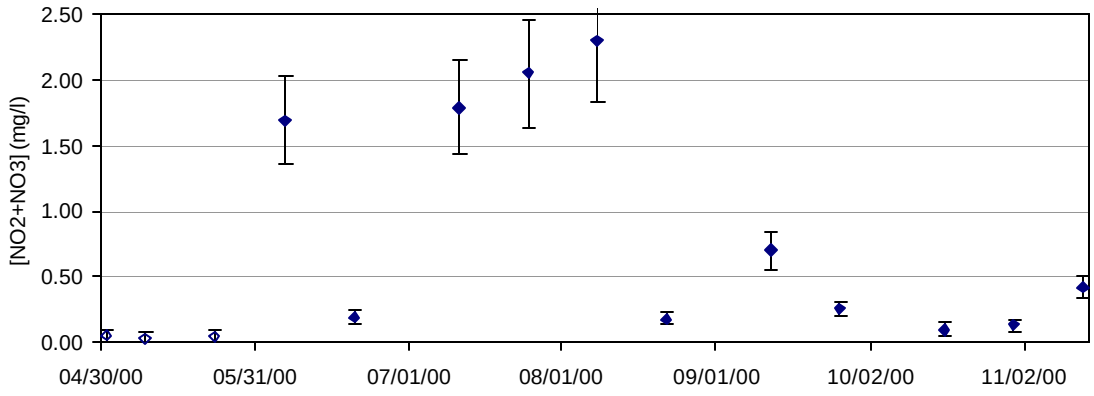


Figure D-21 Klamath River at Miller Island, nitrite plus nitrate concentration, May – November 2000

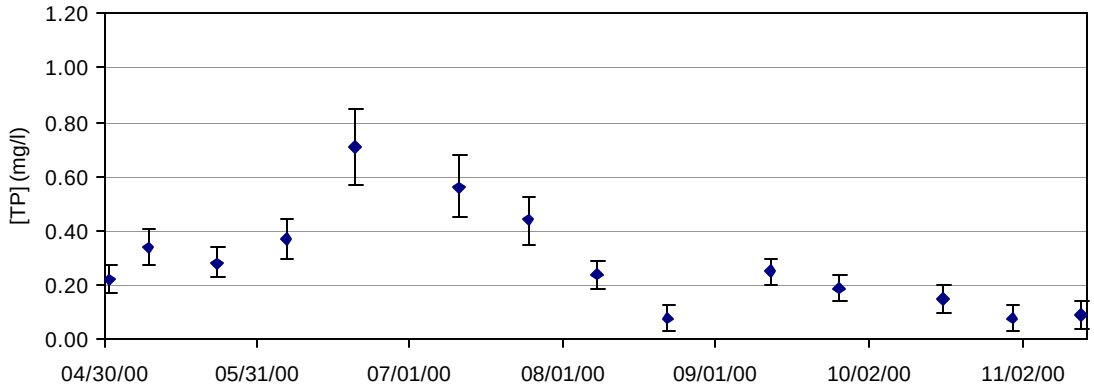


Figure D-22 Klamath River at Miller Island, total phosphorous concentration, May – November 2000

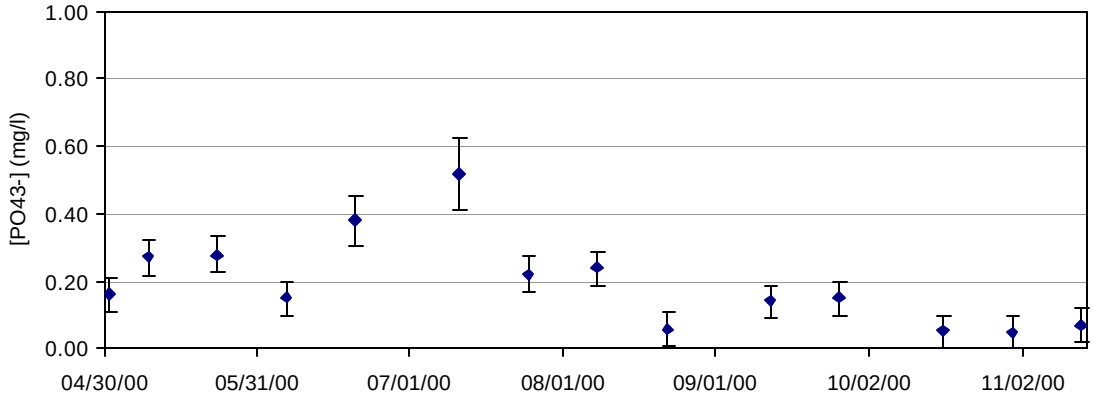


Figure D-23 Klamath River at Miller Island, orthophosphate concentration, May – November 2000

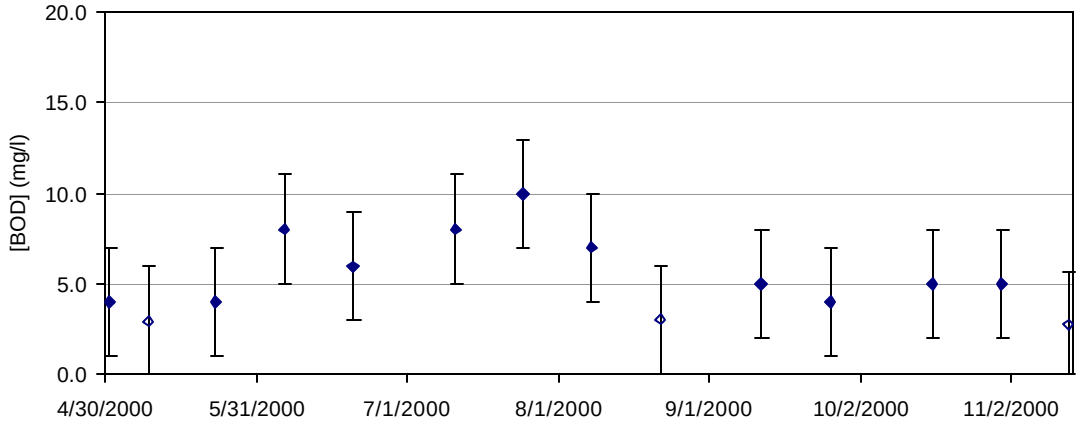


Figure D-24 Klamath River at Miller Island, BOD concentration, May – November 2000

D.5 Klamath River at Keno

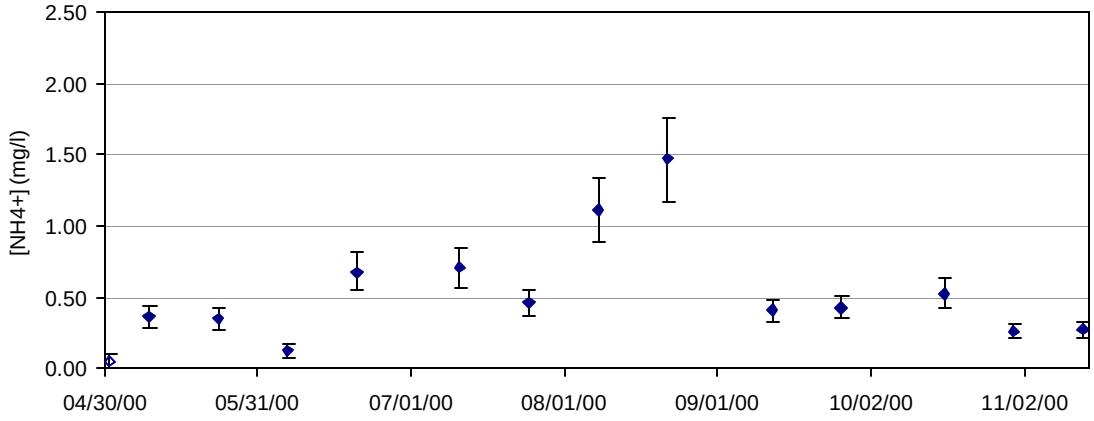


Figure D-25 Klamath River at Keno, ammonia concentration, May – November 2000

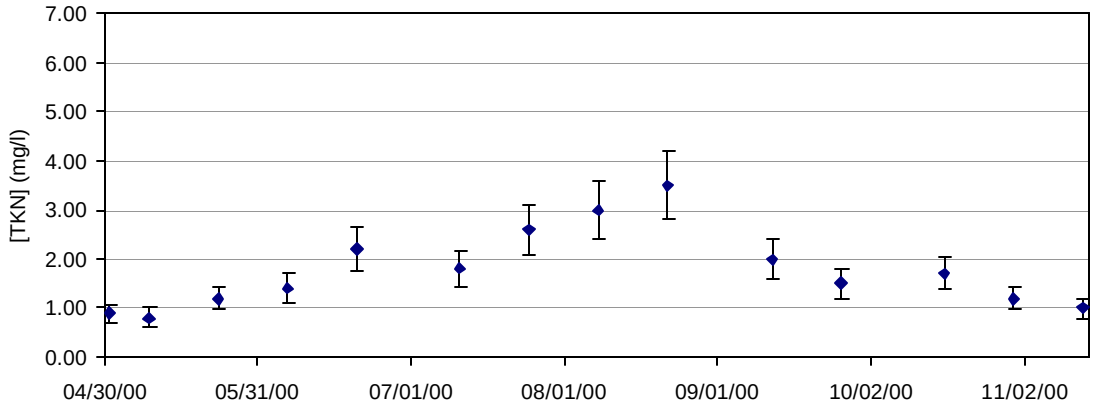


Figure D-26 Klamath River at Keno, total Kjeldahl nitrogen concentration, May – November 2000

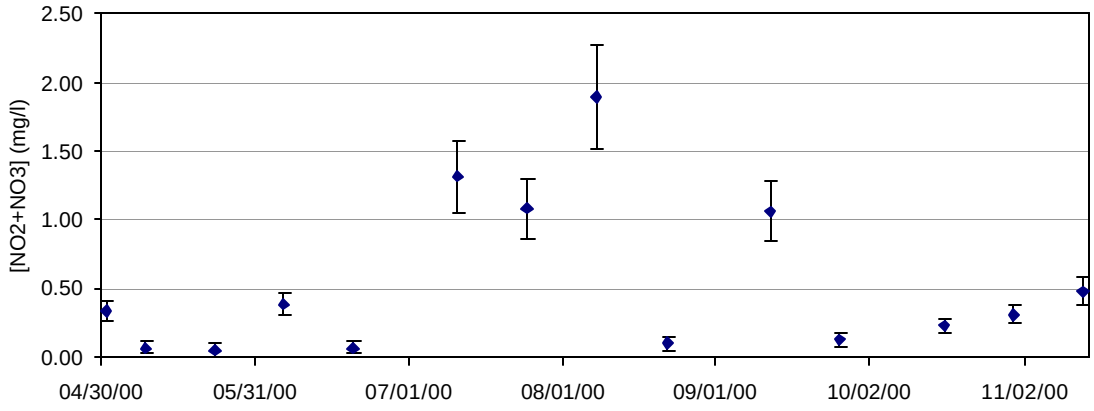


Figure D-27 Klamath River at Keno, nitrite plus nitrate concentration, May – November 2000

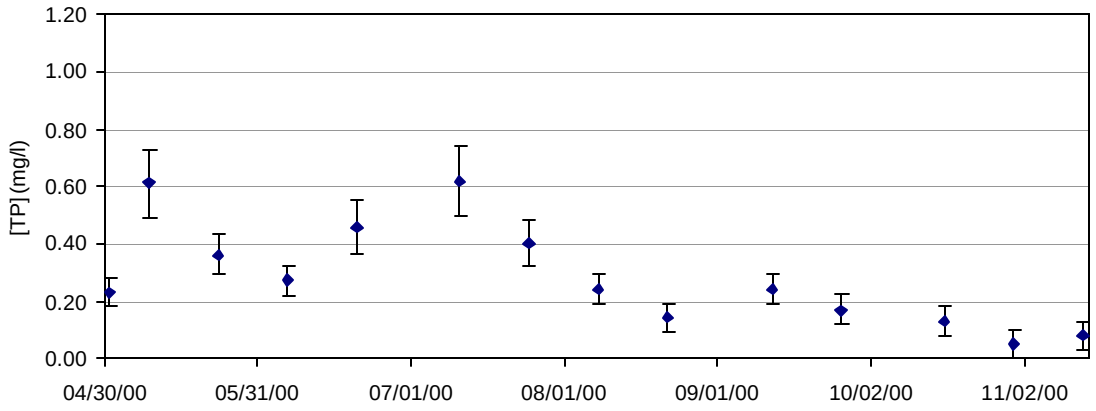


Figure D-28 Klamath River at Keno, total phosphorous concentration, May – November 2000

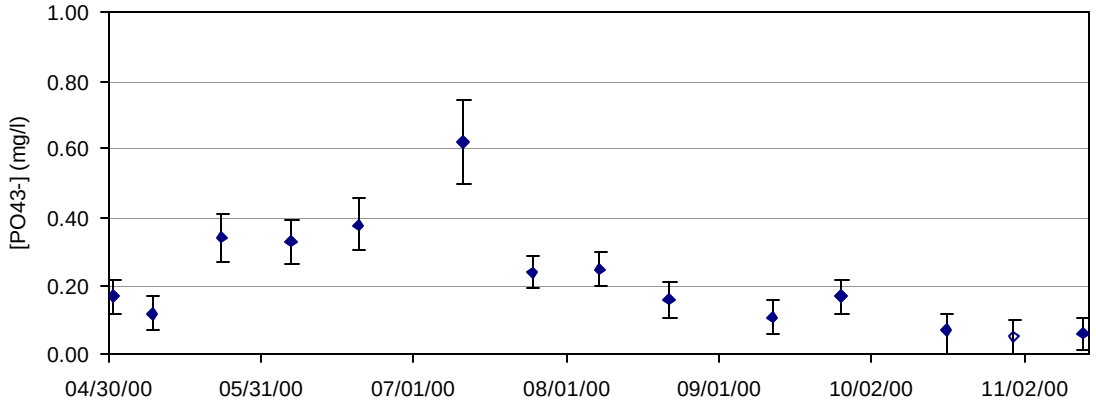


Figure D-29 Klamath River at Keno, orthophosphate concentration, May – November 2000

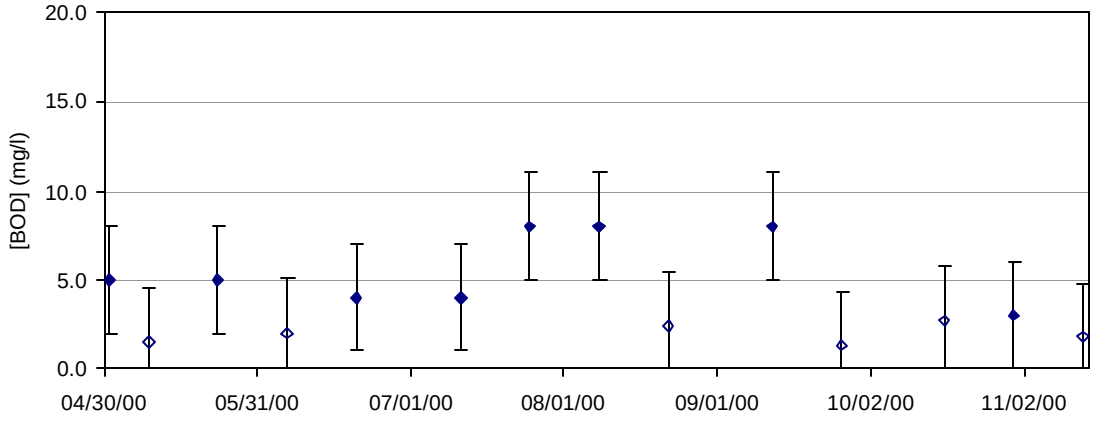


Figure D-30 Klamath River at Keno, BOD concentration, May – November 2000

D.6 Klamath River above Copco Reservoir

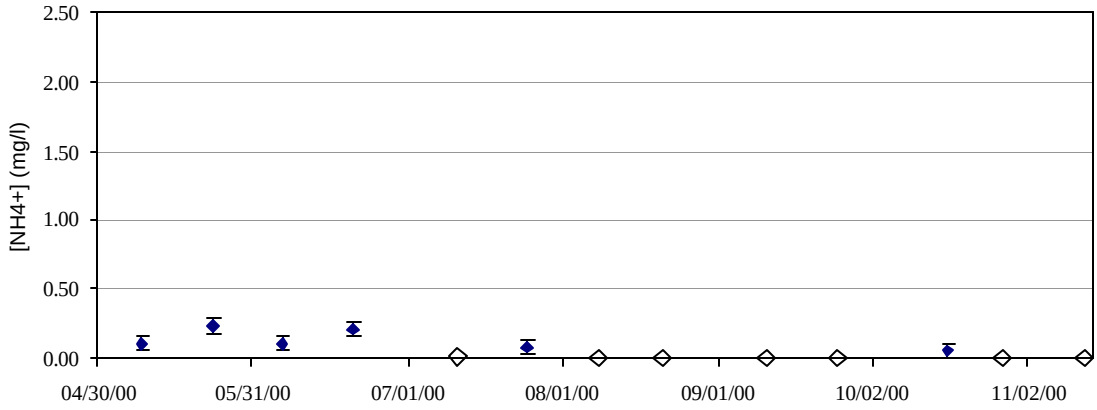


Figure D-31 Klamath River above Copco Reservoir, ammonia concentration, May – November 2000

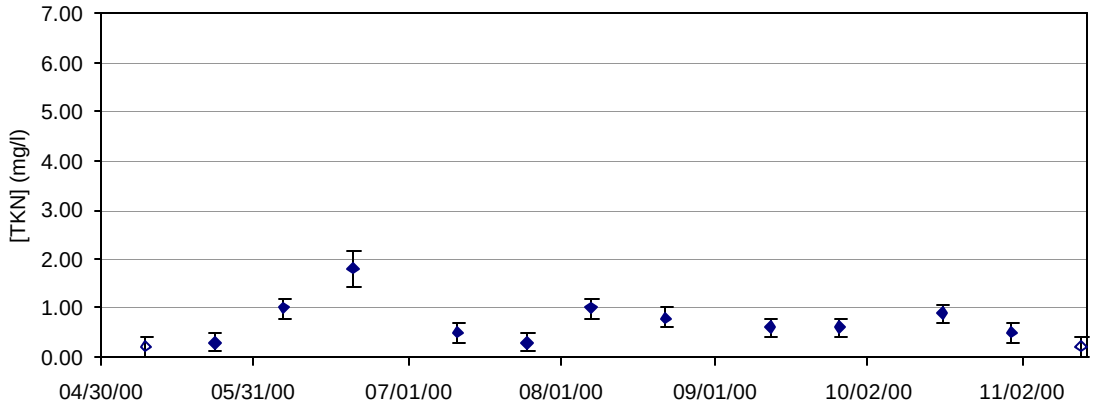


Figure D-32 Klamath River above Copco Reservoir, total Kjeldahl nitrogen concentration, May – November 2000

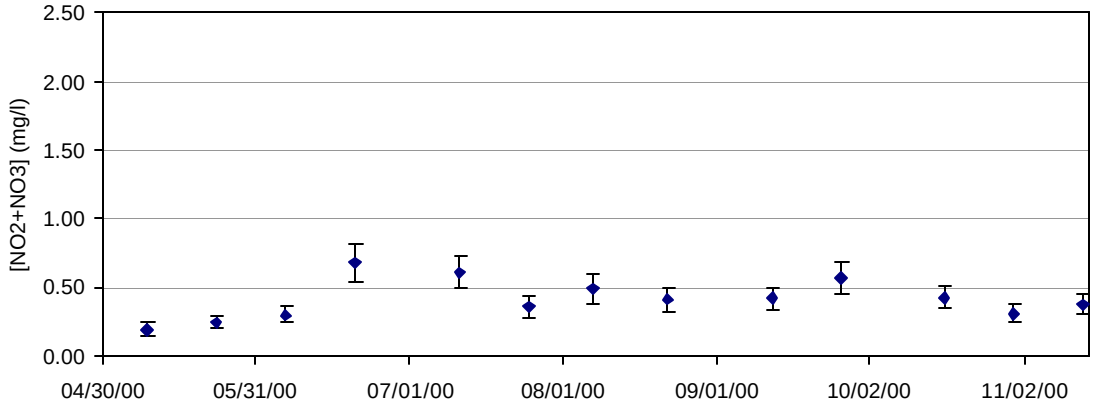


Figure D-33 Klamath River above Copco Reservoir, nitrite plus nitrate concentration, May – November 2000

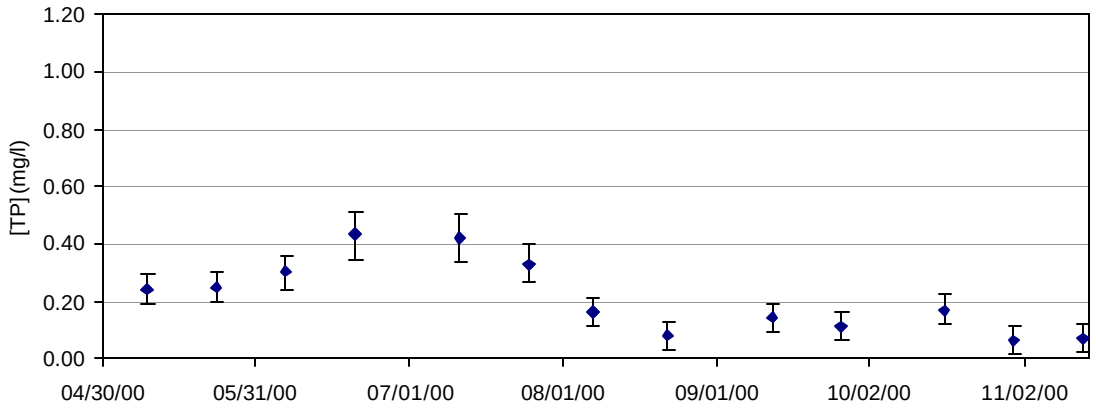


Figure D-34 Klamath River above Copco Reservoir, total phosphorous concentration, May – November 2000

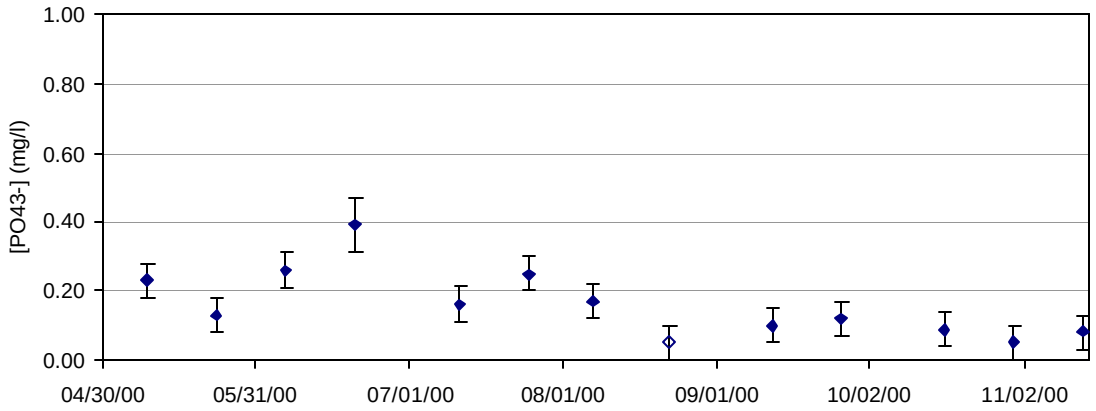


Figure D-35 Klamath River above Copco Reservoir, orthophosphate concentration, May – November 2000

[all values at or below the reporting limit of 3 mg/l]

Figure D-36 Klamath River above Copco Reservoir, BOD concentration, May – November 2000

D.7 Klamath River below Iron Gate Reservoir

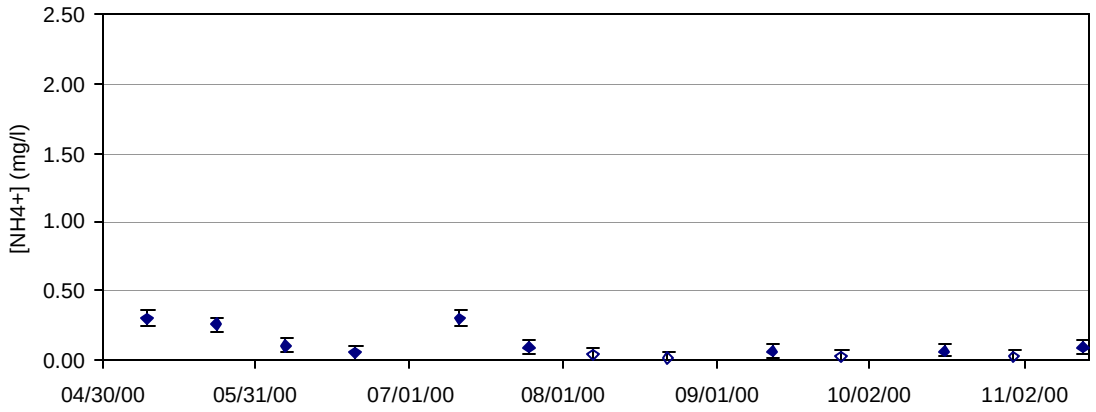


Figure D-37 Klamath River below Iron Gate Reservoir, ammonia concentration, May – November 2000

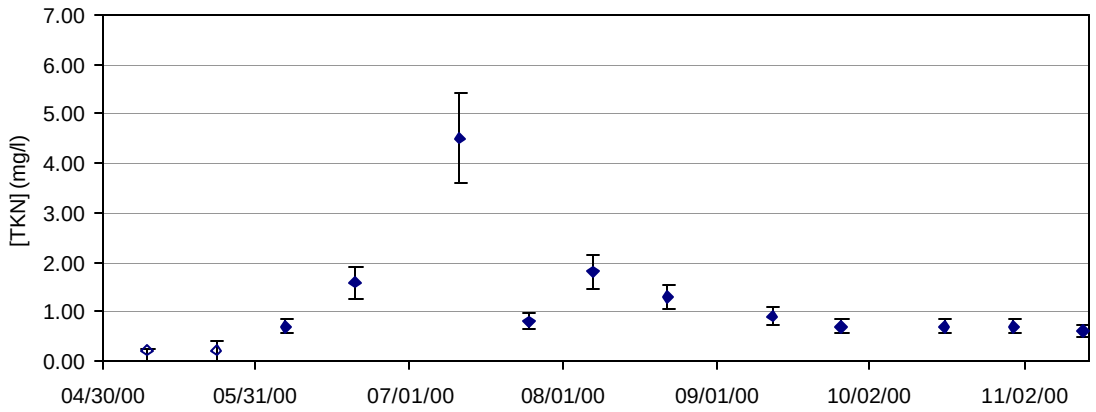


Figure D-38 Klamath River below Iron Gate Reservoir, total Kjeldahl nitrogen concentration, May – November 2000

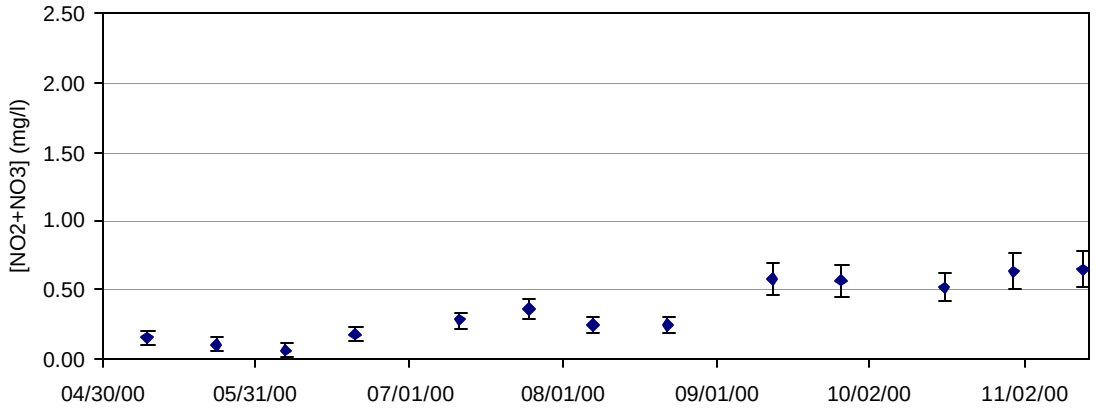


Figure D-39 Klamath River below Iron Gate Reservoir, nitrite plus nitrate concentration, May – November 2000

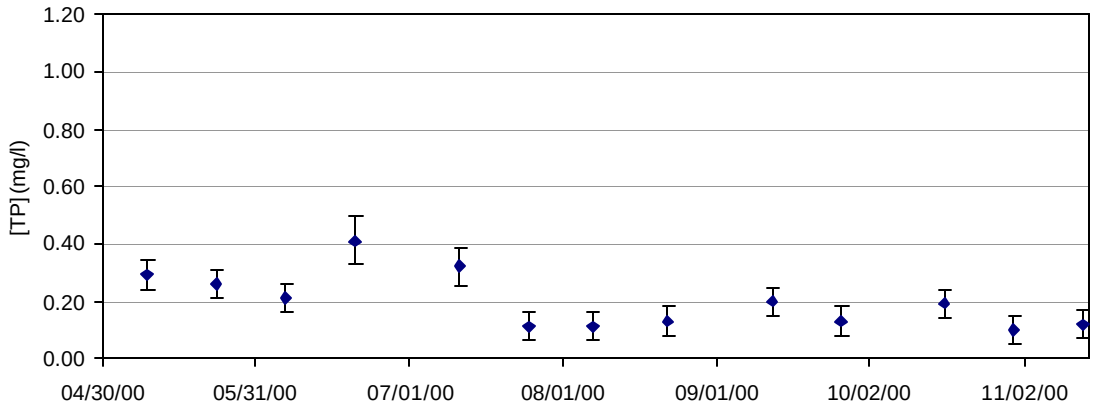


Figure D-40 Klamath River below Iron Gate Reservoir, total phosphorous concentration, May – November 2000

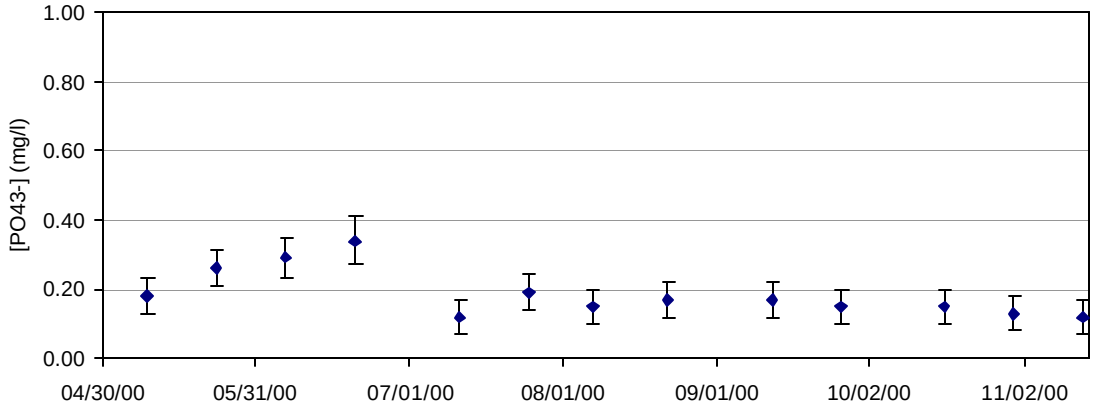


Figure D-41 Klamath River below Iron Gate Reservoir, orthophosphate concentration, May – November 2000

[all values at or below the reporting limit of 3 mg/l]

Figure D-42 Klamath River below Iron Gate Reservoir, BOD concentration, May – November 2000

D.8 Klamath River near Seiad Valley

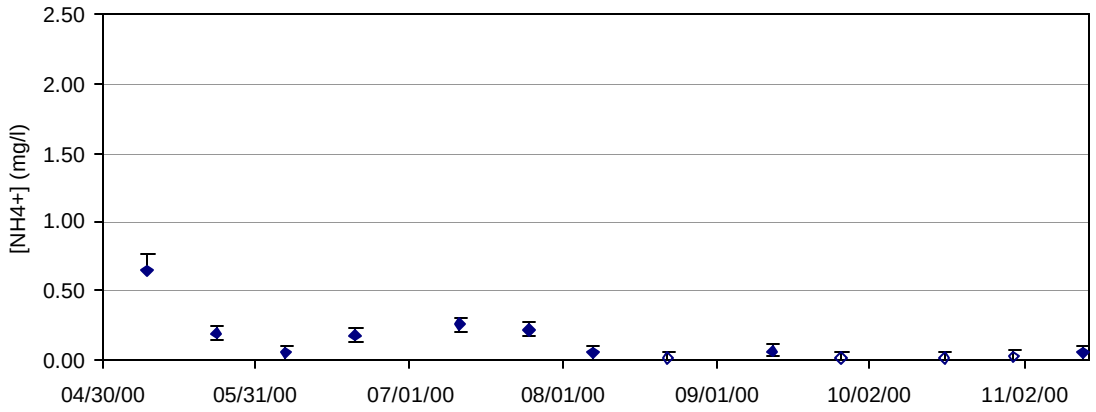


Figure D-43 Klamath River near Seiad Valley, ammonia concentration, May – November 2000

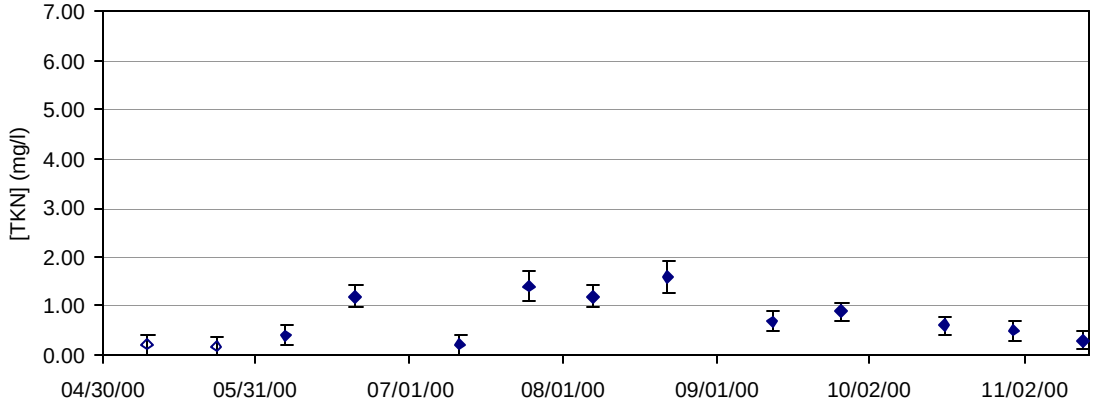


Figure D-44 Klamath River near Seiad Valley, total Kjeldahl nitrogen concentration, May – November 2000

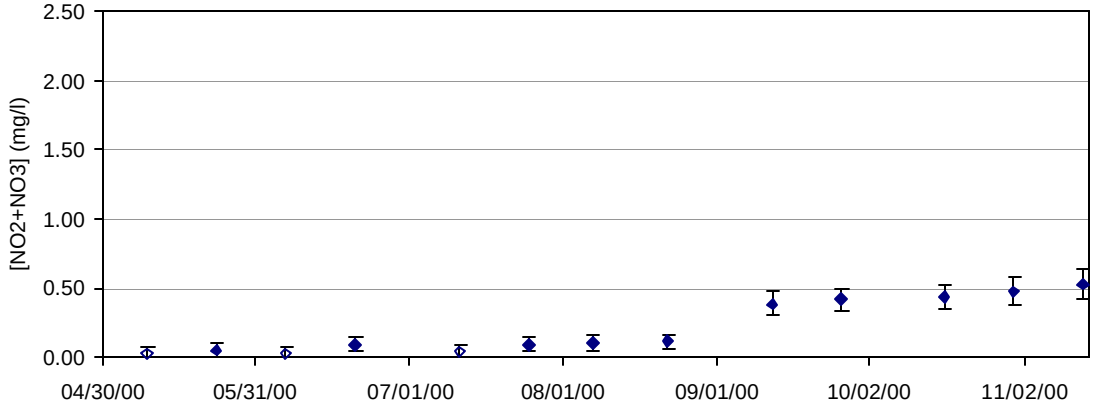


Figure D-45 Klamath River near Seiad Valley, nitrite plus nitrate concentration, May – November 2000

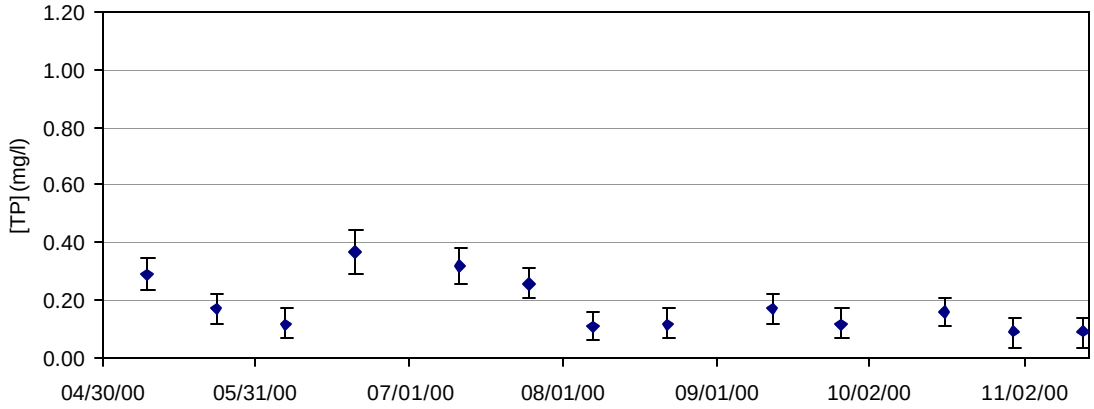
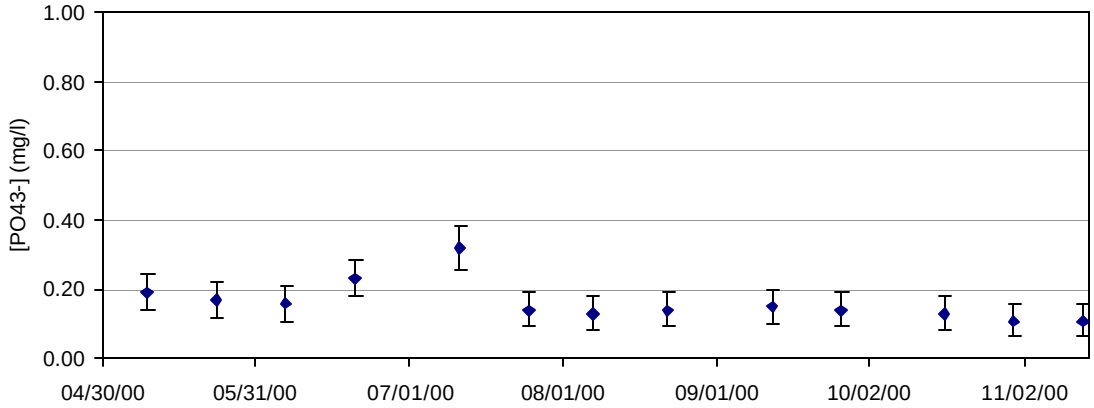


Figure D-46 Klamath River near Seiad Valley, total phosphorous concentration, May – November 2000

Figure D-47 Klamath River near Seiad Valley, orthophosphate concentration, May –



November 2000

[all values at or below the reporting limit of 3 mg/l]

Figure D-48 Klamath River near Seiad Valley, BOD concentration, May – November 2000

D.9 Shasta River (RM 1.0)

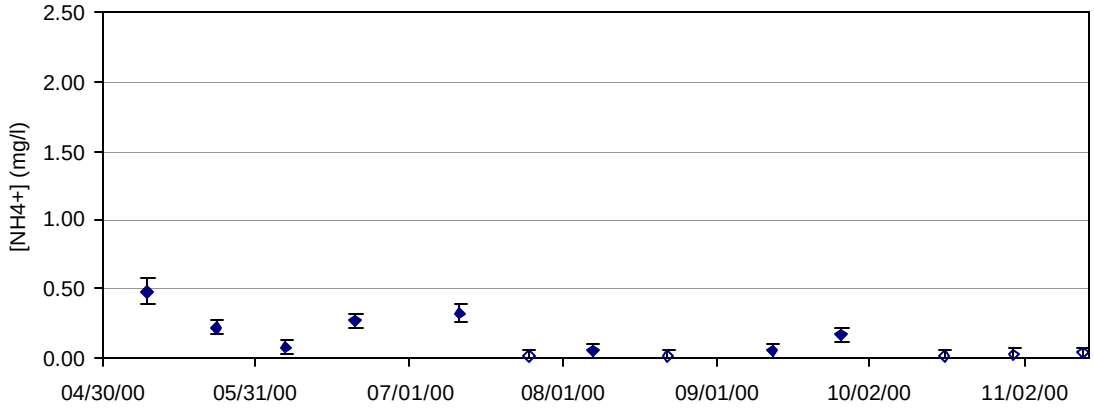


Figure D-49 Shasta River (RM 1.0), ammonia concentration, May – November 2000

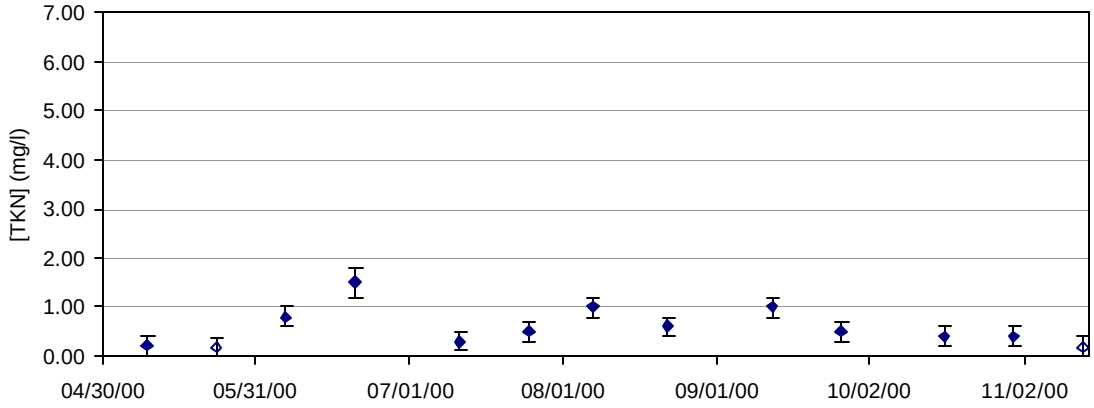


Figure D-50 Shasta River (RM 1.0), total Kjeldahl nitrogen concentration, May – November 2000

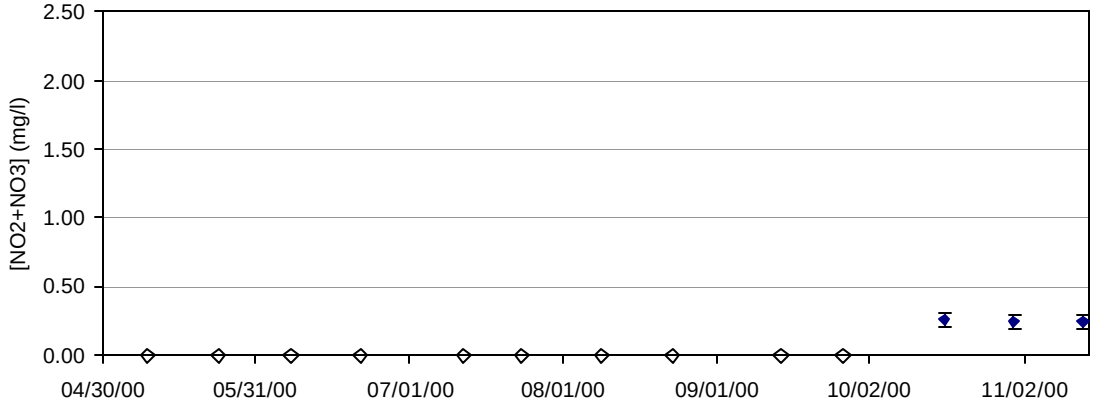


Figure D-51 Shasta River (RM 1.0), nitrite plus nitrate concentration, May – November 2000

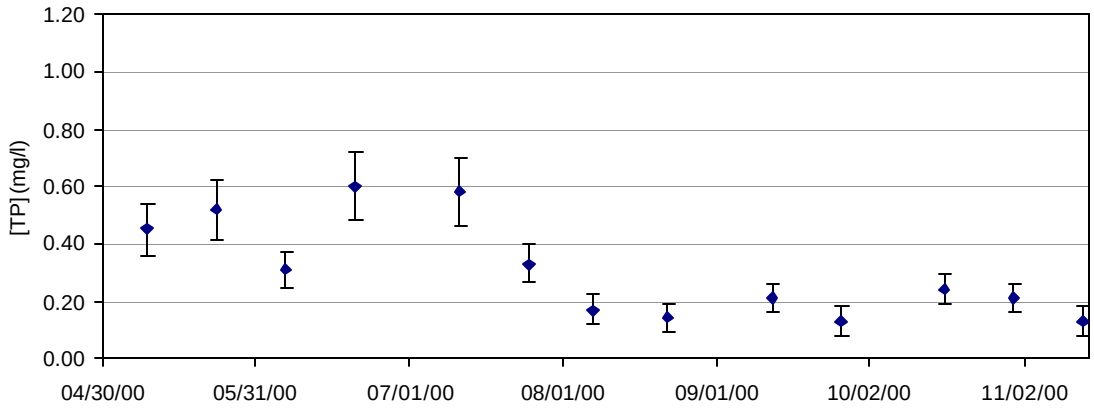


Figure D-52 Shasta River (RM 1.0), total phosphorous concentration, May – November 2000

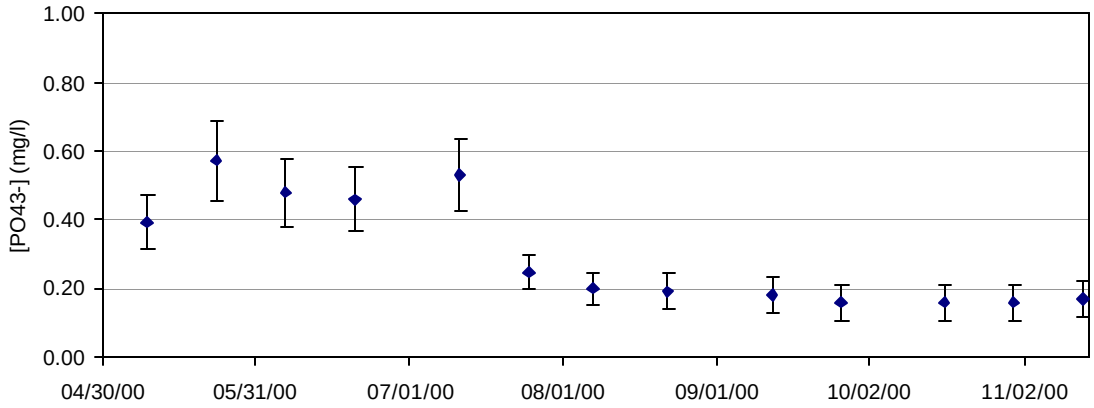


Figure D-53 Shasta River (RM 1.0), orthophosphate concentration, May – November 2000

[all values at or below the reporting limit of 3 mg/l]

Figure D-54 Shasta River (RM 1.0), BOD concentration, May – November 2000

D.10 Scott River near Ft. Jones (RM 23.4)

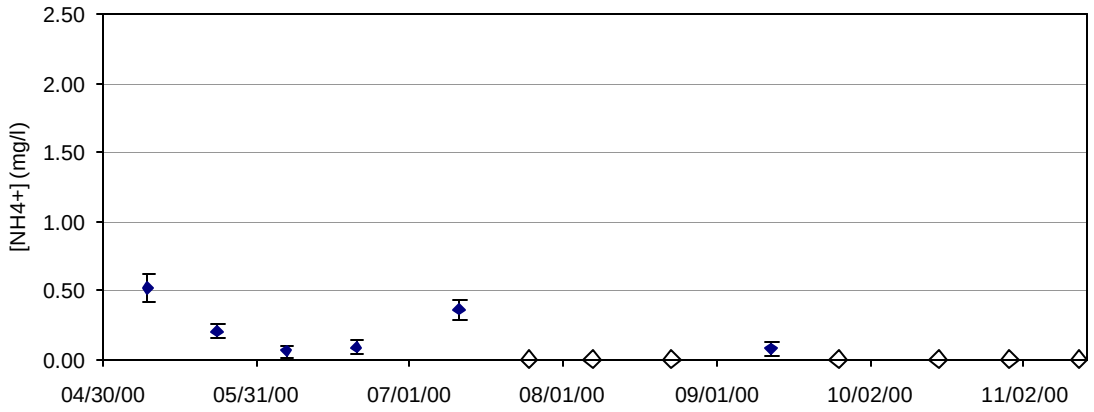


Figure D-55 Scott River near Ft. Jones (RM 23.4), ammonia concentration, May – November 2000

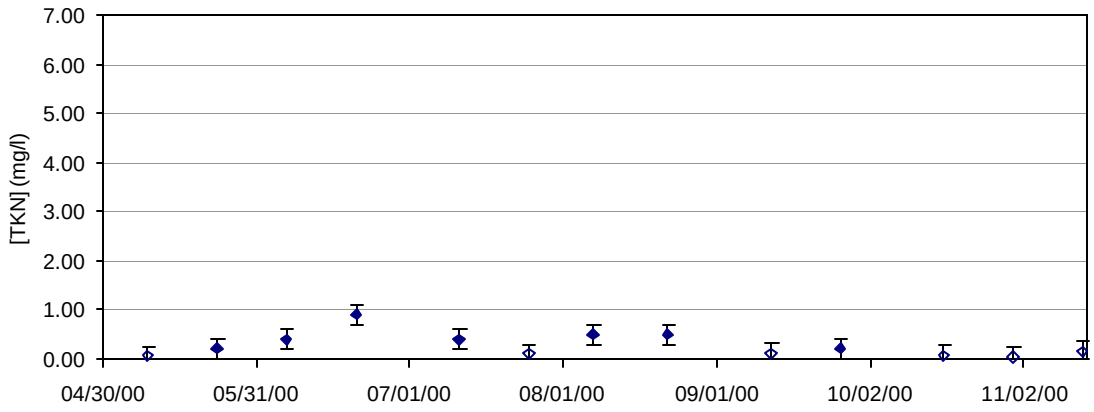


Figure D-56 Scott River near Ft. Jones (RM 23.4), total Kjeldahl nitrogen concentration, May – November 2000

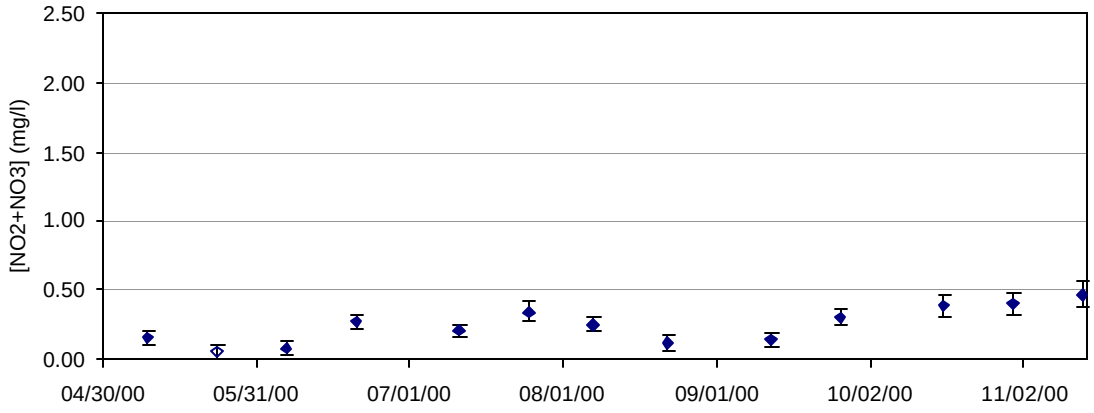


Figure D-57 Scott River near Ft. Jones (RM 23.4), nitrite plus nitrate concentration, May – November 2000

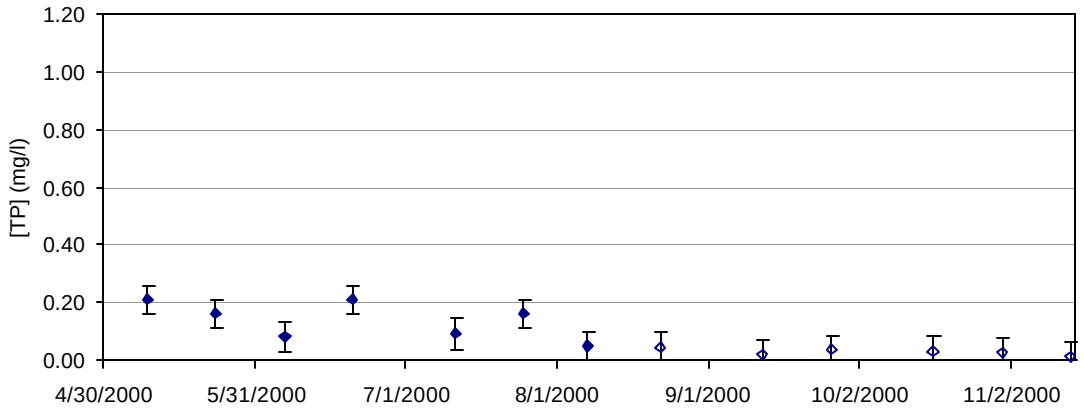


Figure D-58 Scott River near Ft. Jones (RM 23.4), total phosphorous concentration, May – November 2000

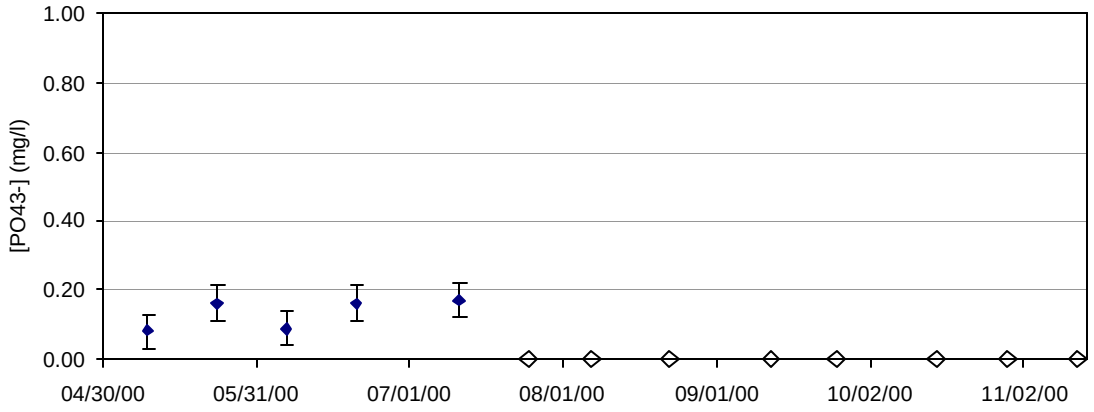


Figure D-59 Scott River near Ft. Jones (RM 23.4), orthophosphate concentration, May – November 2000

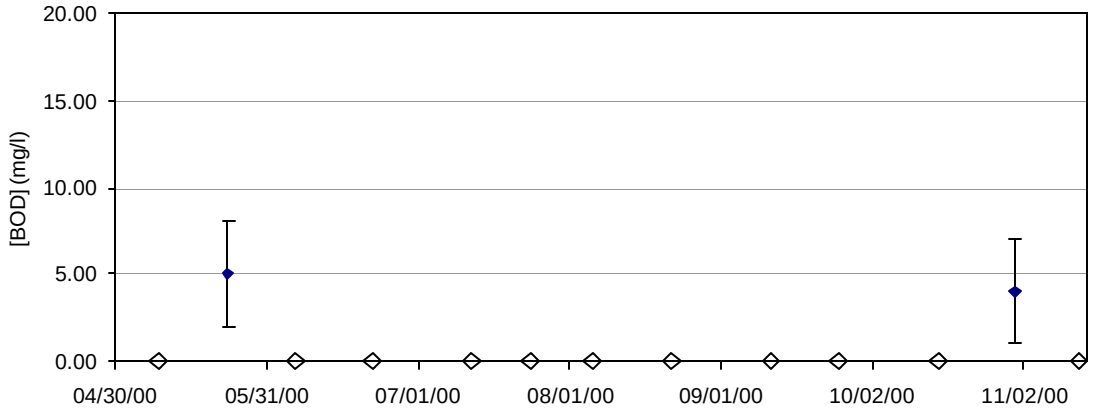


Figure D-60 Scott River near Ft. Jones (RM 23.4), BOD concentration, May – November 2000

E SEMI-MONTHLY DATA: PROBABLILITY PLOTS BY SITE

E.1 Tule Lake Outlet Tunnel

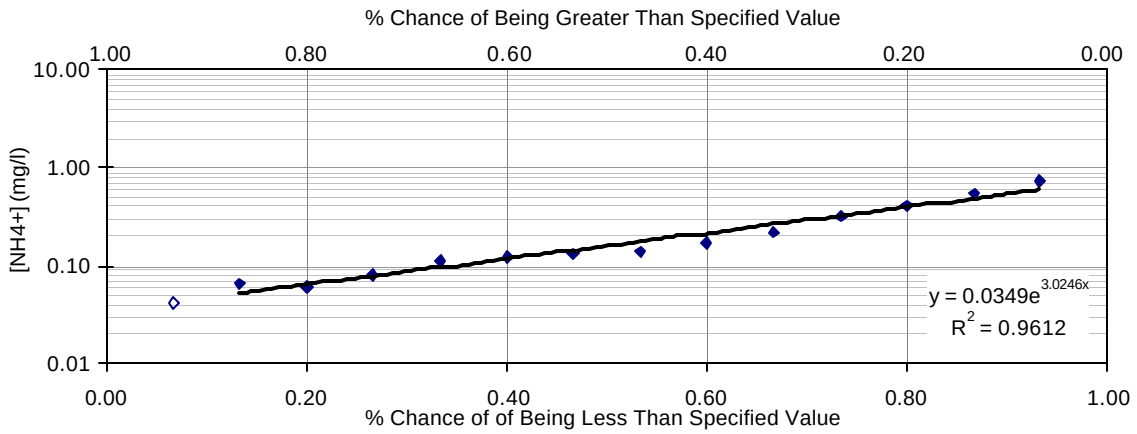


Figure E-1 Tule Lake Outlet Tunnel, probability plot for ammonia, May – November 2000

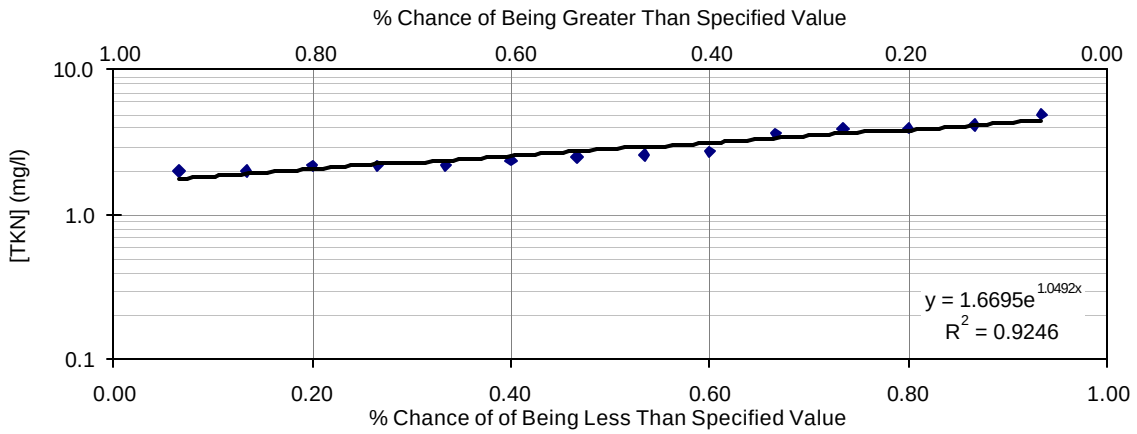
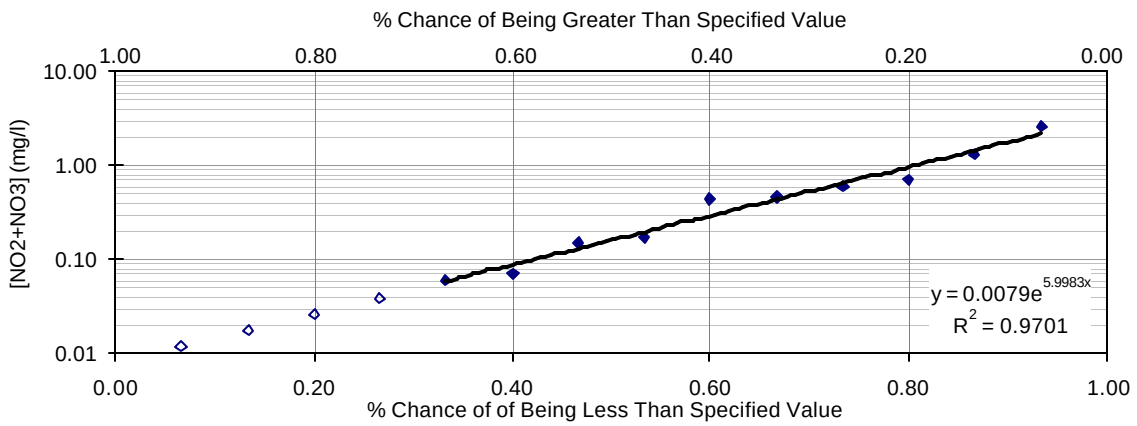


Figure E-2 Tule Lake Outlet Tunnel, probability plot for total Kjeldahl nitrogen, May –



November 2000

Figure E-3 Tule Lake Outlet Tunnel, probability plot for nitrite plus nitrate, May – November 2000

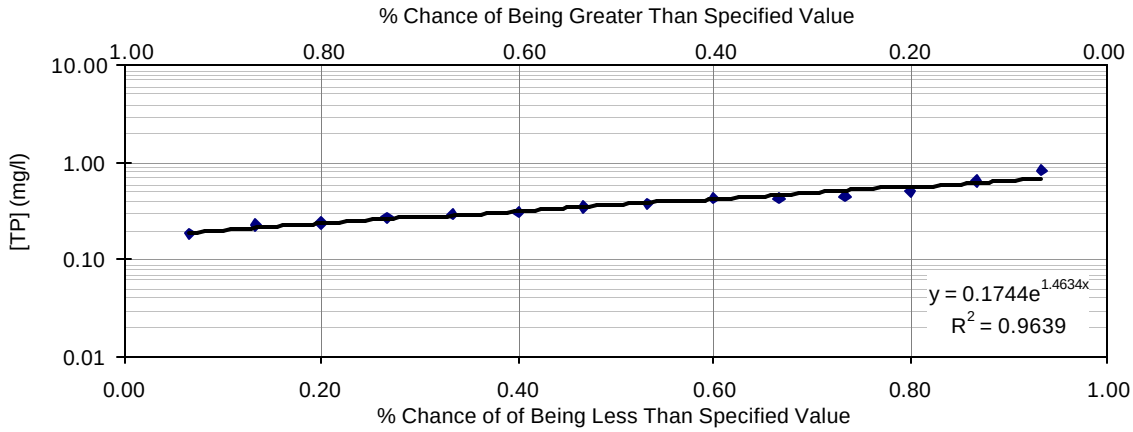


Figure E-4 Tule Lake Outlet Tunnel, probability plot for total phosphorous, May – November 2000

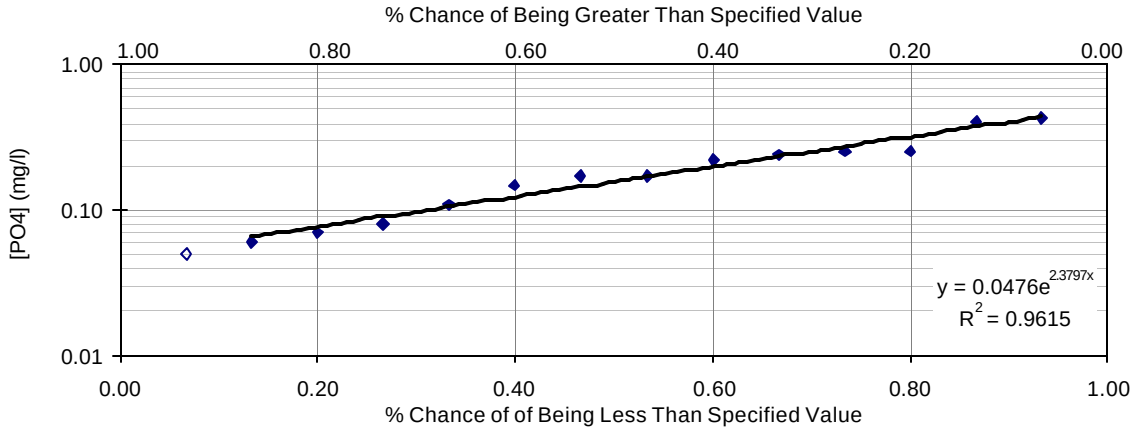


Figure E-5 Tule Lake Outlet Tunnel, probability plot for orthophosphate, May – November 2000

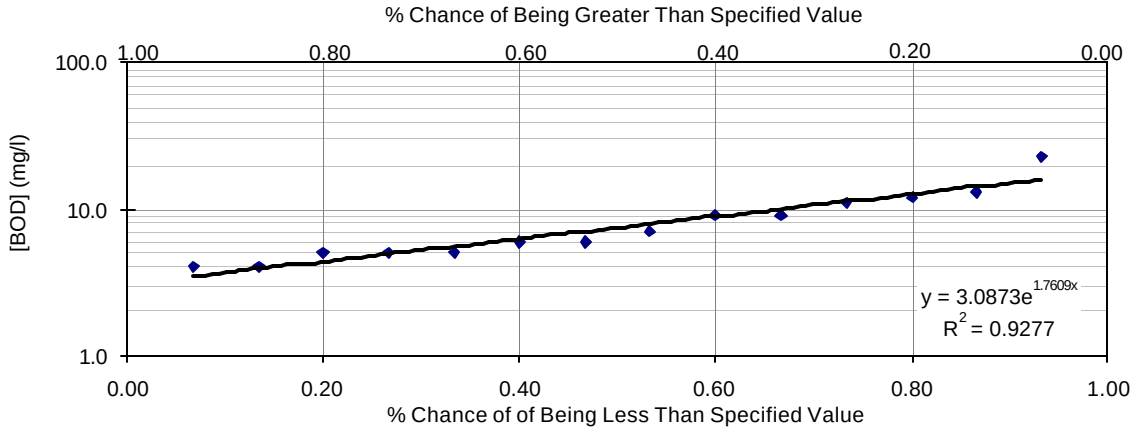


Figure E-6 Tule Lake Outlet Tunnel, probability plot for BOD, May – November 2000

E.2 Klamath Straits Drain at Headworks

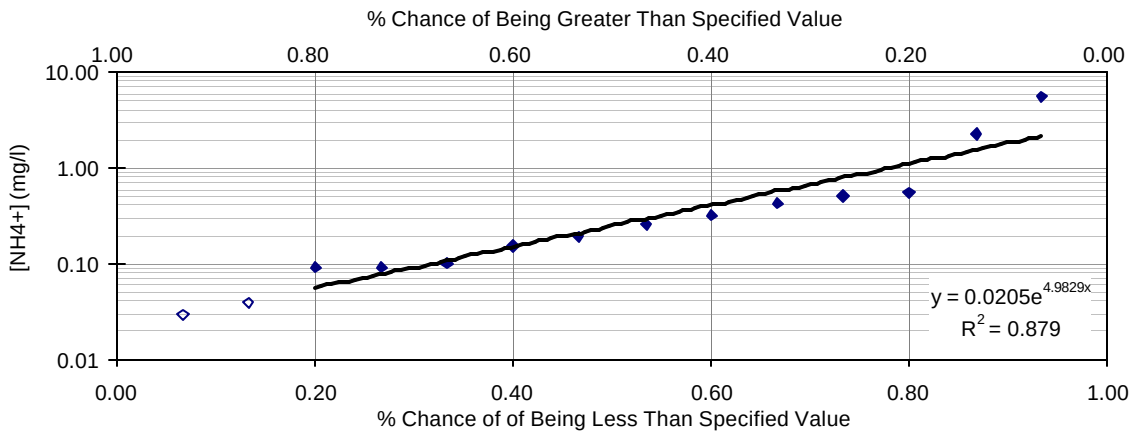


Figure E-7 Klamath Straits Drain at headworks, probability plot for ammonia, May – November 2000

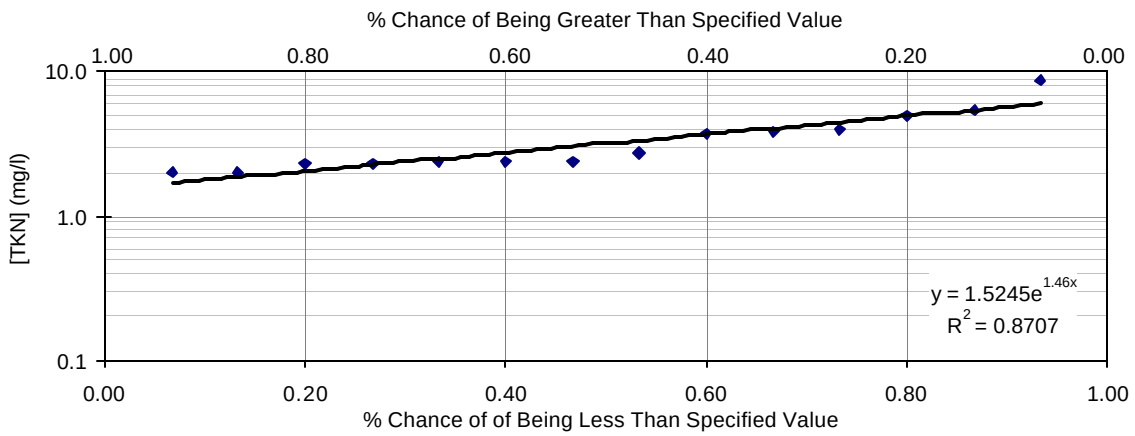


Figure E-8 Klamath Straits Drain at headworks, probability plot for total Kjeldahl nitrogen, May – November 2000

[Insufficient data]

Figure E-9 Klamath Straits Drain at headworks, probability plot for nitrite plus nitrate, May – November 2000

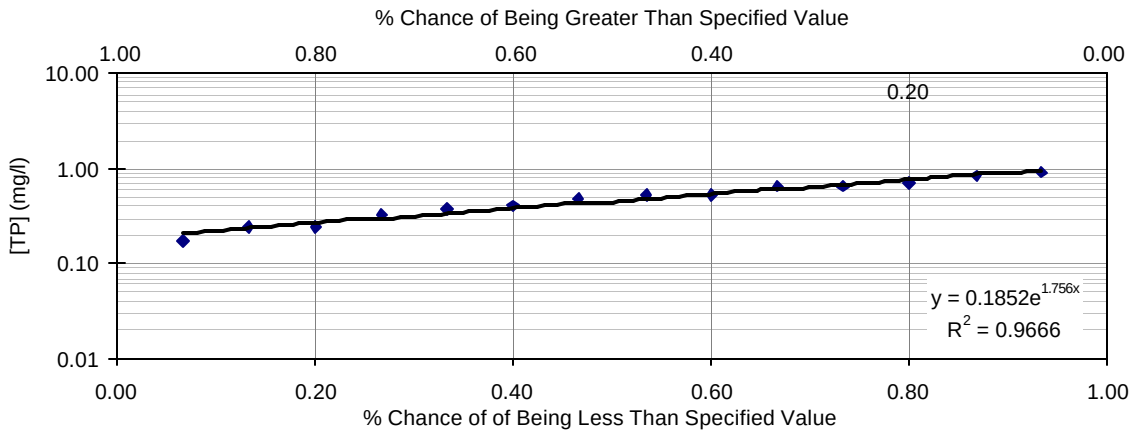


Figure E-10 Klamath Straits Drain at headworks, probability plot for total phosphorous, May – November 2000

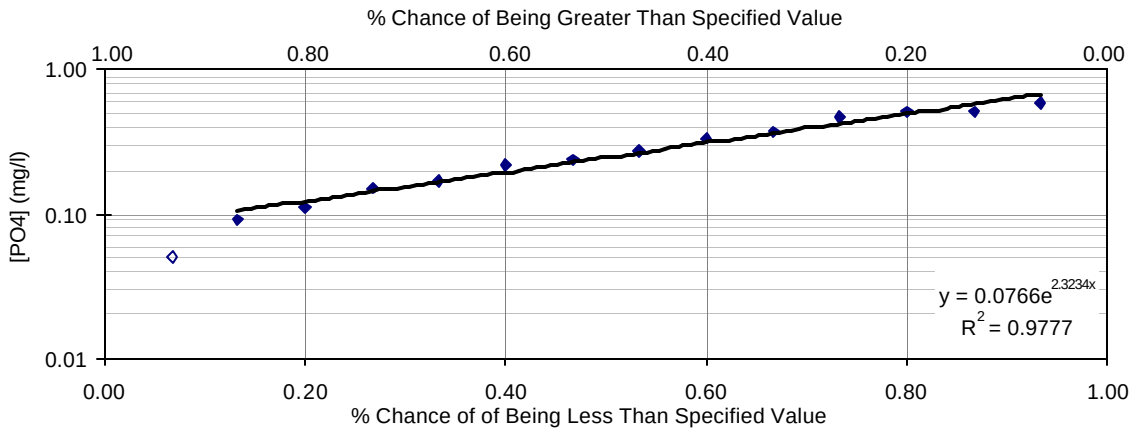


Figure E-11 Klamath Straits Drain at headworks, probability plot for orthophosphate, May – November 2000

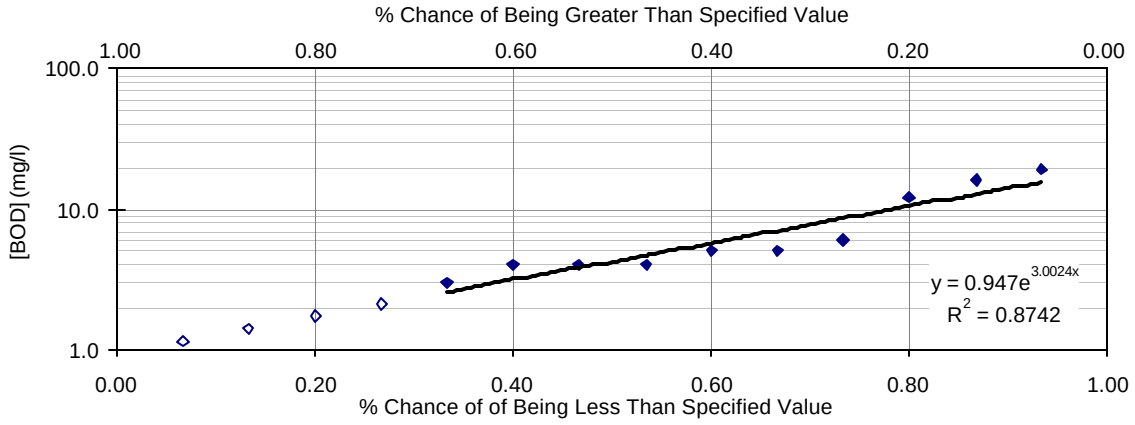


Figure E-12 Klamath Straits Drain at headworks, probability plot for BOD, May – November 2000

E.3 Klamath Straits Drain at Highway 97

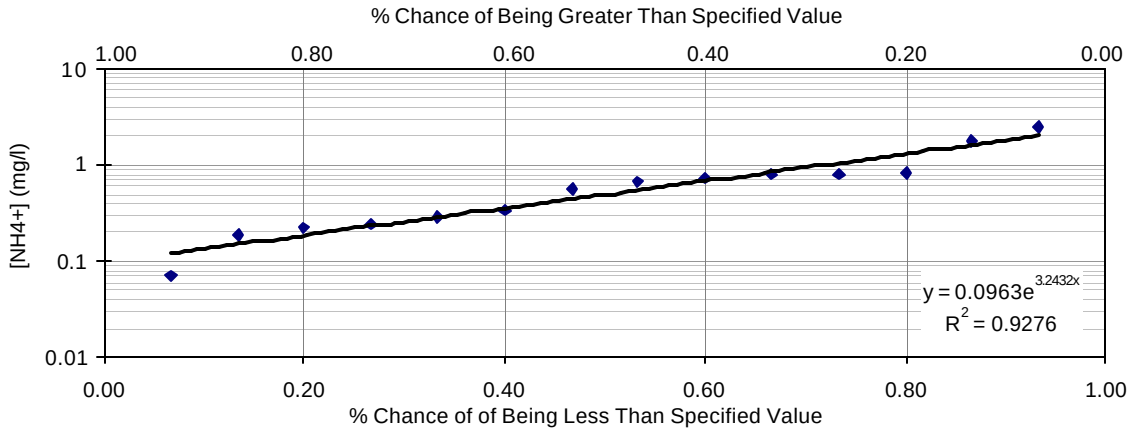


Figure E-13 Klamath Straits Drain at Highway 97, probability plot for ammonia, May – November 2000

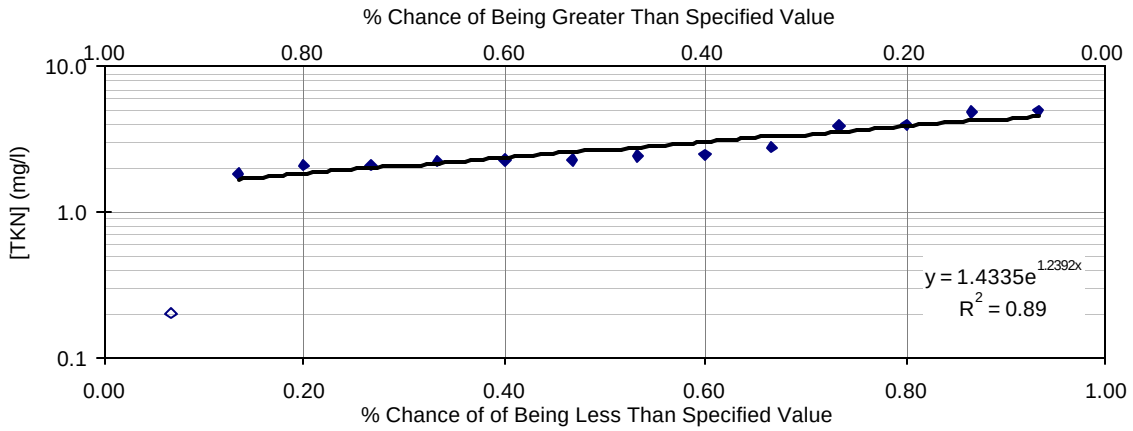


Figure E-14 Klamath Straits Drain at Highway 97, probability plot for total Kjeldahl nitrogen, May – November 2000

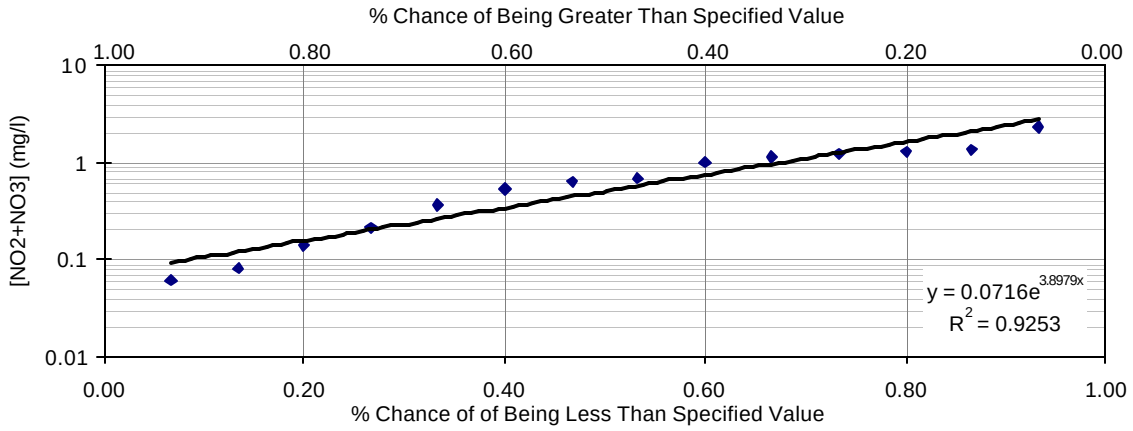


Figure E-15 Klamath Straits Drain at Highway 97, probability plot for nitrite plus nitrate, May – November 2000

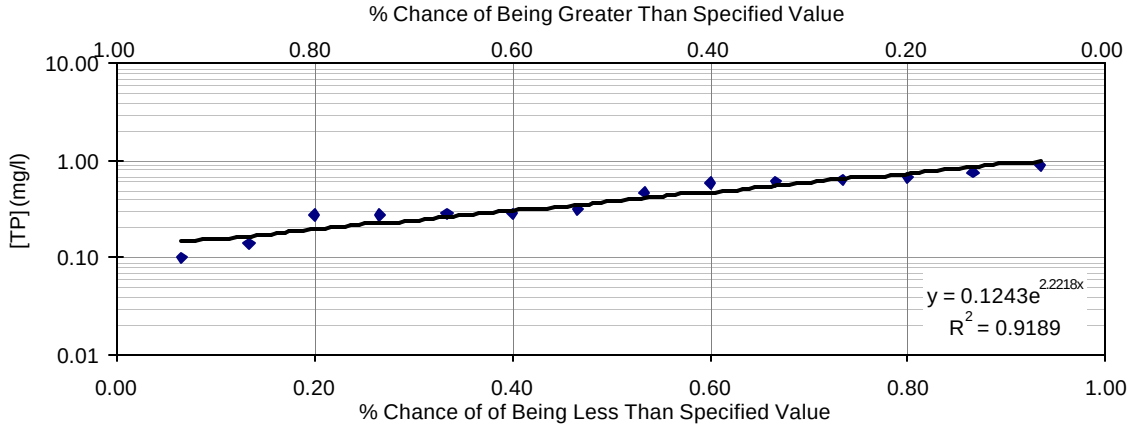


Figure E-16 Klamath Straits Drain at Highway 97, probability plot for total phosphorous, May – November 2000

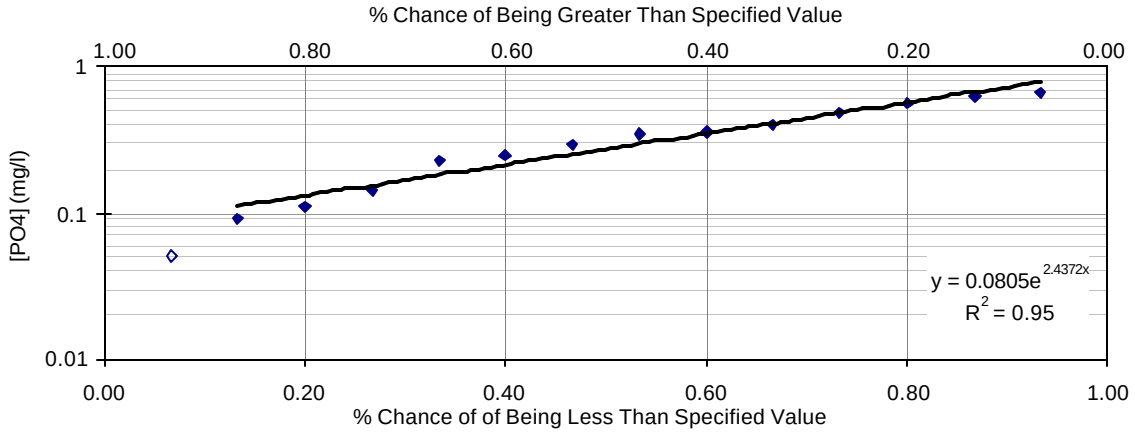


Figure E-17 Klamath Straits Drain at Highway 97, probability plot for orthophosphate, May – November 2000

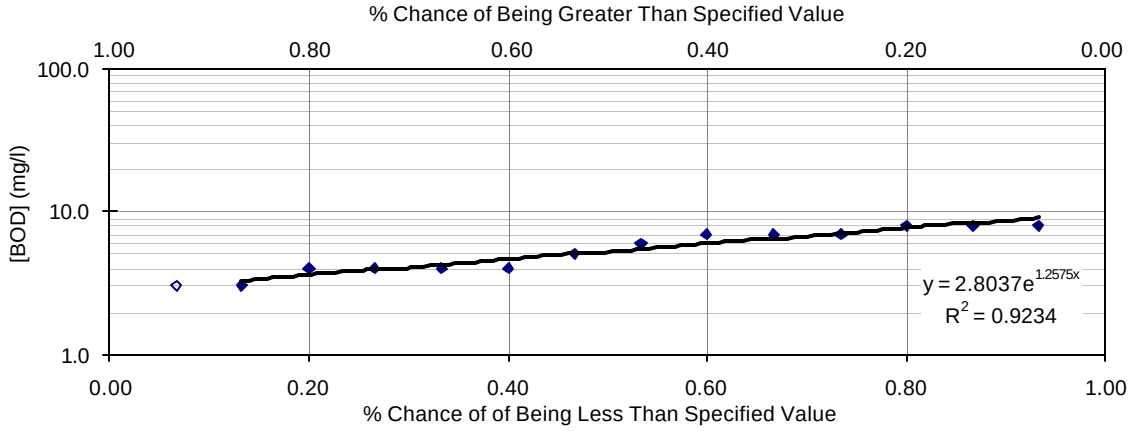


Figure E-18 Klamath Straits Drain at Highway 97, probability plot for BOD, May – November 2000

E.4 Klamath River at Miller Island

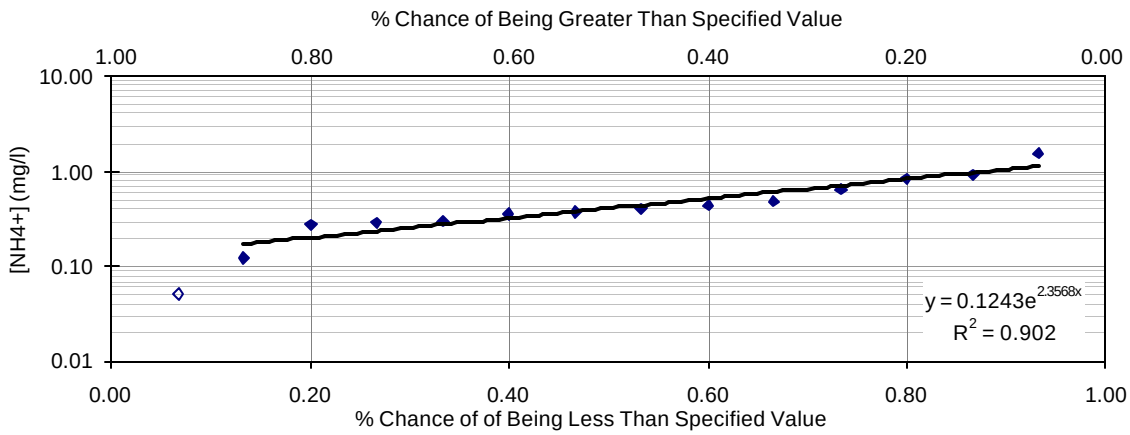


Figure E-19 Klamath River at Miller Island, probability plot for ammonia, May – November 2000

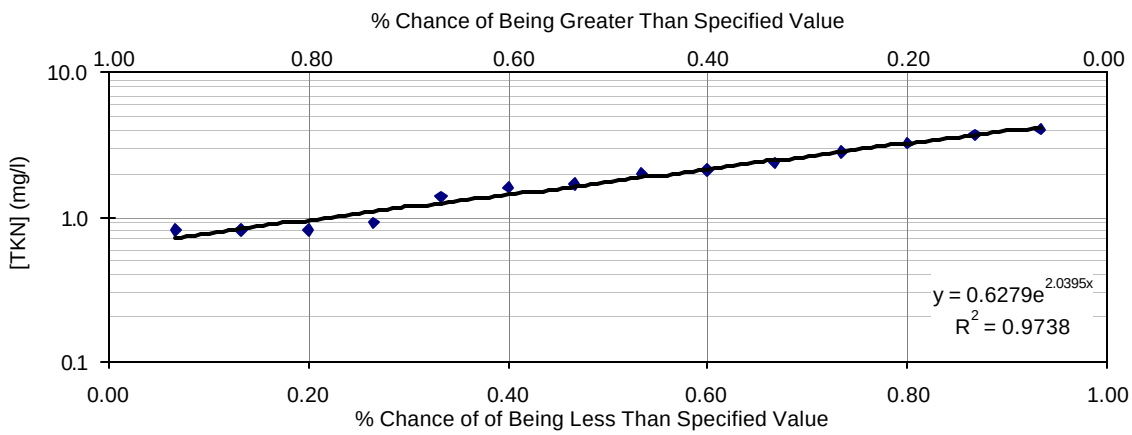


Figure E-20 Klamath River at Miller Island, probability plot for total Kjeldahl nitrogen, May – November 2000

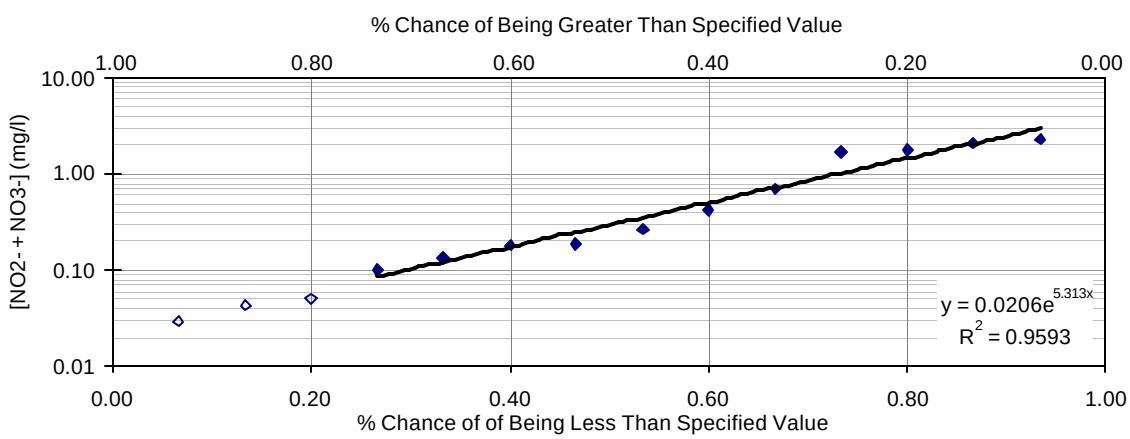


Figure E-21 Klamath River at Miller Island, probability plot for nitrite plus nitrate, May – November 2000

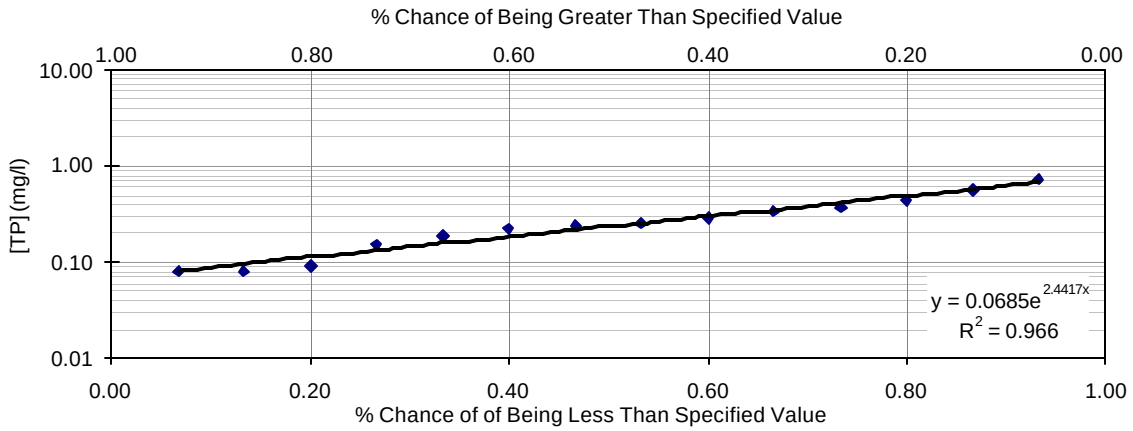


Figure E-22 Klamath River at Miller Island, probability plot for total phosphorous, May – November 2000

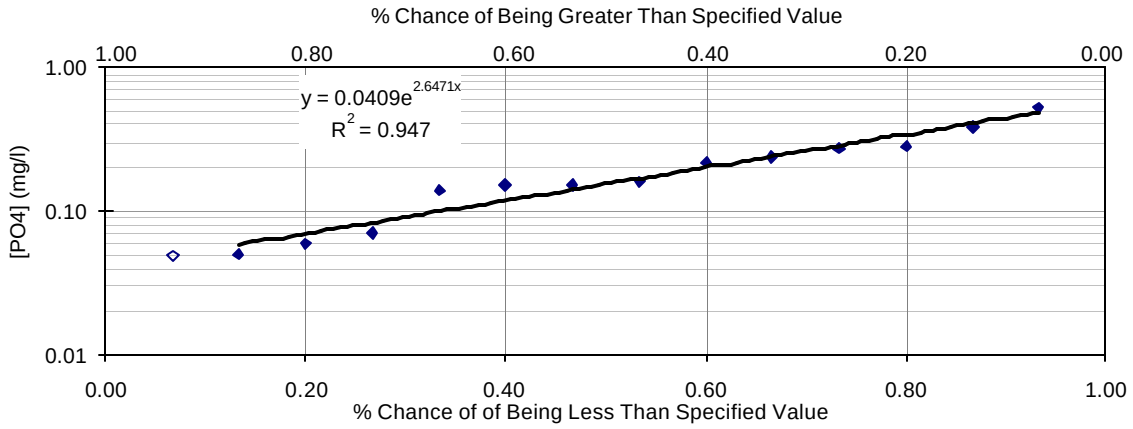


Figure E-23 Klamath River at Miller Island, probability plot for orthophosphate, May – November 2000

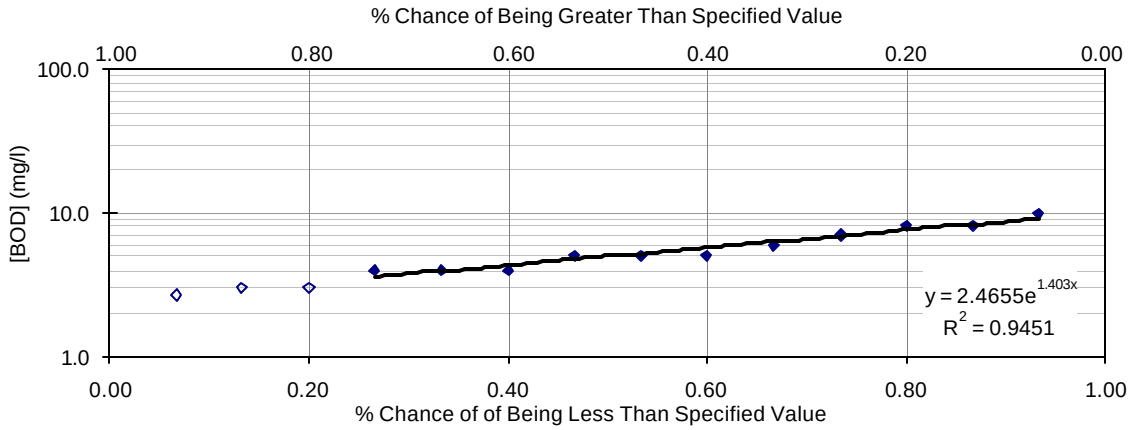


Figure E-24 Klamath River at Miller Island, probability plot for BOD, May – November 2000

E.5 Klamath River at Keno

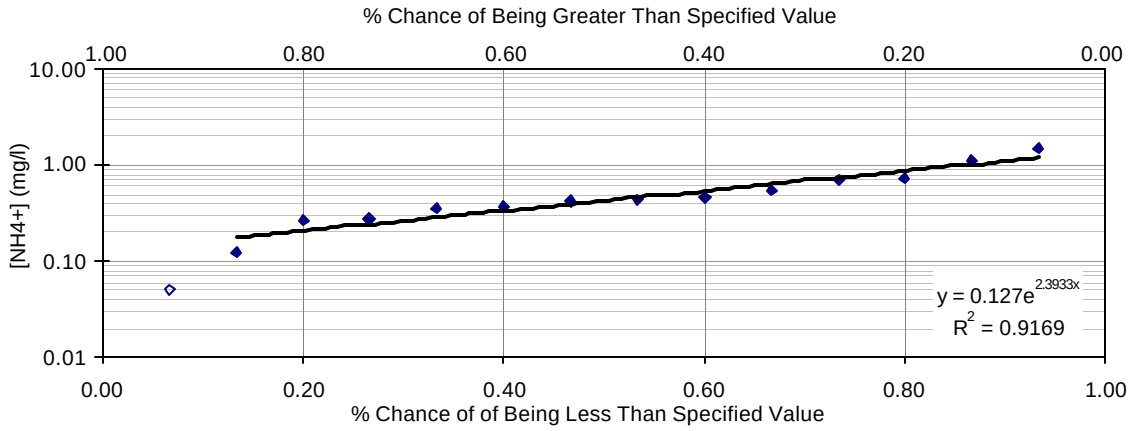


Figure E-25 Klamath River at Keno, probability plot for ammonia, May – November 2000

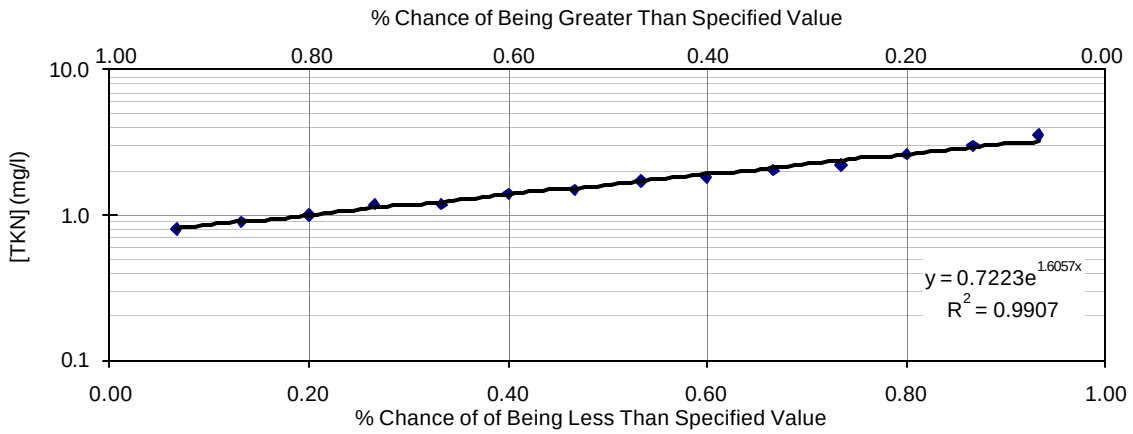


Figure E-26 Klamath River at Keno, probability plot for total Kjeldahl nitrogen, May – November 2000

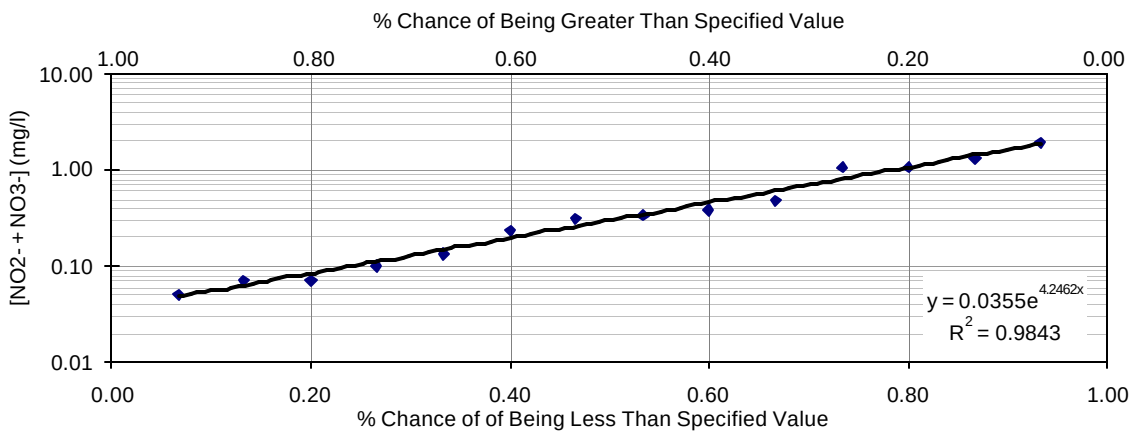


Figure E-27 Klamath River at Keno, probability plot for nitrite plus nitrate, May – November 2000

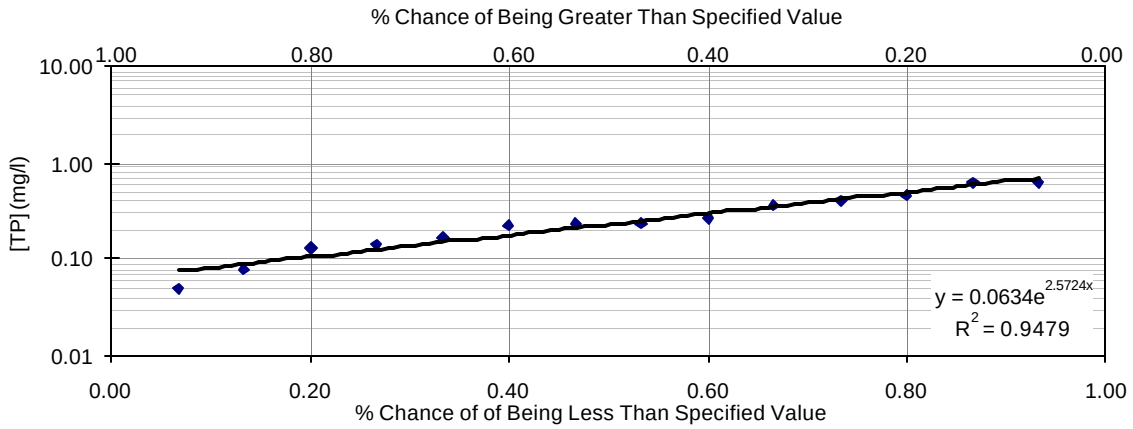


Figure E-28 Klamath River at Keno, probability plot for total phosphorous, May – November 2000

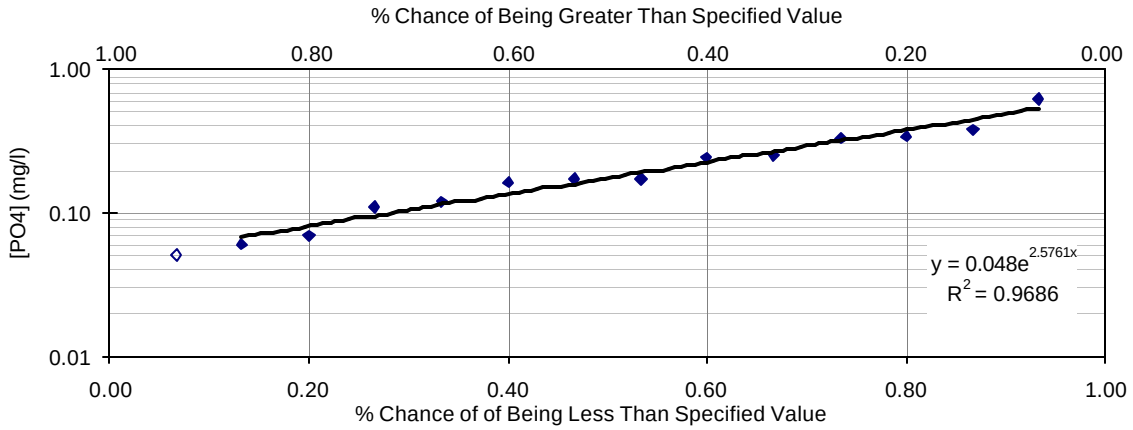


Figure E-29 Klamath River at Keno, probability plot for orthophosphate, May – November 2000

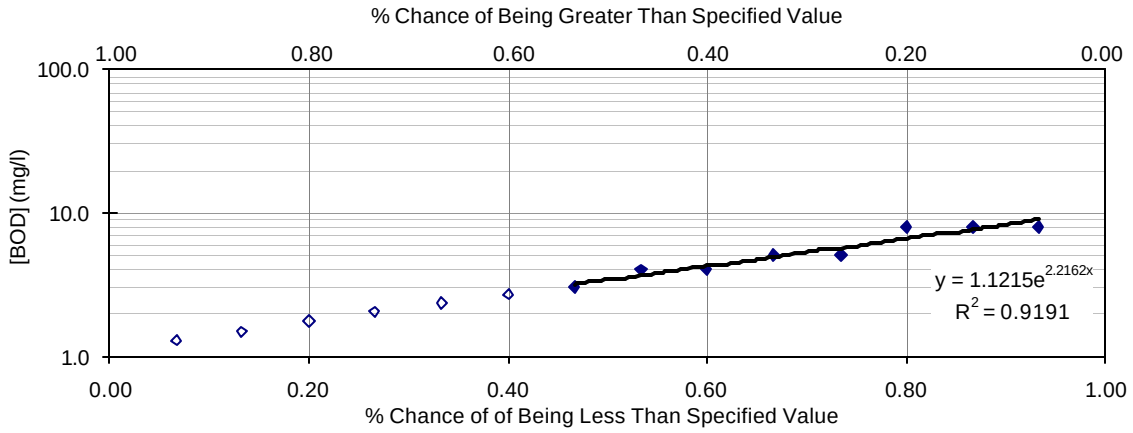


Figure E-30 Klamath River at Keno, probability plot for BOD, May – November 2000

E.6 Klamath River above Copco Reservoir

[Insufficient Data]

Figure E-31 Klamath River above Copco Reservoir, probability plot for ammonia, May – November 2000

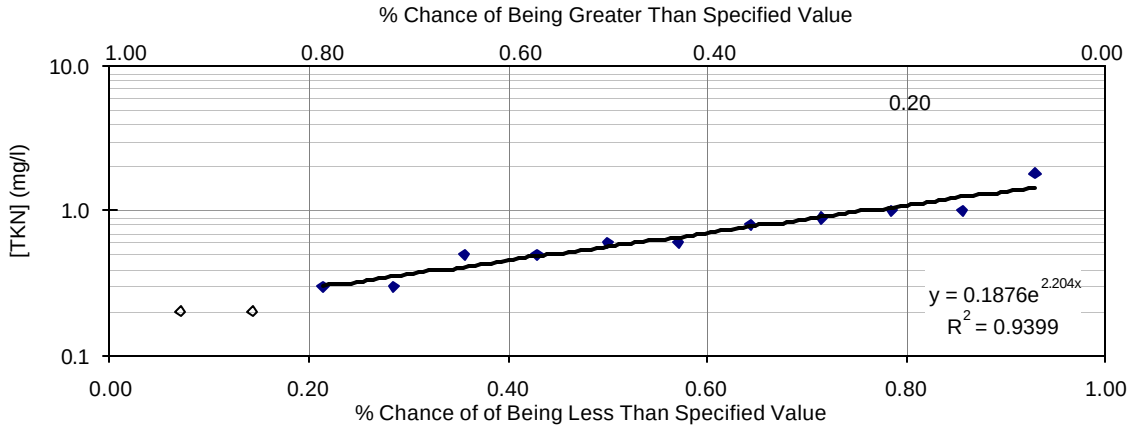


Figure E-32 Klamath River above Copco Reservoir, probability plot for total Kjeldahl nitrogen, May – November 2000

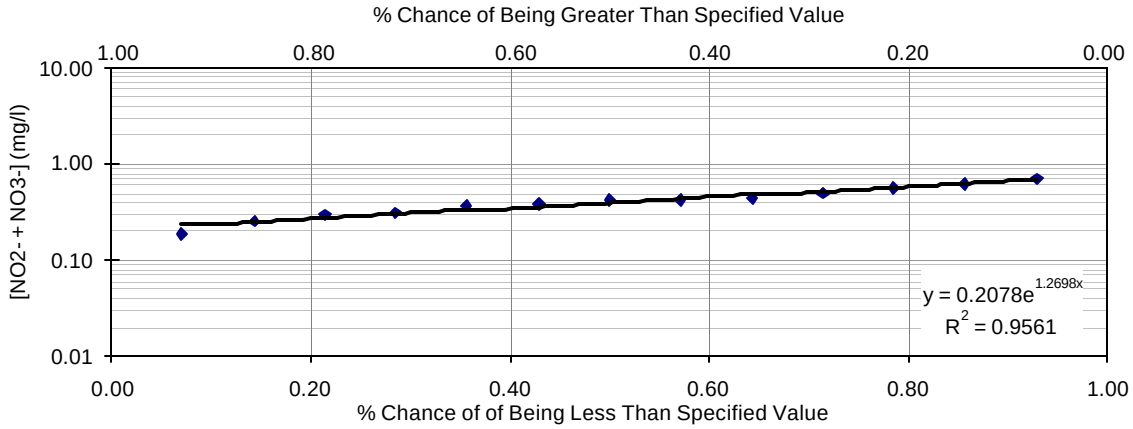


Figure E-33 Klamath River above Copco Reservoir, probability plot for nitrite plus nitrate, May – November 2000

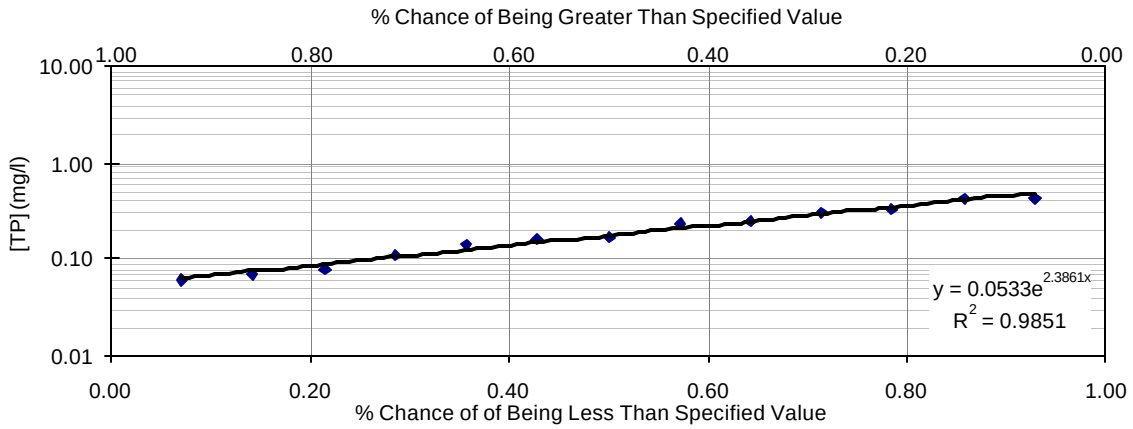


Figure E-34 Klamath River above Copco Reservoir, probability plot for total phosphorous, May – November 2000

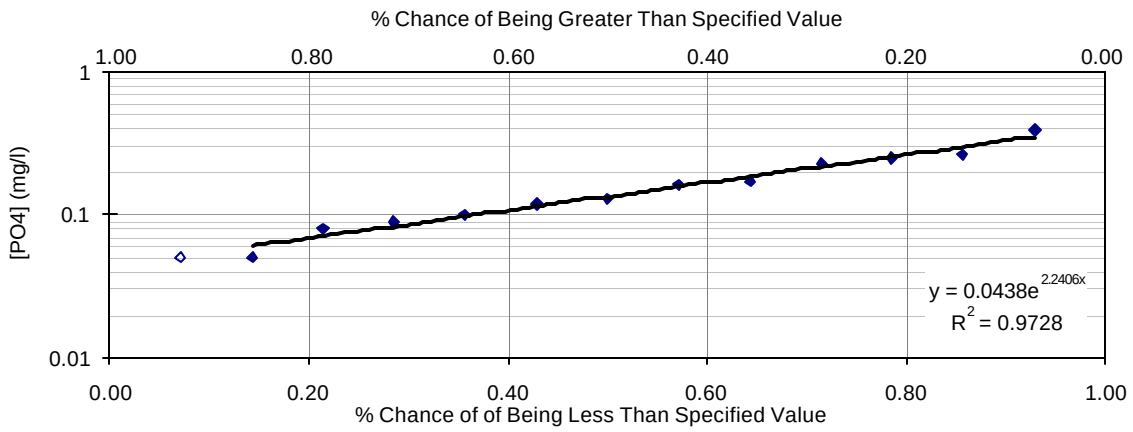


Figure E-35 Klamath River above Copco Reservoir, probability plot for orthophosphate, May – November 2000

[Insufficient Data]

Figure E-36 Klamath River above Copco Reservoir, probability plot for BOD, May – November 2000

E.7 Klamath River below Iron Gate Reservoir

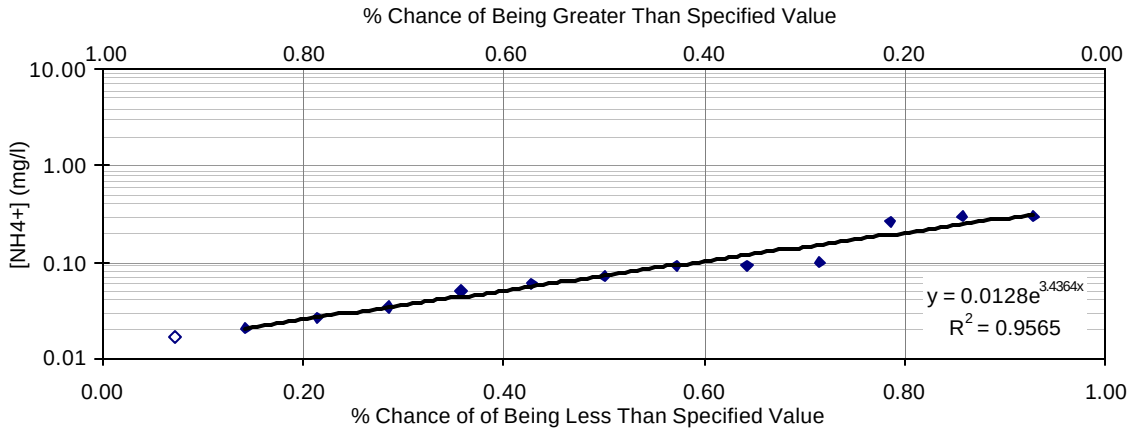


Figure E-37 Klamath River below Iron Gate Reservoir, probability plot for ammonia, May – November 2000

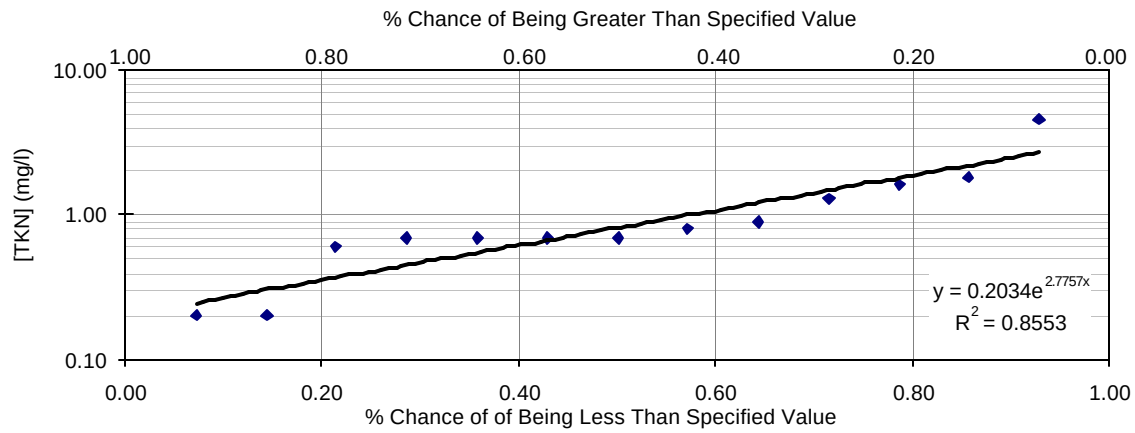


Figure E-38 Klamath River below Iron Gate Reservoir, probability plot for total Kjeldahl nitrogen, May – November 2000

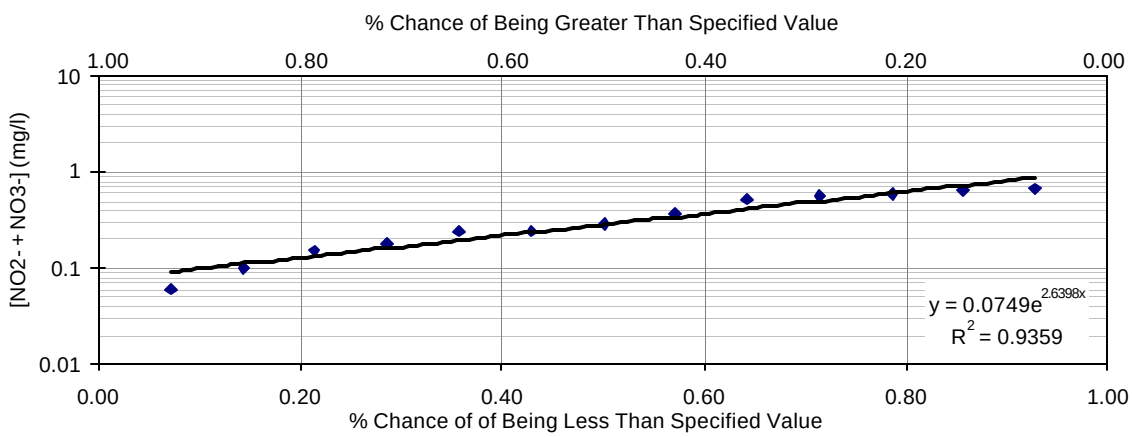


Figure E-39 Klamath River below Iron Gate Reservoir, probability plot for nitrite plus nitrate, May – November 2000

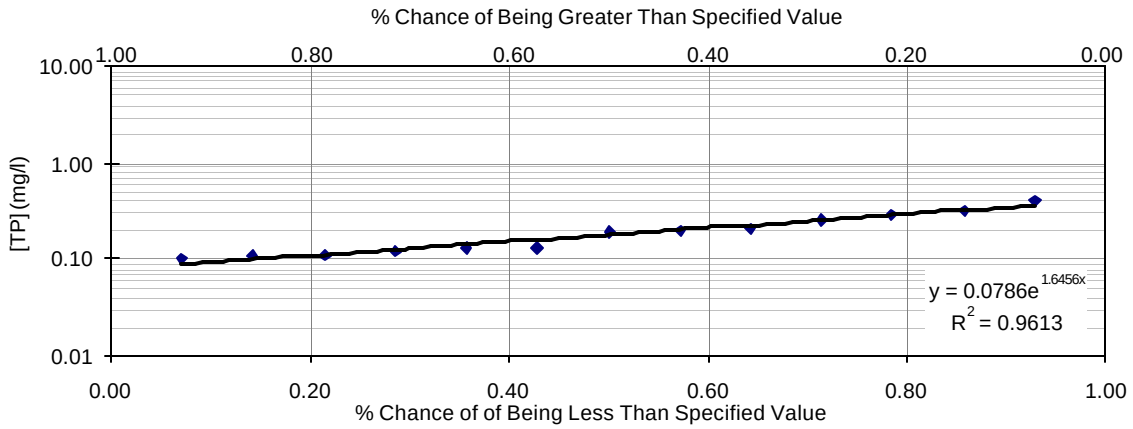


Figure E-40 Klamath River below Iron Gate Reservoir, probability plot for total phosphorous, May – November 2000

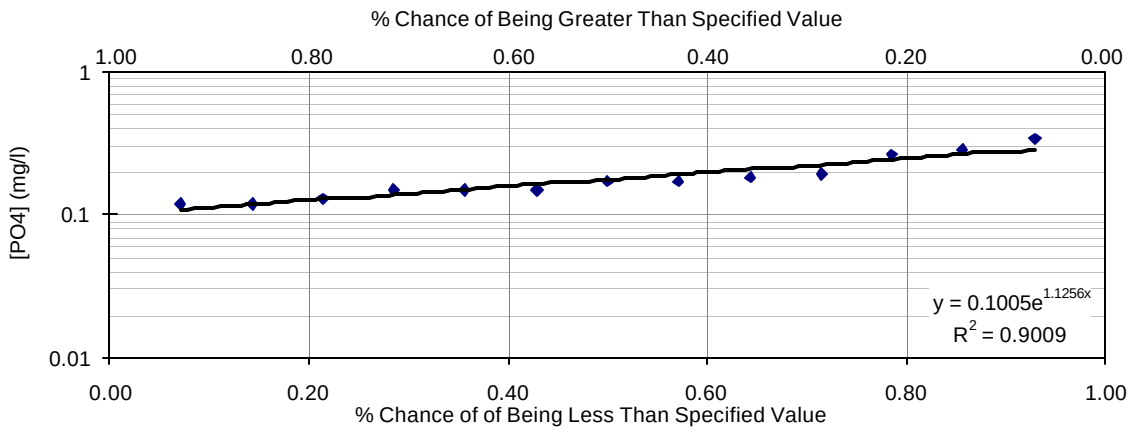


Figure E-41 Klamath River below Iron Gate Reservoir, probability plot for orthophosphate, May – November 2000

[Insufficient Data]

Figure E-42 Klamath River below Iron Gate Reservoir, probability plot for BOD, May – November 2000

E.8 Klamath River near Seiad Valley

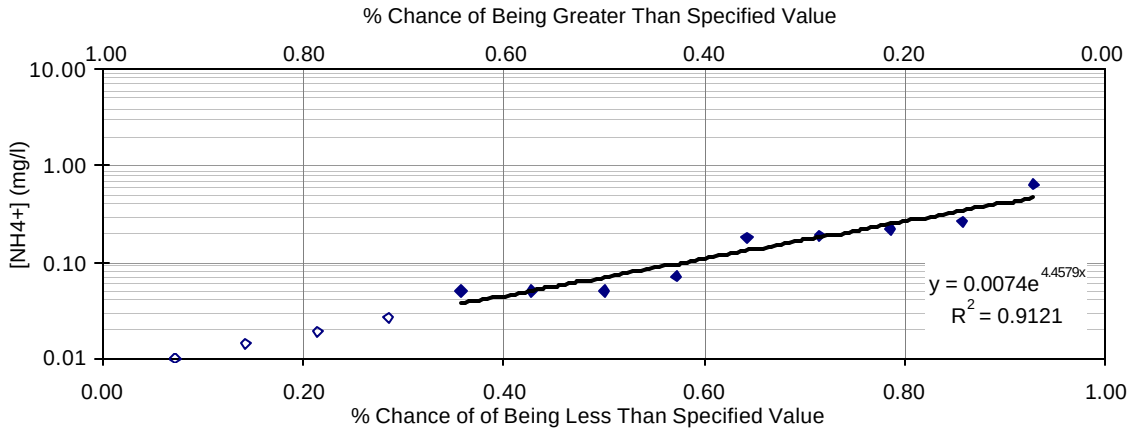


Figure E-43 Klamath River near Seiad Valley, probability plot for ammonia, May – November 2000

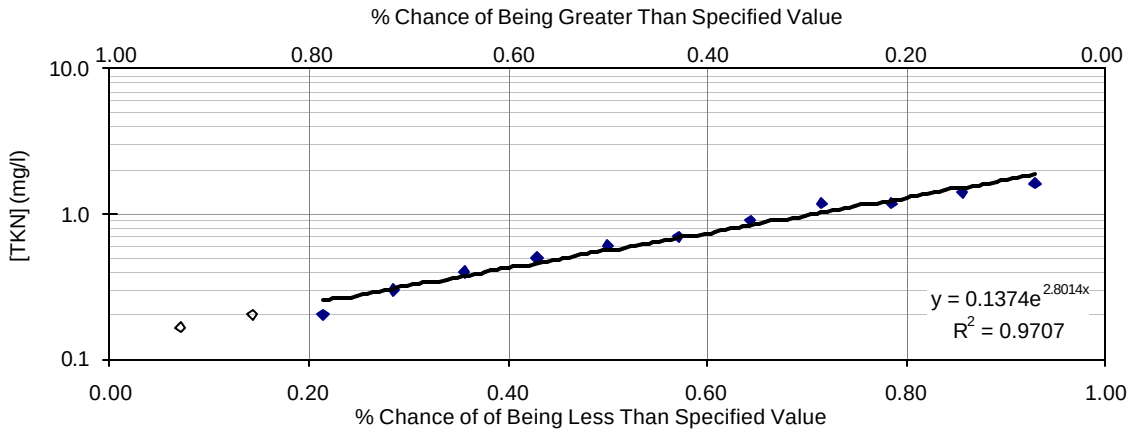


Figure E-44 Klamath River near Seiad Valley, probability plot for total Kjeldahl nitrogen, May – November 2000

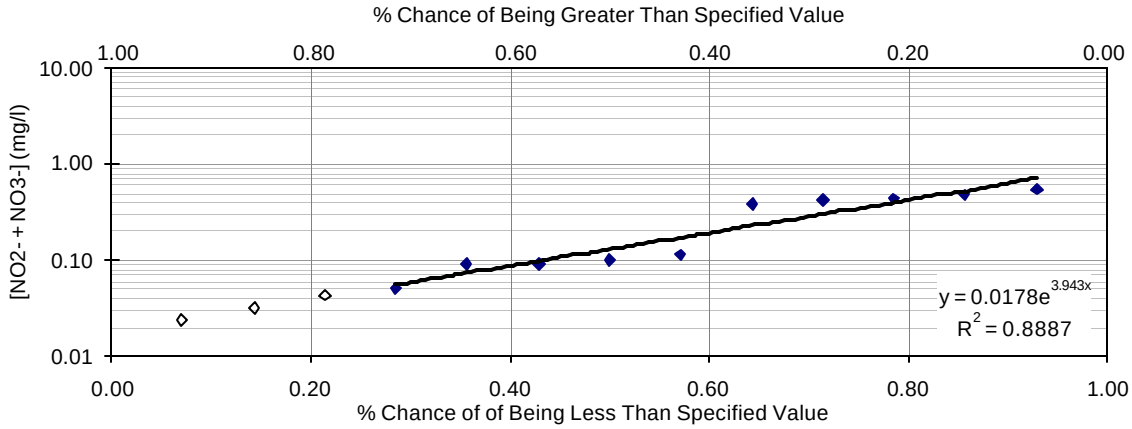


Figure E-45 Klamath River near Seiad Valley, probability plot for nitrite plus nitrate, May – November 2000

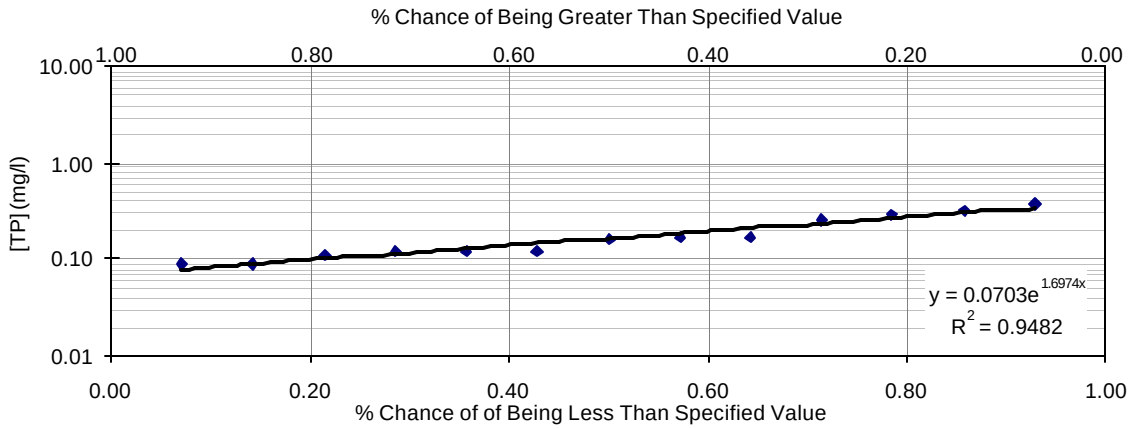


Figure E-46 Klamath River near Seiad Valley, probability plot for total phosphorous, May – November 2000

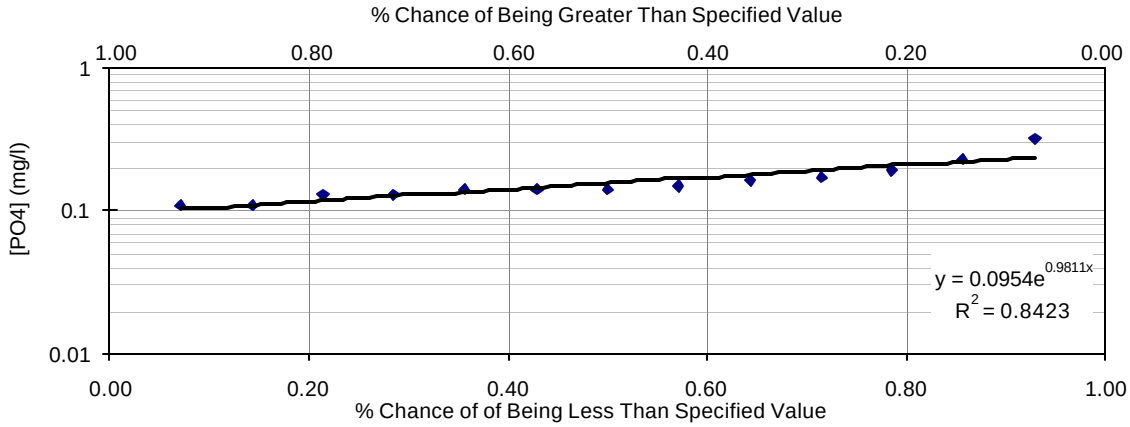


Figure E-47 Klamath River near Seiad Valley, probability plot for orthophosphate, May – November 2000

[Insufficient Data]

Figure E-48 Klamath River near Seiad Valley, probability plot for BOD, May – November 2000

E.9 Shasta River (RM 1.0)

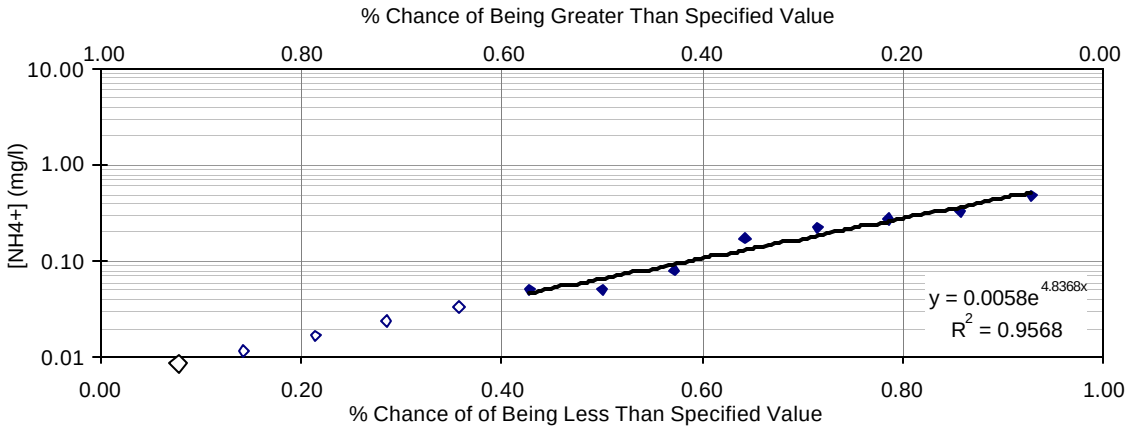


Figure E-49 Shasta River (RM 1.0), probability plot for ammonia, May – November 2000

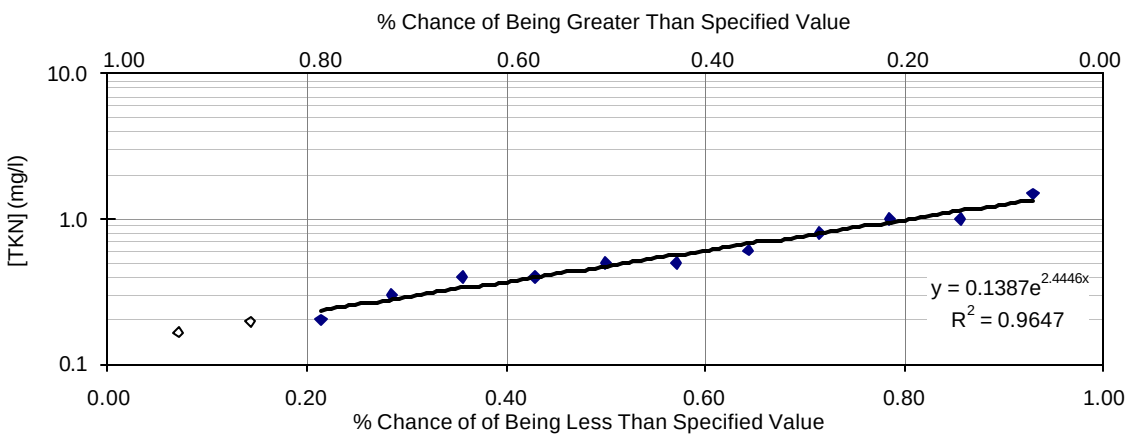


Figure E-50 Shasta River (RM 1.0), probability plot for total Kjeldahl nitrogen, May – November 2000

[Insufficient Data]

Figure E-51 Shasta River (RM 1.0), probability plot for nitrite plus nitrate, May – November 2000

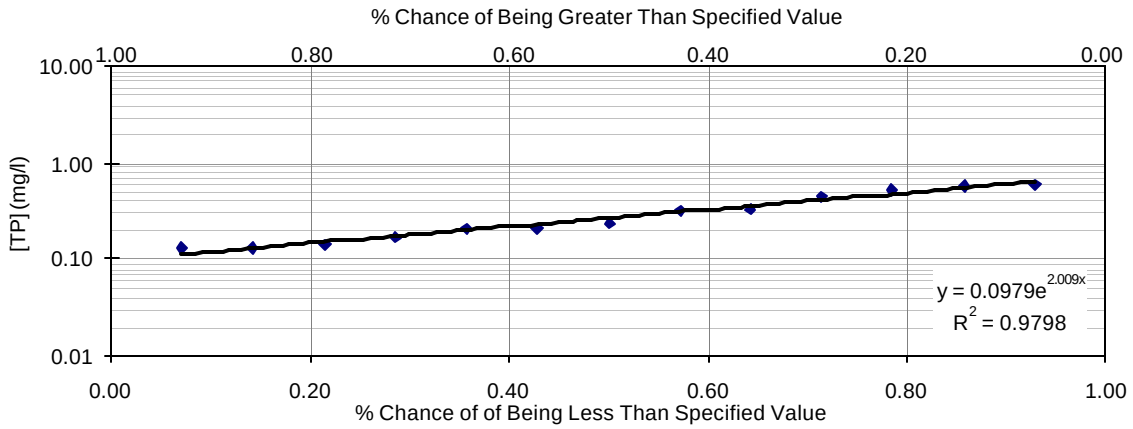


Figure E-52 Shasta River (RM 1.0), probability plot for total phosphorous, May – November 2000

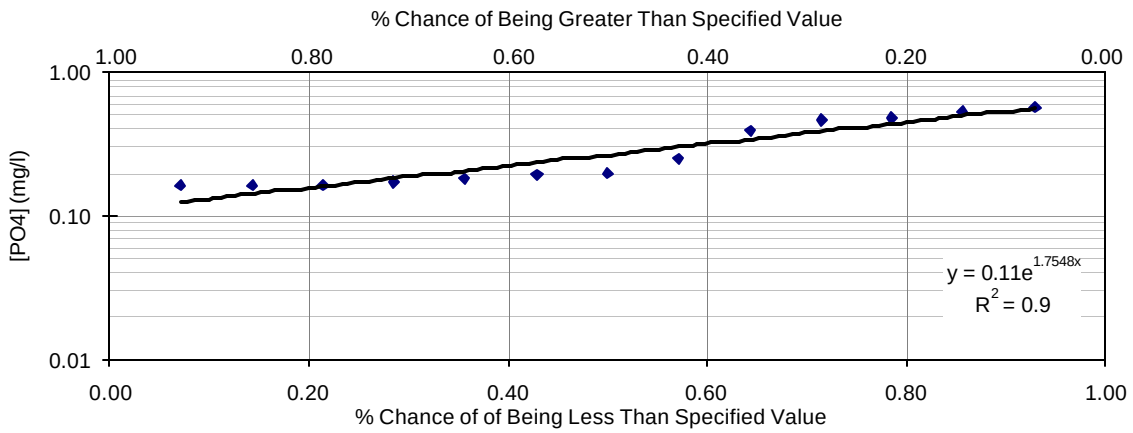


Figure E-53 Shasta River (RM 1.0), probability plot for orthophosphate, May – November 2000

[Insufficient Data]

Figure E-54 Shasta River (RM 1.0), probability plot for BOD, May – November 2000

E.10 Scott River near Ft. Jones (RM 23.4)

[Insufficient Data]

Figure E-55 Scott River near Ft. Jones (RM 23.4), probability plot for ammonia, May – November 2000

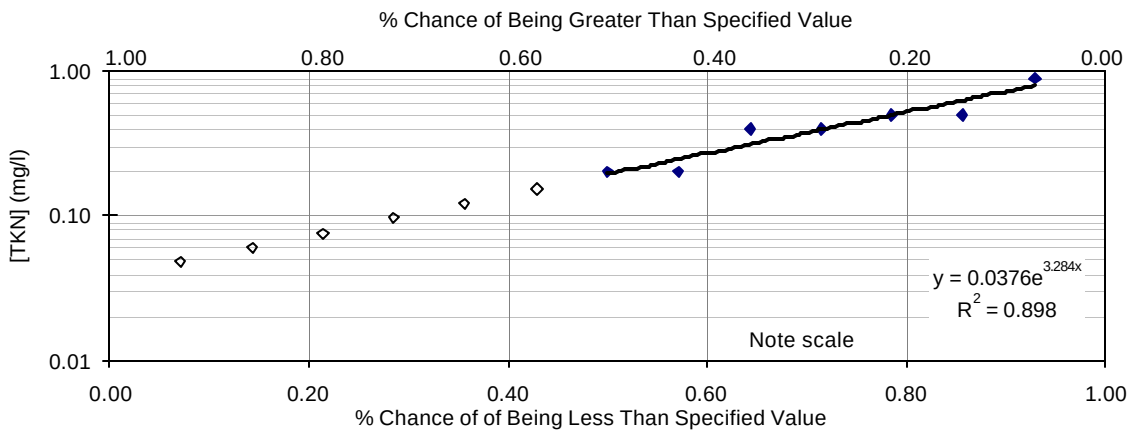


Figure E-56 Scott River near Ft. Jones (RM 23.4), probability plot for total Kjeldahl nitrogen, May – November 2000

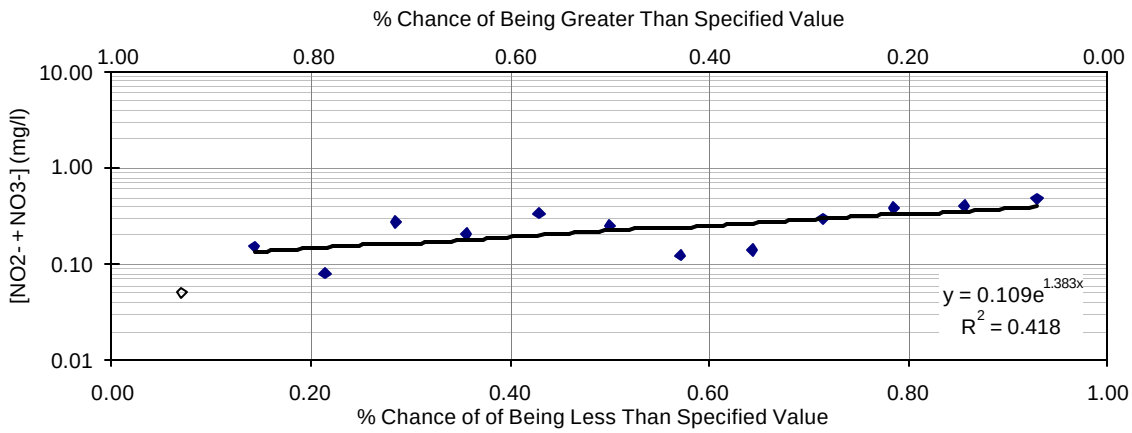


Figure E-57 Scott River near Ft. Jones (RM 23.4), probability plot for nitrite plus nitrate, May – November 2000

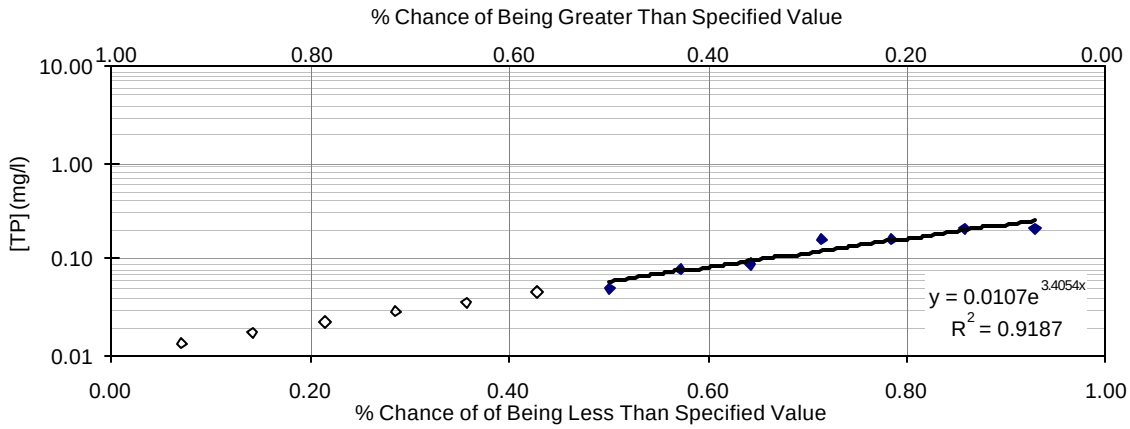


Figure E-58 Scott River near Ft. Jones (RM 23.4), probability plot for total phosphorous, May – November 2000

[Insufficient Data]

Figure E-59 Scott River near Ft. Jones (RM 23.4), probability plot for orthophosphate, May – November 2000

[Insufficient Data]

Figure E-60 Scott River near Ft. Jones (RM 23.4), probability plot for BOD, May – November 2000

F SYNOPTIC SURVEY DATA

Table F-1 Klamath River below Iron Gate Dam synoptic survey water quality data, June 5-7 and August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	NO_3^- + NO2- (mg/l)	Dissolv. Org N (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	Dissolv. Org P (mg/l)
KR bel.Irongate	KRIG	06/05/00	7:40	<0.05	0.8	0.07	0.3	0.25	0.23	<0.05
KR bel.Irongate	KRIG	06/05/00	12:50	0.14	0.8	0.08	0.3	0.35	0.25	0.12
KR bel.Irongate	KRIG	06/05/00	16:00	0.10	0.8	0.07	0.6	0.29	0.29	<0.05
KR bel.Irongate	KRIG	06/06/00	7:20	<0.05	0.7	0.07	0.9	0.26	0.24	0.06
KR bel.Irongate	KRIG	06/06/00	12:40	<0.05	0.7	0.06	0.5	0.44	0.29	0.06
KR bel.Irongate	KRIG	06/06/00	16:00	<0.05	0.7	0.07	0.9	0.28	0.28	0.05
KR bel.Irongate	KRIG	06/07/00	7:00	0.07	0.8	0.06	0.3	0.28	0.21	<0.05
KR bel.Irongate	KRIG	06/07/00	12:30	0.09	0.8	<0.05	0.6	0.26	0.23	<0.05
KR bel.Irongate	KRIG	06/07/00	14:50	0.10	0.8	<0.05	0.5	0.25	0.24	<0.05
KR bel.Irongate	KRIG	08/07/00	7:30	0.08	1.0	0.24	0.5	0.16	0.15	<0.05
KR bel.Irongate	KRIG	08/07/00	12:15	<0.05	1.8	0.24	0.7	0.11	0.15	<0.05
KR bel.Irongate	KRIG	08/07/00	16:00	0.07	0.8	0.26	0.6	0.16	0.14	<0.05
KR bel.Irongate	KRIG	08/08/00	7:15	0.05	0.7	0.36	0.5	0.12	0.16	<0.05
KR bel.Irongate	KRIG	08/08/00	11:50	0.05	0.4	0.32	0.5	0.13	0.15	<0.05
KR bel.Irongate	KRIG	08/08/00	16:00	0.07	0.4	0.32	0.6	0.13	0.16	<0.05
KR bel.Irongate	KRIG	08/09/00	7:15	0.10	0.7	0.28	0.3	0.12	0.16	<0.05
KR bel.Irongate	KRIG	08/09/00	10:40	0.09	0.3	0.37	0.3	0.12	0.15	<0.05
KR bel.Irongate	KRIG	08/09/00	14:30	0.09	0.6	0.35	0.3	0.12	0.16	<0.05

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) no data available

Table F-2 Klamath River above Shasta River synoptic survey water quality data, June 5-7 and August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	NO_3^- + NO2- (mg/l)	Dissolv. Org N (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	Dissolv. Org P (mg/l)
KR ab.Shasta	KRASH	06/05/00	6:00	<0.05	0.6	0.12	0.6	0.29	0.25	0.05
KR ab.Shasta	KRASH	06/05/00	11:10	0.29	0.7	0.06	0.5	0.22	0.21	<0.05
KR ab.Shasta	KRASH	06/05/00	15:00	<0.05	0.6	<0.05	0.7	0.35	0.22	<0.05
KR ab.Shasta	KRASH	06/06/00	6:00	<0.05	0.4	0.07	0.2	0.36	0.24	<0.05
KR ab.Shasta	KRASH	06/06/00	11:20	0.06	0.7	<0.05	0.7	0.25	0.23	0.08
KR ab.Shasta	KRASH	06/06/00	15:00	0.55	0.7	<0.05	0.7	0.28	0.24	<0.05
KR ab.Shasta	KRASH	06/07/00	6:00	0.09	0.6	<0.05	0.5	0.30	0.26	0.14
KR ab.Shasta	KRASH	06/07/00	11:15	0.08	0.8	<0.05	0.4	0.28	0.28	0.14
KR ab.Shasta	KRASH	06/07/00	15:45	0.12	0.7	<0.05	0.5	0.35	0.30	0.08
KR ab.Shasta	KRASH	08/07/00	6:30	0.06	0.8	0.23	0.6	0.15	0.14	<0.05
KR ab.Shasta	KRASH	08/07/00	11:15	0.06	1.1	0.25	0.6	0.15	0.15	<0.05
KR ab.Shasta	KRASH	08/07/00	15:00	0.05	0.7	0.21	0.8	0.15	0.15	<0.05
KR ab.Shasta	KRASH	08/08/00	6:10	<0.05	0.6	0.31	0.5	0.11	0.14	<0.05
KR ab.Shasta	KRASH	08/08/00	11:15	0.07	0.6	0.32	0.5	0.12	0.15	<0.05
KR ab.Shasta	KRASH	08/08/00	15:00	0.07	0.5	0.29	0.6	0.12	0.16	<0.05
KR ab.Shasta	KRASH	08/09/00	6:10	0.09	0.6	0.27	0.4	0.12	0.14	<0.05
KR ab.Shasta	KRASH	08/09/00	12:15	0.08	1.0	0.25	0.2	0.12	0.15	<0.05
KR ab.Shasta	KRASH	08/09/00	15:10	0.09	0.6	0.29	0.2	0.12	0.15	<0.05

(<) less than reporting limit
(k) below reporting limit of 40 ug/l
(-) no data available

Table F-3 Klamath River above Scott River synoptic survey water quality data, June 5-7 and August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	NO_3^- + NO2- (mg/l)	Dissolv. Org N (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	Dissolv. Org P (mg/l)
KR ab. Scott	KRASC	06/05/00	6:40	0.07	0.8	<0.05	0.7	0.32	0.25	<0.05
KR ab.Scott	KRASC	06/05/00	12:20	0.34	0.6	<0.05	0.4	0.24	0.23	0.07
KR ab.Scott	KRASC	06/05/00	16:20	0.70	0.8	<0.05	0.8	0.25	0.23	0.06
KR ab.Scott	KRASC	06/06/00	6:45	<0.05	0.6	<0.05	0.7	0.38	0.25	0.1
KR ab.Scott	KRASC	06/06/00	12:00	0.15	0.7	<0.05	0.2	0.32	0.25	<0.05
KR ab.Scott	KRASC	06/06/00	15:15	<0.05	0.8	<0.05	0.8	0.31	0.26	<0.05
KR ab.Scott	KRASC	06/07/00	7:25	<0.05	0.6	<0.05	0.3	0.23	0.26	<0.05
KR ab.Scott	KRASC	06/07/00	11:20	<0.05	0.7	<0.05	0.2	0.25	0.25	<0.05
KR ab.Scott	KRASC	06/07/00	15:15	<0.05	1.0	<0.05	0.4	0.33	0.30	<0.05
KR ab.Scott	KRASC	08/07/00	6:50	0.08	0.8	0.16	0.3	0.15	0.14	<0.05
KR ab.Scott	KRASC	08/07/00	11:00	0.08	0.6	0.16	0.4	0.15	0.15	<0.05
KR ab.Scott	KRASC	08/07/00	15:25	0.05	0.8	0.15	0.2	0.17	0.25	<0.05
KR ab.Scott	KRASC	08/08/00	6:15	0.05	0.5	0.19	0.5	0.11	0.14	<0.05
KR ab.Scott	KRASC	08/08/00	11:00	<0.05	0.4	0.30	0.2	0.12	0.14	<0.05
KR ab.Scott	KRASC	08/08/00	15:50	<0.05	0.6	0.18	0.2	0.11	0.15	<0.05
KR ab.Scott	KRASC	08/09/00	6:15	0.09	0.5	0.2	0.2	0.11	0.14	<0.05
KR ab.Scott	KRASC	08/09/00	11:00	0.08	1.0	0.16	0.2	0.12	0.14	<0.05
KR ab.Scott	KRASC	08/09/00	15:15	0.10	1.0	0.15	0.3	0.12	0.14	<0.05

(<) less than reporting limit
(l) below reporting limit of 40 ug/l
(-) no data available

Table F-4 Klamath River near Seiad Valley synoptic survey water quality data, June 5-7 and August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	NO_3^- + NO2- (mg/l)	Dissolv. Org N (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	Dissolv. Org P (mg/l)
KR @ Seiad	KRSV	06/05/00	7:30	0.36	0.4	<0.05	0.4	0.27	0.21	<0.05
KR @ Seiad	KRSV	06/05/00	13:00	<0.05	0.5	<0.05	0.5	0.20	0.18	<0.05
KR @ Seiad	KRSV	06/05/00	16:00	0.05	0.5	<0.05	0.4	0.22	0.20	<0.05
KR @ Seiad	KRSV	06/06/00	7:20	0.26	0.6	<0.05	0.6	0.27	0.23	<0.05
KR @ Seiad	KRSV	06/06/00	10:45	0.32	0.4	<0.05	0.5	0.19	0.16	0.09
KR @ Seiad	KRSV	06/06/00	14:30	0.27	0.4	<0.05	0.5	0.23	0.23	<0.05
KR @ Seiad	KRSV	06/07/00	6:30	<0.05	0.6	<0.05	0.3	0.21	0.20	<0.05
KR @ Seiad	KRSV	06/07/00	10:30	0.08	0.6	<0.05	0.3	0.18	0.18	<0.05
KR @ Seiad	KRSV	06/07/00	14:30	0.11	0.5	<0.05	0.1	0.22	0.22	0.05
KR @ Seiad	KRSV	08/07/00	7:45	0.08	0.8	0.13	0.4	0.16	0.13	<0.05
KR @ Seiad	KRSV	08/07/00	11:45	0.05	1.20	0.10	0.4	0.11	0.13	<0.05
KR @ Seiad	KRSV	08/07/00	14:40	0.05	0.4	0.07	0.4	0.13	0.12	<0.05
KR @ Seiad	KRSV	08/08/00	7:30	<0.05	0.7	0.14	0.4	0.11	0.13	<0.05
KR @ Seiad	KRSV	08/08/00	12:00	0.06	0.4	0.11	0.4	0.11	0.12	<0.05
KR @ Seiad	KRSV	08/08/00	14:45	0.12	0.5	0.06	0.4	0.10	0.12	<0.05
KR @ Seiad	KRSV	08/09/00	7:10	0.08	0.2	0.16	0.3	0.11	0.13	<0.05
KR @ Seiad	KRSV	08/09/00	12:10	0.08	0.6	0.08	<0.2	0.11	0.12	<0.05
KR @ Seiad	KRSV	08/09/00	14:30	0.08	0.5	0.10	0.2	0.11	0.11	<0.05

(<) less than reporting limit
(m) below reporting limit of 40 ug/l
(-) no data available

Table F-5 Shasta River near mouth synoptic survey water quality data, June 5-7 and August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	NO_3^- + NO2- (mg/l)	Dissolv. Org N (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	Dissolv. Org P (mg/l)
Shasta River	SHR1	06/05/00	6:30	<0.05	0.5	<0.05	0.6	0.52	0.46	0.10
Shasta River	SHR1	06/05/00	11:45	0.08	0.5	<0.05	0.6	0.44	0.42	0.08
Shasta River	SHR1	06/05/00	15:15	0.34	0.5	<0.05	0.6	0.51	0.41	0.05
Shasta River	SHR1	06/06/00	6:30	<0.05	0.6	<0.05	0.9	0.71	0.49	<0.05
Shasta River	SHR1	06/06/00	11:00	0.23	0.8	<0.05	0.7	0.61	0.48	0.21
Shasta River	SHR1	06/06/00	15:15	<0.05	0.7	<0.05	0.7	0.56	0.56	<0.05
Shasta River	SHR1	06/07/00	10:00	0.12	0.8	<0.05	0.4	0.57	0.50	0.06
Shasta River	SHR1	06/07/00	11:30	0.09	0.6	<0.05	0.3	0.51	0.44	<0.05
Shasta River	SHR1	06/07/00	15:55	0.08	0.7	<0.05	0.3	0.50	0.50	0.05
Shasta River	SHR1	08/07/00	7:00	<0.05	0.6	<0.05	0.5	0.18	0.22	<0.05
Shasta River	SHR1	08/07/00	10:45	0.05	1.0	<0.05	0.4	0.17	0.20	<0.05
Shasta River	SHR1	08/07/00	14:45	0.05	0.5	<0.05	0.4	0.18	0.20	<0.05
Shasta River	SHR1	08/08/00	6:40	0.05	0.3	<0.05	0.5	0.16	0.20	<0.05
Shasta River	SHR1	08/08/00	10:50	0.05	0.3	<0.05	0.3	0.15	0.20	<0.05
Shasta River	SHR1	08/08/00	14:45	0.05	0.4	<0.05	0.4	0.12	0.20	<0.05
Shasta River	SHR1	08/09/00	6:30	0.07	0.7	<0.05	0.3	0.20	0.25	<0.05
Shasta River	SHR1	08/09/00	12:00	0.06	0.6	<0.05	0.4	0.19	0.26	<0.05
Shasta River	SHR1	08/09/00	15:30	0.07	0.3	<0.05	0.2	0.21	0.25	<0.05

(<) less than reporting limit
(n) below reporting limit of 40 ug/l
(-) no data available

Table F-6 Scott River near mouth synoptic survey water quality data, June 5-7 and August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	NO_3^- + NO2- (mg/l)	Dissolv. Org N (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	Dissolv. Org P (mg/l)
Scott River Mouth	SCR1	06/05/00	6:20	0.35	0.4	<0.05	0.4	0.14	0.10	<0.05
Scott River Mouth	SCR1	06/05/00	12:05	<0.05	0.2	<0.05	0.3	0.15	0.13	<0.05
Scott River Mouth	SCR1	06/05/00	16:15	0.28	<0.2	<0.05	0.4	0.14	0.09	<0.05
Scott River Mouth	SCR1	06/06/00	6:20	<0.05	0.4	<0.05	0.6	0.26	0.10	<0.05
Scott River Mouth	SCR1	06/06/00	11:50	0.33	0.4	<0.05	0.5	0.13	0.11	<0.05
Scott River Mouth	SCR1	06/06/00	15:00	0.16	0.3	<0.05	0.5	0.18	0.13	<0.05
Scott River Mouth	SCR1	06/07/00	7:05	<0.05	0.6	<0.05	<0.2	0.10	0.10	<0.05
Scott River Mouth	SCR1	06/07/00	11:35	0.10	0.3	<0.05	<0.2	0.18	0.12	<0.05
Scott River Mouth	SCR1	06/07/00	15:00	<0.05	0.4	<0.05	0.2	0.15	0.15	<0.05
Scott River Mouth	SCR1	08/07/00	6:35	<0.05	<0.2	<0.05	<0.2	<0.05	<0.05	<0.05
Scott River Mouth	SCR1	08/07/00	11:15	<0.05	<0.2	<0.05	<0.2	<0.05	<0.05	<0.05
Scott River Mouth	SCR1	08/07/00	15:10	<0.05	<0.2	<0.05	<0.2	0.05	<0.05	<0.05
Scott River Mouth	SCR1	08/08/00	6:45	<0.05	<0.2	<0.05	<0.2	<0.05	<0.05	<0.05
Scott River Mouth	SCR1	08/08/00	11:30	<0.05	<0.2	<0.05	<0.2	<0.05	<0.05	<0.05
Scott River Mouth	SCR1	08/08/00	15:30	<0.05	<0.2	<0.05	<0.2	<0.05	<0.05	<0.05
Scott River Mouth	SCR1	08/09/00	6:30	0.06	<0.2	<0.05	<0.2	<0.05	<0.05	<0.05
Scott River Mouth	SCR1	08/09/00	11:20	<0.05	0.2	<0.05	<0.2	<0.05	<0.05	<0.05
Scott River Mouth	SCR1	08/09/00	15:00	<0.05	<0.2	<0.05	<0.2	<0.05	<0.05	<0.05

(<) less than reporting limit
(o) below reporting limit of 40 ug/l
(-) no data available

G SYNOPTIC SURVEY DATA: SUMMARY STATISTICS

Table G-1 Klamath River below Iron Gate Dam synoptic survey water quality data, June 5-7, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
KR bel.Irongate	KRIG	06/05/00	7:40	**0.05**	0.8	0.07	0.3	0.25	0.23	**<0.05**
KR bel.Irongate	KRIG	06/05/00	12:50	0.14	0.8	0.08	0.3	0.35	0.25	0.12
KR bel.Irongate	KRIG	06/05/00	16:00	0.10	0.8	0.07	0.6	0.29	0.29	**<0.05**
KR bel.Irongate	KRIG	06/06/00	7:20	**0.05**	0.7	0.07	0.9	0.26	0.24	0.06
KR bel.Irongate	KRIG	06/06/00	12:40	**0.05**	0.7	0.06	0.5	0.44	0.29	0.06
KR bel.Irongate	KRIG	06/06/00	16:00	**0.04**	0.7	0.07	0.9	0.28	0.28	0.05
KR bel.Irongate	KRIG	06/07/00	7:00	0.07	0.8	0.06	0.3	0.28	0.21	**<0.05**
KR bel.Irongate	KRIG	06/07/00	12:30	0.09	0.8	**0.05**	0.6	0.26	0.23	**<0.05**
KR bel.Irongate	KRIG	06/07/00	14:50	0.10	0.8	**0.05**	0.5	0.25	0.24	**<0.05**
			average	0.08	0.77	0.06	0.54	0.30	0.25	-
			minimum	0.04	0.70	0.05	0.30	0.25	0.21	<0.05
			maximum	0.14	0.80	0.08	0.90	0.44	0.29	0.12
			median	0.07	0.80	0.07	0.50	0.28	0.24	-
			std. dev	0.033	0.050	0.010	0.235	0.062	0.029	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-2 Klamath River below Iron Gate Dam synoptic survey water quality data, August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
KR bel.Irongate	KRIG	08/07/00	7:30	0.08	1.0	0.24	0.5	0.16	0.15	**<0.05**
KR bel.Irongate	KRIG	08/07/00	12:15	**0.05**	1.8	0.24	0.7	0.11	0.15	**<0.05**
KR bel.Irongate	KRIG	08/07/00	16:00	0.07	0.8	0.26	0.6	0.16	0.14	**<0.05**
KR bel.Irongate	KRIG	08/08/00	7:15	0.05	0.7	0.36	0.5	0.12	0.16	**<0.05**
KR bel.Irongate	KRIG	08/08/00	11:50	0.05	0.4	0.32	0.5	0.13	0.15	**<0.05**
KR bel.Irongate	KRIG	08/08/00	16:00	0.07	0.4	0.32	0.6	0.13	0.16	**<0.05**
KR bel.Irongate	KRIG	08/09/00	7:15	0.10	0.7	0.28	0.3	0.12	0.16	**<0.05**
KR bel.Irongate	KRIG	08/09/00	10:40	0.09	0.3	0.37	0.3	0.12	0.15	**<0.05**
KR bel.Irongate	KRIG	08/09/00	14:30	0.09	0.6	0.35	0.3	0.12	0.16	**<0.05**
			average	0.07	0.74	0.30	0.48	0.13	0.15	-
			minimum	0.05	0.30	0.24	0.30	0.11	0.14	<0.05
			maximum	0.10	1.80	0.37	0.70	0.16	0.16	-
			median	0.07	0.70	0.32	0.50	0.12	0.15	-
			std. dev	0.019	0.453	0.051	0.148	0.018	0.007	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-3 Klamath River above Shasta River synoptic survey water quality data, June 5-7, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
KR ab.Shasta	KRASH	06/05/00	6:00	**0.02**	0.6	0.12	0.6	0.29	0.25	0.05
KR ab.Shasta	KRASH	06/05/00	11:10	0.29	0.7	0.06	0.5	0.22	0.21	**<0.05**
KR ab.Shasta	KRASH	06/05/00	15:00	**0.01**	0.6	**<0.05**	0.7	0.35	0.22	**<0.05**
KR ab.Shasta	KRASH	06/06/00	6:00	**0.03**	0.4	0.07	0.2	0.36	0.24	**<0.05**
KR ab.Shasta	KRASH	06/06/00	11:20	0.06	0.7	**<0.05**	0.7	0.25	0.23	0.08
KR ab.Shasta	KRASH	06/06/00	15:00	0.55	0.7	**<0.05**	0.7	0.28	0.24	**<0.05**
KR ab.Shasta	KRASH	06/07/00	6:00	0.09	0.6	**<0.05**	0.5	0.30	0.26	0.14
KR ab.Shasta	KRASH	06/07/00	11:15	0.08	0.8	**<0.05**	0.4	0.28	0.28	0.14
KR ab.Shasta	KRASH	06/07/00	15:45	0.12	0.7	**<0.05**	0.5	0.35	0.30	0.08
			average	0.14	0.64	-	0.53	0.30	0.25	-
			minimum	0.01	0.40	<0.05	0.20	0.22	0.21	<0.05
			maximum	0.55	0.80	0.12	0.70	0.36	0.30	0.14
			median	0.08	0.70	-	0.50	0.29	0.24	-
			std. dev	0.176	0.113	-	0.166	0.048	0.029	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)
If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-4 Klamath River above Shasta River synoptic survey water quality data, August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
KR ab.Shasta	KRASH	08/07/00	6:30	0.06	0.8	0.23	0.6	0.15	0.14	**<0.05**
KR ab.Shasta	KRASH	08/07/00	11:15	0.06	1.1	0.25	0.6	0.15	0.15	**<0.05**
KR ab.Shasta	KRASH	08/07/00	15:00	0.05	0.7	0.21	0.8	0.15	0.15	**<0.05**
KR ab.Shasta	KRASH	08/08/00	6:10	**0.05**	0.6	0.31	0.5	0.11	0.14	**<0.05**
KR ab.Shasta	KRASH	08/08/00	11:15	0.07	0.6	0.32	0.5	0.12	0.15	**<0.05**
KR ab.Shasta	KRASH	08/08/00	15:00	0.07	0.5	0.29	0.6	0.12	0.16	**<0.05**
KR ab.Shasta	KRASH	08/09/00	6:10	0.09	0.6	0.27	0.4	0.12	0.14	**<0.05**
KR ab.Shasta	KRASH	08/09/00	12:15	0.08	1.0	0.25	0.2	0.12	0.15	**<0.05**
KR ab.Shasta	KRASH	08/09/00	15:10	0.09	0.6	0.29	0.2	0.12	0.15	**<0.05**
			average	0.07	0.72	0.27	0.49	0.13	0.15	-
			minimum	0.05	0.50	0.21	0.20	0.11	0.14	<0.05
			maximum	0.09	1.10	0.32	0.80	0.15	0.16	-
			median	0.07	0.60	0.27	0.50	0.12	0.15	-
			std. dev	0.015	0.205	0.037	0.196	0.016	0.007	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)
If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-5 Klamath River above Scott River synoptic survey water quality data, June 5-7, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
KR ab. Scott	KRASC	06/05/00	6:40	0.07	0.8	**<0.05**	0.7	0.32	0.25	**<0.05**
KR ab.Scott	KRASC	06/05/00	12:20	0.34	0.6	**<0.05**	0.4	0.24	0.23	0.07
KR ab.Scott	KRASC	06/05/00	16:20	0.70	0.8	**<0.05**	0.8	0.25	0.23	0.06
KR ab.Scott	KRASC	06/06/00	6:45	**<0.05**	0.6	**<0.05**	0.7	0.38	0.25	0.1
KR ab.Scott	KRASC	06/06/00	12:00	0.15	0.7	**<0.05**	0.2	0.32	0.25	**<0.05**
KR ab.Scott	KRASC	06/06/00	15:15	**<0.05**	0.8	**<0.05**	0.8	0.31	0.26	**<0.05**
KR ab.Scott	KRASC	06/07/00	7:25	**<0.05**	0.6	**<0.05**	0.3	0.23	0.26	**<0.05**
KR ab.Scott	KRASC	06/07/00	11:20	**<0.05**	0.7	**<0.05**	0.2	0.25	0.25	**<0.05**
KR ab.Scott	KRASC	06/07/00	15:15	**<0.05**	1.0	**<0.05**	0.4	0.33	0.30	**<0.05**
			average	-	0.73	-	0.50	0.29	0.25	-
			minimum	<0.05	0.60	<0.05	0.20	0.23	0.23	<0.05
			maximum	0.70	1.00	-	0.80	0.38	0.30	0.10
			median	-	0.70	-	0.40	0.31	0.25	-
			std. dev	-	0.132	-	0.250	0.051	0.021	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-6 Klamath River above Scott River synoptic survey water quality data, August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
KR ab.Scott	KRASC	08/07/00	6:50	0.08	0.8	0.16	0.3	0.15	0.14	**<0.05**
KR ab.Scott	KRASC	08/07/00	11:00	0.08	0.6	0.16	0.4	0.15	0.15	**<0.05**
KR ab.Scott	KRASC	08/07/00	15:25	0.05	0.8	0.15	0.2	0.17	0.25	**<0.05**
KR ab.Scott	KRASC	08/08/00	6:15	0.05	0.5	0.19	0.5	0.11	0.14	**<0.05**
KR ab.Scott	KRASC	08/08/00	11:00	**0.05**	0.4	0.30	0.2	0.12	0.14	**<0.05**
KR ab.Scott	KRASC	08/08/00	15:50	**0.04**	0.6	0.18	0.2	0.11	0.15	**<0.05**
KR ab.Scott	KRASC	08/09/00	6:15	0.09	0.5	0.2	0.2	0.11	0.14	**<0.05**
KR ab.Scott	KRASC	08/09/00	11:00	0.08	1.0	0.16	0.2	0.12	0.14	**<0.05**
KR ab.Scott	KRASC	08/09/00	15:15	0.10	1.0	0.15	0.3	0.12	0.14	**<0.05**
			average	0.07	0.69	0.18	0.28	0.13	0.15	-
			minimum	0.04	0.40	0.15	0.20	0.11	0.14	<0.05
			maximum	0.10	1.00	0.30	0.50	0.17	0.25	-
			median	0.08	0.60	0.16	0.20	0.12	0.14	-
			std. dev	0.021	0.220	0.047	0.109	0.022	0.036	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-7 Klamath River near Seiad Valley synoptic survey water quality data, June 5-7, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
KR @ Seiad	KRSV	06/05/00	7:30	0.36	0.4	**<0.05**	0.4	0.27	0.21	**<0.05**
KR @ Seiad	KRSV	06/05/00	13:00	**0.03**	0.5	**<0.05**	0.5	0.20	0.18	**<0.05**
KR @ Seiad	KRSV	06/05/00	16:00	0.05	0.5	**<0.05**	0.4	0.22	0.20	**<0.05**
KR @ Seiad	KRSV	06/06/00	7:20	0.26	0.6	**<0.05**	0.6	0.27	0.23	**<0.05**
KR @ Seiad	KRSV	06/06/00	10:45	0.32	0.4	**<0.05**	0.5	0.19	0.16	0.09
KR @ Seiad	KRSV	06/06/00	14:30	0.27	0.4	**<0.05**	0.5	0.23	0.23	**<0.05**
KR @ Seiad	KRSV	06/07/00	6:30	**0.04**	0.6	**<0.05**	0.3	0.21	0.20	**<0.05**
KR @ Seiad	KRSV	06/07/00	10:30	0.08	0.6	**<0.05**	0.3	0.18	0.18	**<0.05**
KR @ Seiad	KRSV	06/07/00	14:30	0.11	0.5	**<0.05**	0.1	0.22	0.22	0.05
			average	0.17	0.50	-	0.40	0.22	0.20	-
			minimum	0.03	0.40	<0.05	0.10	0.18	0.16	<0.05
			maximum	0.36	0.60	-	0.60	0.27	0.23	0.09
			median	0.11	0.50	-	0.40	0.22	0.20	-
			std. dev	0.132	0.087	-	0.150	0.032	0.024	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-8 Klamath River near Seiad Valley synoptic survey water quality data, August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
KR @ Seiad	KRSV	08/07/00	7:45	0.08	0.8	0.13	0.4	0.16	0.13	**<0.05**
KR @ Seiad	KRSV	08/07/00	11:45	0.05	1.20	0.10	0.4	0.11	0.13	**<0.05**
KR @ Seiad	KRSV	08/07/00	14:40	0.05	0.4	0.07	0.4	0.13	0.12	**<0.05**
KR @ Seiad	KRSV	08/08/00	7:30	**0.04**	0.7	0.14	0.4	0.11	0.13	**<0.05**
KR @ Seiad	KRSV	08/08/00	12:00	0.06	0.4	0.11	0.4	0.11	0.12	**<0.05**
KR @ Seiad	KRSV	08/08/00	14:45	0.12	0.5	0.06	0.4	0.10	0.12	**<0.05**
KR @ Seiad	KRSV	08/09/00	7:10	0.08	0.2	0.16	0.3	0.11	0.13	**<0.05**
KR @ Seiad	KRSV	08/09/00	12:10	0.08	0.6	0.08	**<0.2**	0.11	0.12	**<0.05**
KR @ Seiad	KRSV	08/09/00	14:30	0.08	0.5	0.10	0.2	0.11	0.11	**<0.05**
			average	0.07	0.59	0.11	-	0.12	0.12	-
			minimum	0.04	0.20	0.06	<0.2	0.10	0.11	<0.05
			maximum	0.12	1.20	0.16	0.40	0.16	0.13	-
			median	0.08	0.50	0.10	-	0.11	0.12	-
			std. dev	0.024	0.289	0.033	-	0.018	0.007	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-9 Shasta River near mouth synoptic survey water quality data, June 5-7, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Shasta River	SHR1	06/05/00	6:30	**0.05**	0.5	**<0.05**	0.6	0.52	0.46	0.10
Shasta River	SHR2	06/05/00	11:45	0.08	0.5	**<0.05**	0.6	0.44	0.42	0.08
Shasta River	SHR3	06/05/00	15:15	0.34	0.5	**<0.05**	0.6	0.51	0.41	0.05
Shasta River	SHR4	06/06/00	6:30	**0.02**	0.6	**<0.05**	0.9	0.71	0.49	**<0.05**
Shasta River	SHR5	06/06/00	11:00	0.23	0.8	**<0.05**	0.7	0.61	0.48	0.21
Shasta River	SHR6	06/06/00	15:15	**0.03**	0.7	**<0.05**	0.7	0.56	0.56	**<0.05**
Shasta River	SHR7	06/07/00	10:00	0.12	0.8	**<0.05**	0.4	0.57	0.50	0.06
Shasta River	SHR8	06/07/00	11:30	0.09	0.6	**<0.05**	0.3	0.51	0.44	**<0.05**
Shasta River	SHR9	06/07/00	15:55	0.08	0.7	**<0.05**	0.3	0.50	0.50	0.05
			average	0.12	0.63	-	0.57	0.55	0.47	-
			minimum	0.02	0.50	<0.05	0.30	0.44	0.41	<0.05
			maximum	0.34	0.80	-	0.90	0.71	0.56	0.21
			median	0.08	0.60	-	0.60	0.52	0.48	-
			std. dev	0.105	0.122	-	0.200	0.078	0.047	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-10 Shasta River near mouth synoptic survey water quality data, August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Shasta River	SHR10	08/07/00	7:00	**0.04**	0.6	**<0.05**	0.5	0.18	0.22	**<0.05**
Shasta River	SHR11	08/07/00	10:45	0.05	1.0	**<0.05**	0.4	0.17	0.20	**<0.05**
Shasta River	SHR12	08/07/00	14:45	0.05	0.5	**<0.05**	0.4	0.18	0.20	**<0.05**
Shasta River	SHR13	08/08/00	6:40	0.05	0.3	**<0.05**	0.5	0.16	0.20	**<0.05**
Shasta River	SHR14	08/08/00	10:50	0.05	0.3	**<0.05**	0.3	0.15	0.20	**<0.05**
Shasta River	SHR15	08/08/00	14:45	0.05	0.4	**<0.05**	0.4	0.12	0.20	**<0.05**
Shasta River	SHR16	08/09/00	6:30	0.07	0.7	**<0.05**	0.3	0.20	0.25	**<0.05**
Shasta River	SHR17	08/09/00	12:00	0.06	0.6	**<0.05**	0.4	0.19	0.26	**<0.05**
Shasta River	SHR18	08/09/00	15:30	0.07	0.3	**<0.05**	0.2	0.21	0.25	**<0.05**
			average	0.05	0.52	-	0.38	0.17	0.22	-
			minimum	0.04	0.30	<0.05	0.20	0.12	0.20	<0.05
			maximum	0.07	1.00	-	0.50	0.21	0.26	-
			median	0.05	0.50	-	0.40	0.18	0.20	-
			std. dev	0.010	0.233	-	0.097	0.028	0.026	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-11 Scott River near mouth synoptic survey water quality data, June 5-7, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Scott River Mouth	SCR1	06/05/00	6:20	0.35	0.4	**<0.05**	0.4	0.14	0.10	**<0.05**
Scott River Mouth	SCR2	06/05/00	12:05	**0.05**	0.2	**<0.05**	0.3	0.15	0.13	**<0.05**
Scott River Mouth	SCR3	06/05/00	16:15	0.28	**0.05**	**<0.05**	0.4	0.14	0.09	**<0.05**
Scott River Mouth	SCR4	06/06/00	6:20	**0.04**	0.4	**<0.05**	0.6	0.26	0.10	**<0.05**
Scott River Mouth	SCR5	06/06/00	11:50	0.33	0.4	**<0.05**	0.5	0.13	0.11	**<0.05**
Scott River Mouth	SCR6	06/06/00	15:00	0.16	0.3	**<0.05**	0.5	0.18	0.13	**<0.05**
Scott River Mouth	SCR7	06/07/00	7:05	**0.03**	0.6	**<0.05**	**<0.2**	0.10	0.10	**<0.05**
Scott River Mouth	SCR8	06/07/00	11:35	0.10	0.3	**<0.05**	**<0.2**	0.18	0.12	**<0.05**
Scott River Mouth	SCR9	06/07/00	15:00	**0.05**	0.4	**<0.05**	0.2	0.15	0.15	**<0.05**
			average	0.15	0.34	-	-	0.16	0.11	-
			minimum	0.03	0.05	<0.05	<0.2	0.10	0.09	<0.05
			maximum	0.35	0.60	-	0.60	0.26	0.15	-
			median	0.10	0.40	-	-	0.15	0.11	-
			std. dev	0.131	0.154	-	-	0.045	0.019	-

Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

Table G-12 Scott River near mouth synoptic survey water quality data, August 7-9, 2000

SITE	SITE	Date	Time	NH_4^+	TKN	NO_3^- + NO2-	Dissolv. Org N	TP	PO_4^{3-}	Dissolv. Org P
				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Scott River Mouth	SCR10	08/07/00	6:35	**<0.05**	**<0.2**	**<0.05**	**<0.2**	**<0.05**	**<0.05**	**<0.05**
Scott River Mouth	SCR11	08/07/00	11:15	**<0.05**	**<0.2**	**<0.05**	**<0.2**	**<0.05**	**<0.05**	**<0.05**
Scott River Mouth	SCR12	08/07/00	15:10	**<0.05**	**<0.2**	**<0.05**	**<0.2**	0.05	**<0.05**	**<0.05**
Scott River Mouth	SCR13	08/08/00	6:45	**<0.05**	**<0.2**	**<0.05**	**<0.2**	**<0.05**	**<0.05**	**<0.05**
Scott River Mouth	SCR14	08/08/00	11:30	**<0.05**	**<0.2**	**<0.05**	**<0.2**	**<0.05**	**<0.05**	**<0.05**
Scott River Mouth	SCR15	08/08/00	15:30	**<0.05**	**<0.2**	**<0.05**	**<0.2**	**<0.05**	**<0.05**	**<0.05**
Scott River Mouth	SCR16	08/09/00	6:30	0.06	**<0.2**	**<0.05**	**<0.2**	**<0.05**	**<0.05**	**<0.05**
Scott River Mouth	SCR17	08/09/00	11:20	**<0.05**	0.2	**<0.05**	**<0.2**	**<0.05**	**<0.05**	**<0.05**
Scott River Mouth	SCR18	08/09/00	15:00	**<0.05**	**<0.2**	**<0.05**	**<0.2**	**<0.05**	**<0.05**	**<0.05**
			average	-	-	-	-	-	-	-
			minimum	0.06	<0.2	<0.05	<0.2	<0.05	<0.05	<0.05
			maximum	0.06	0.20	-	-	0.05	-	-
			median	-	-	-	-	-	-	-
			std. dev	-	-	-	-	-	-	-

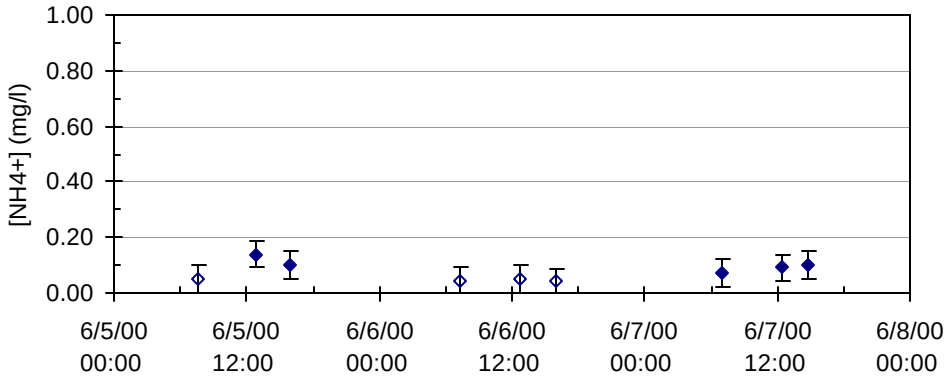
Values in bold are estimated at or below the reporting limit (Organic const. not included)

If more than 50% of the data are censored, values below the detection limit are not estimated.

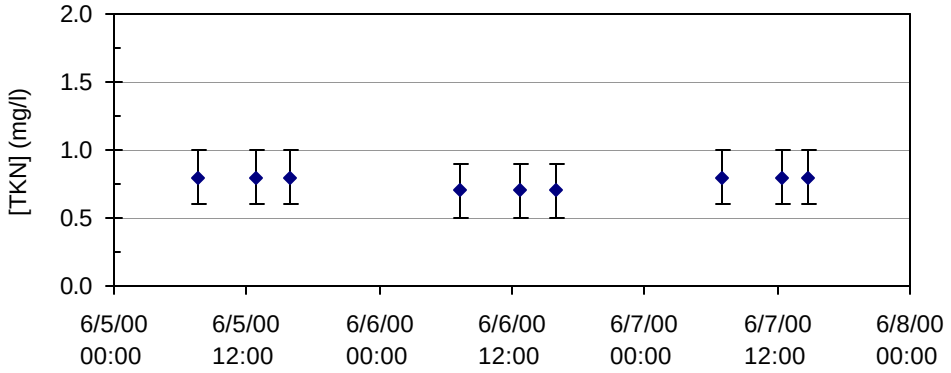
H SYNOPTIC SURVEY DATA: GRAPHICAL PRESENTATION BY SITE

Synoptic survey data were processes in a similar manner to other grab sample data. Points below the detection limit were estimated by fitting a least squares regression to a log-normal plot of available data. More than fifty percent of the data were required to complete these estimations (i.e., maximum missing data points was less than or equal to four). Estimated points are depicted by an open symbol. At certain sampling stations all data were below the reporting limit. If less than two data points were available, a plot was not provided. (Nitrate refers to nitrate+nitrite)

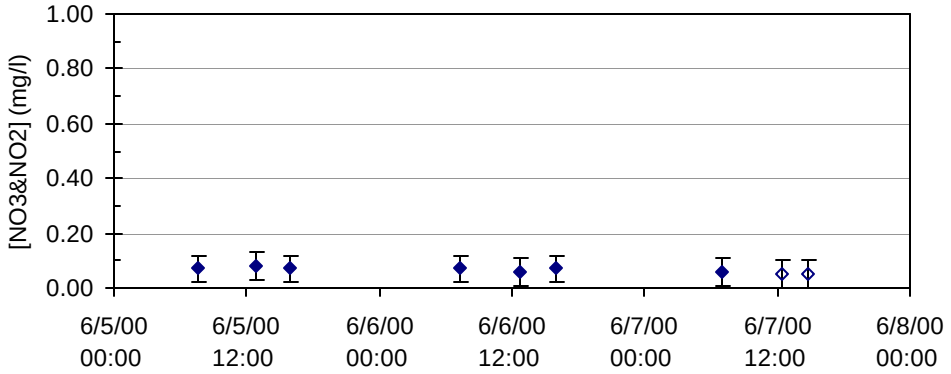
June 5-7, 2000 Synoptic



(a)

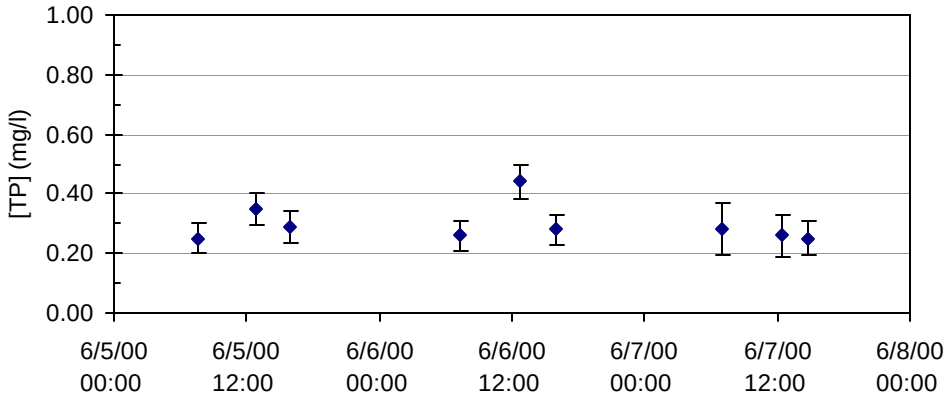


(b)

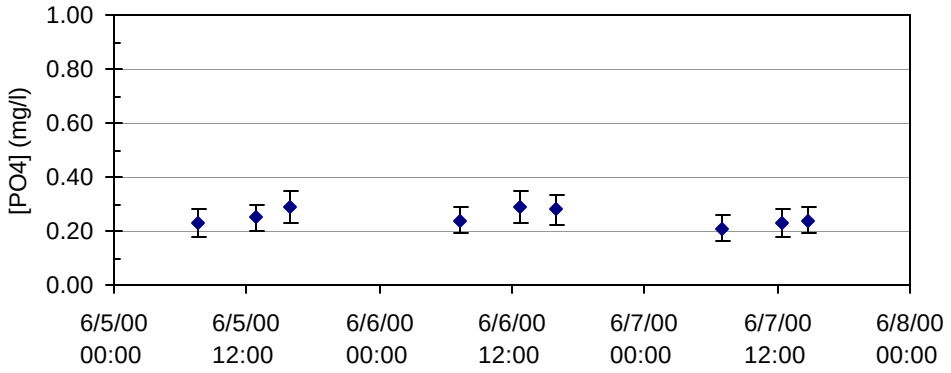


(c)

Figure H-1 Klamath River below Iron Gate Dam, synoptic grab samples – June 5-7, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate

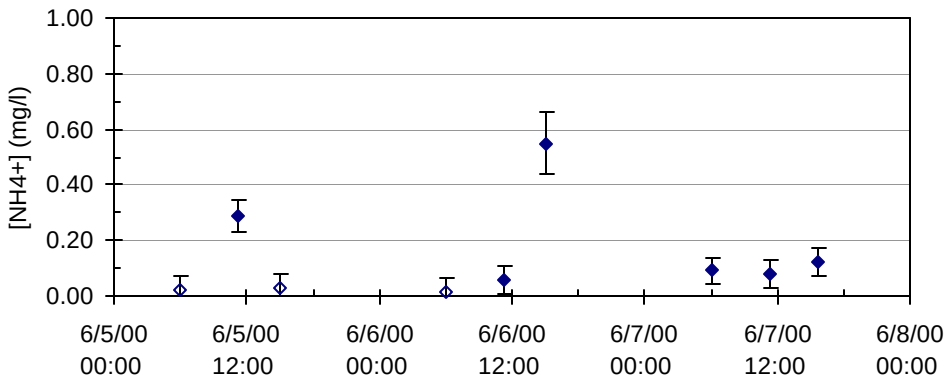


(a)

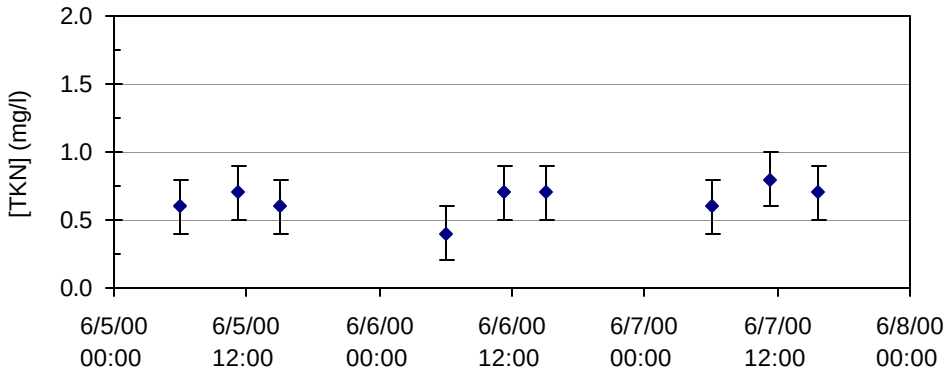


(b)

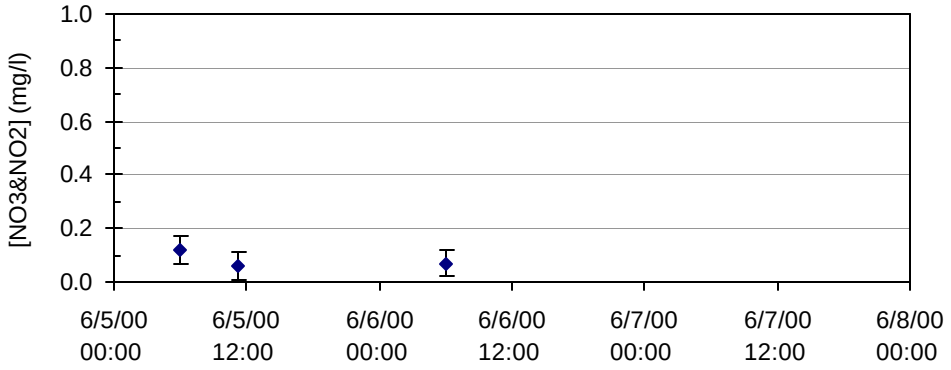
Figure H-2 Klamath River below Iron Gate Dam synoptic grab samples – June 5-7, 2000: (a) total phosphorous, (b) orthophosphate



(a)

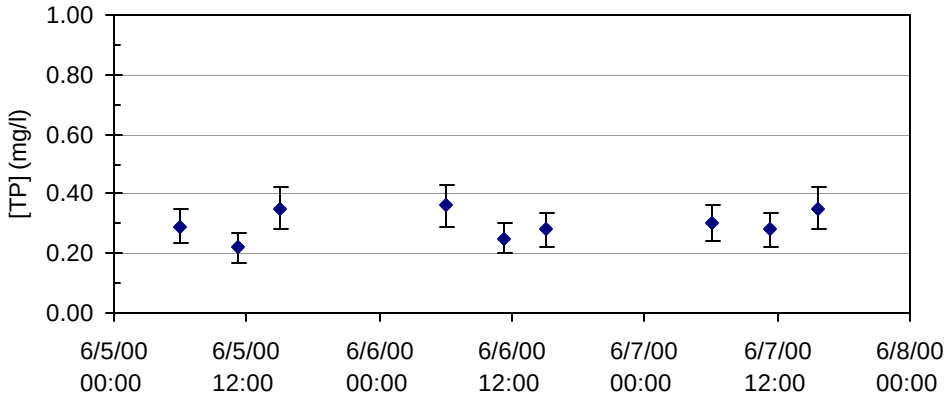


(b)

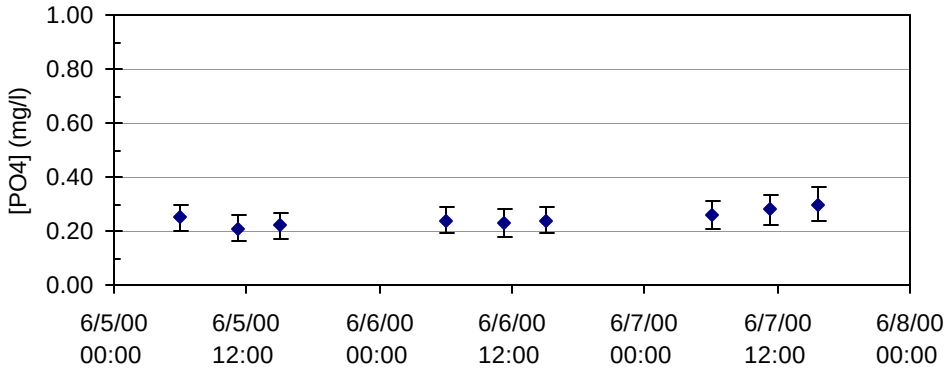


(c)

Figure H-3 Klamath River above Shasta River synoptic grab samples – June 5-7, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate

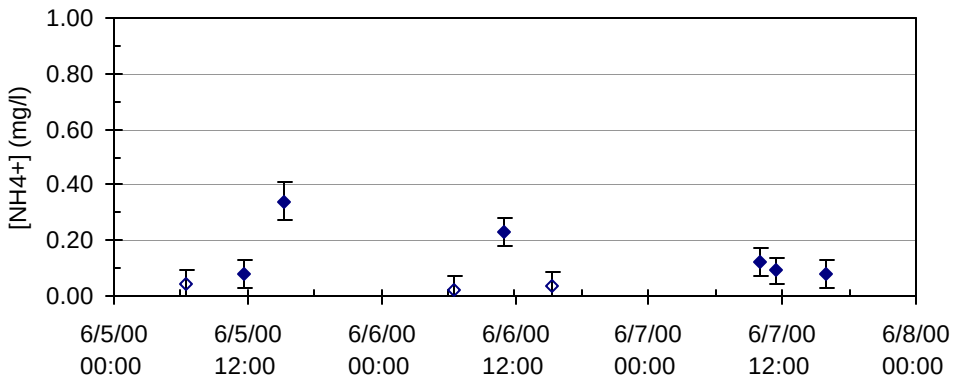


(a)

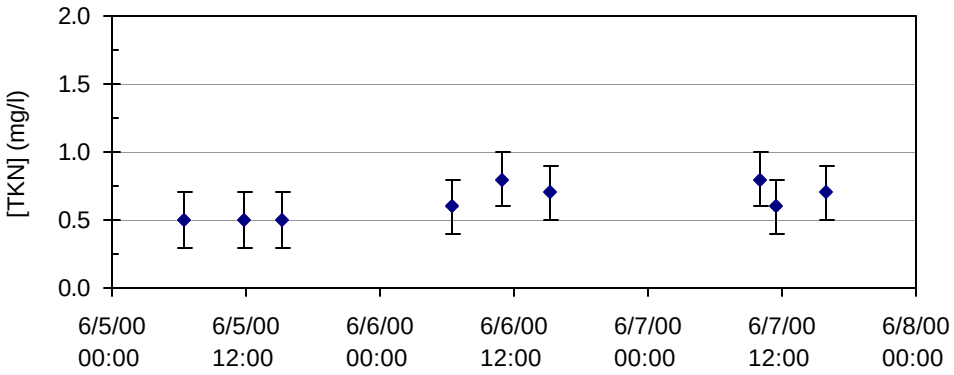


(b)

Figure H-4 Klamath River above Shasta River synoptic grab samples – June 5-7, 2000: (a) total phosphorous, (b) orthophosphate



(a)

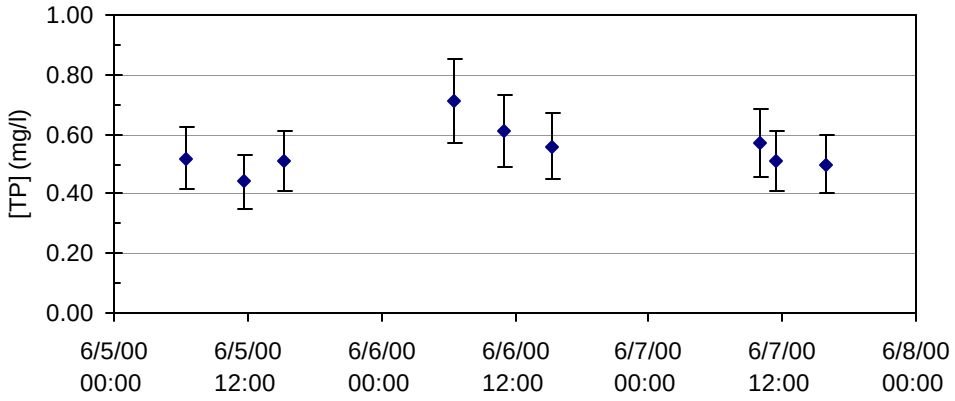


(b)

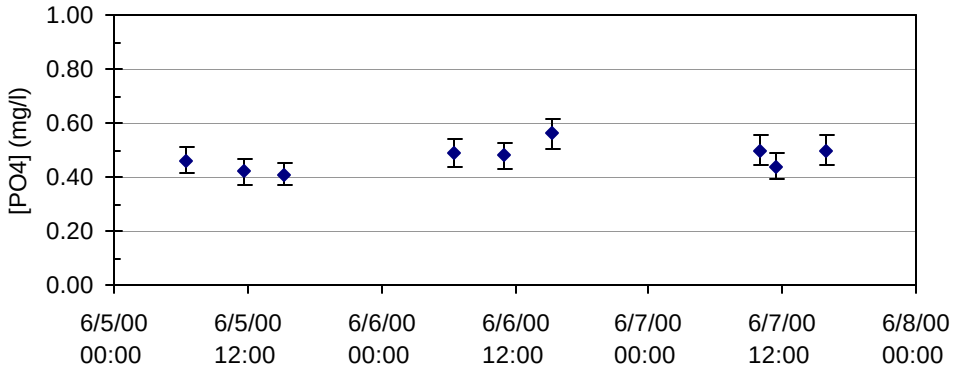
[less than Reporting Limit]

(c)

Figure H-5 Shasta River synoptic grab samples – June 5-7, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate

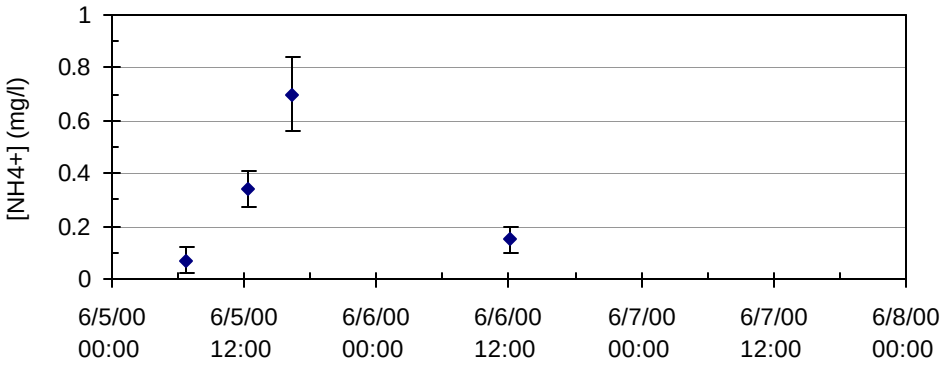


(a)

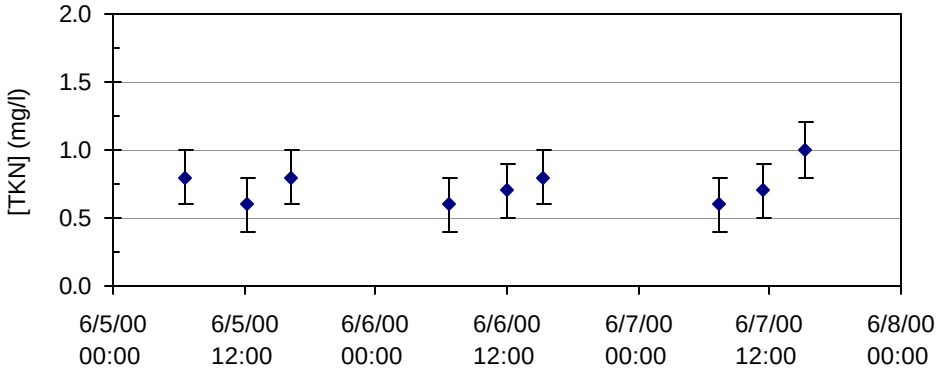


(b)

Figure H-6 Shasta River synoptic grab samples – June 5-7, 2000: (a) total phosphorous, (b) orthophosphate



(a)

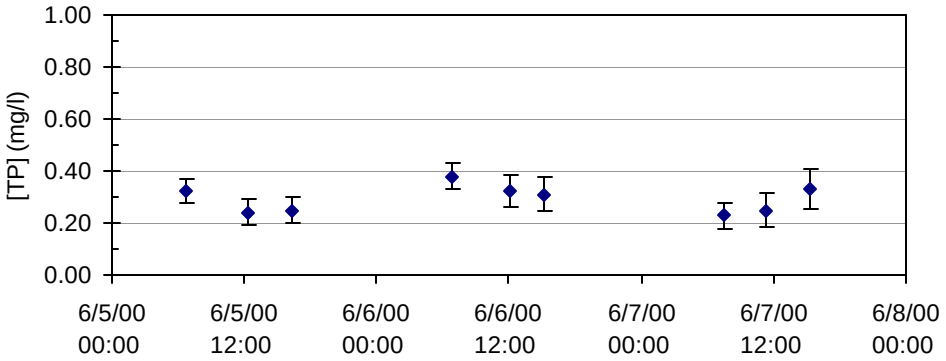


(b)

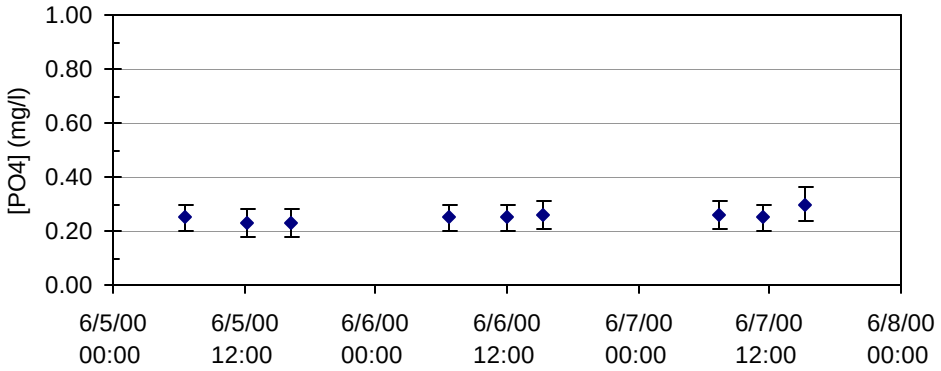
[less than Reporting Limit]

(c)

Figure H-7 Klamath River above Scott River synoptic grab samples – June 5-7, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate

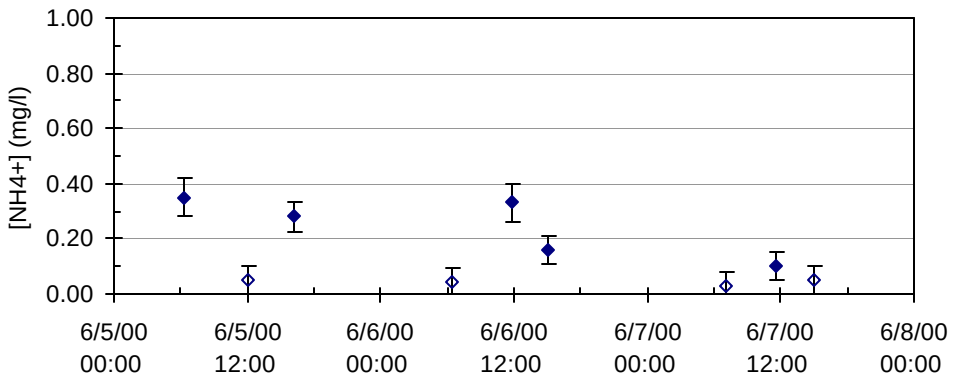


(a)

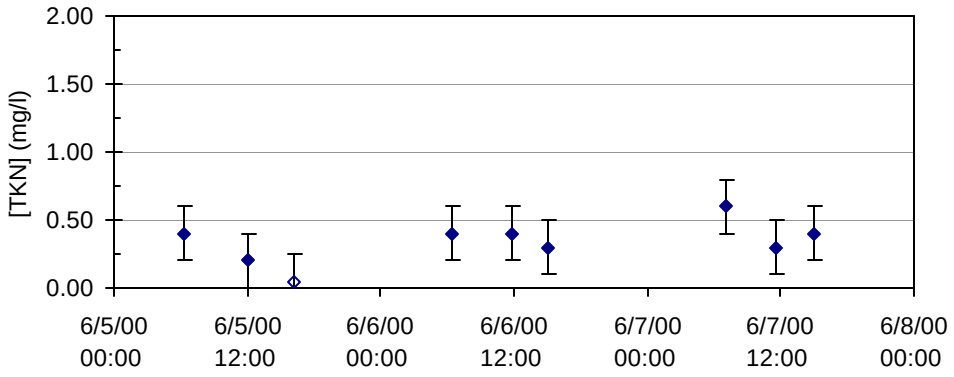


(b)

Figure H-8 Klamath River above Scott River synoptic grab samples – June 5-7, 2000: (a) total phosphorous, (b) orthophosphate



(a)

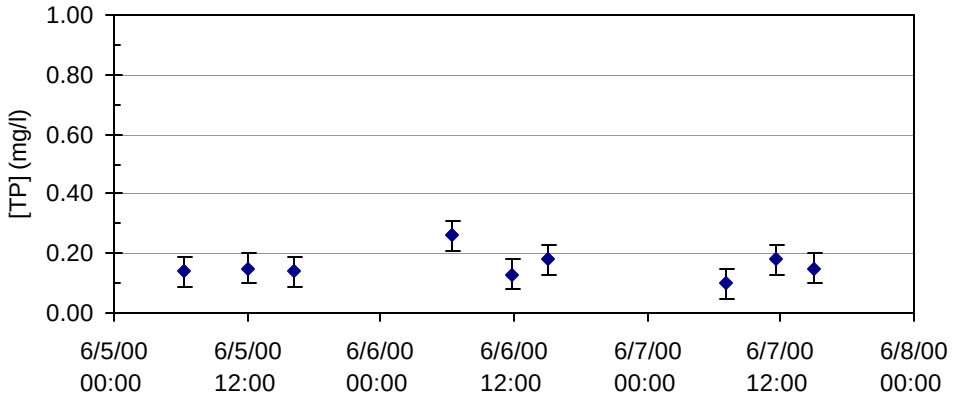


(b)

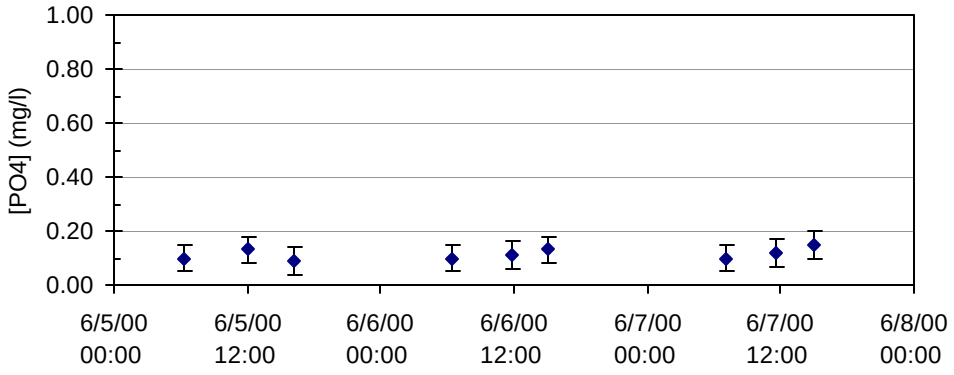
[less than Reporting Limit]

(c)

Figure H-9 Scott River (mouth) synoptic grab samples – June 5-7, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate

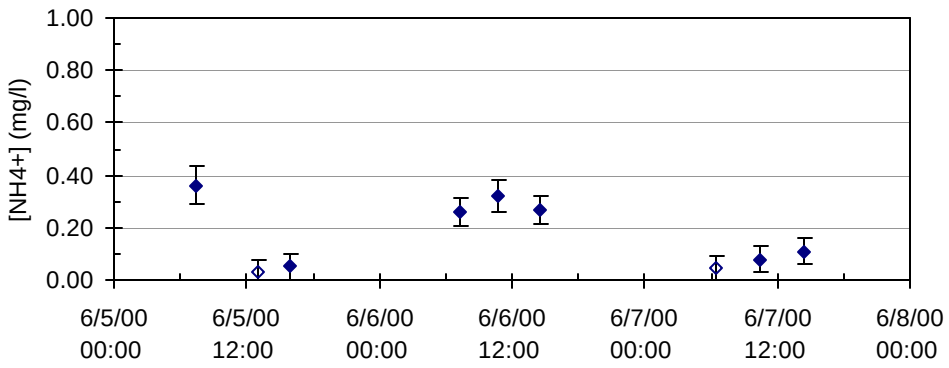


(a)

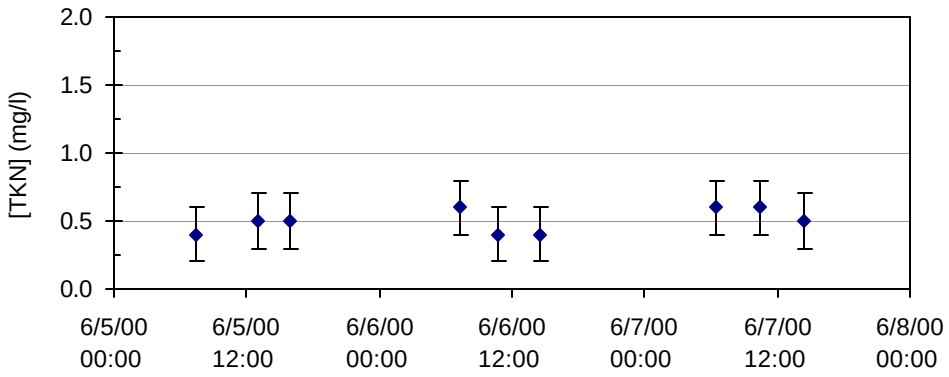


(b)

Figure H-10 Scott River (mouth) synoptic grab samples – June 5-7, 2000: (a) total phosphorous, (b) orthophosphate



(a)

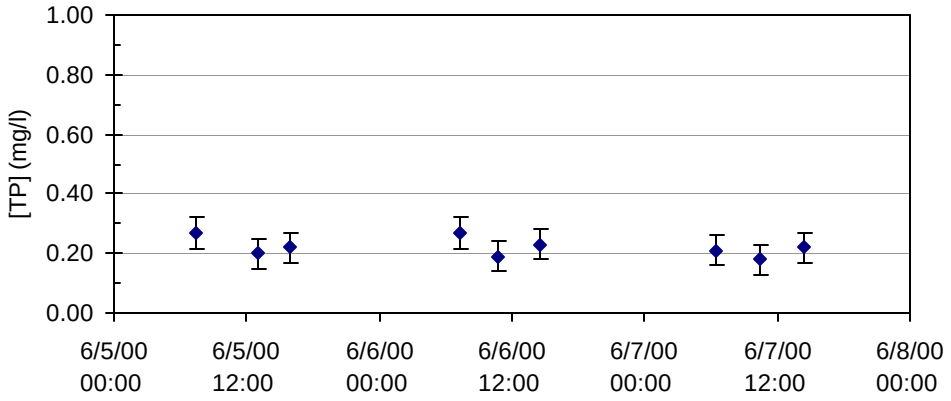


(b)

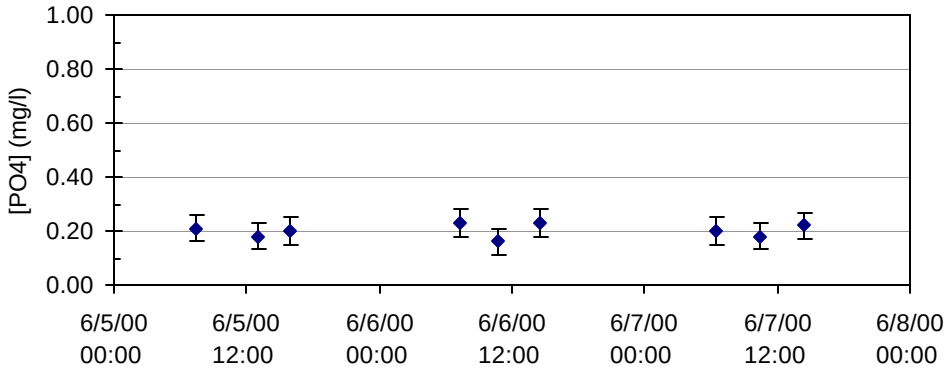
[less than Reporting Limit]

(c)

Figure H-11 Klamath River near Seiad Valley synoptic grab samples– June 5-7, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate



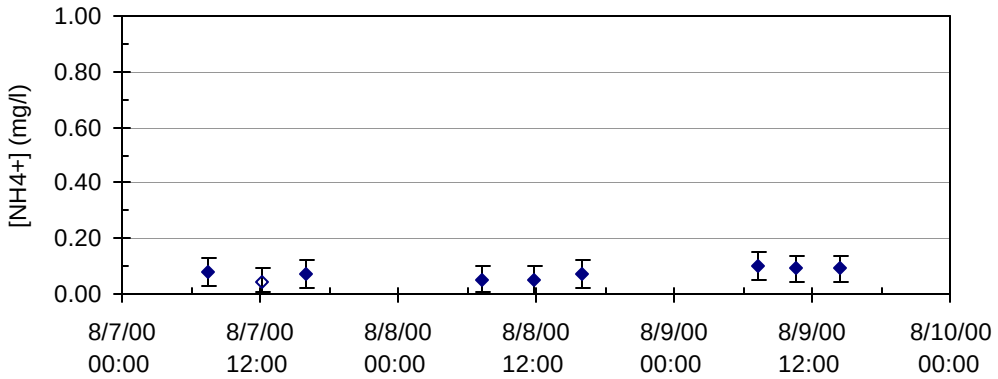
(a)



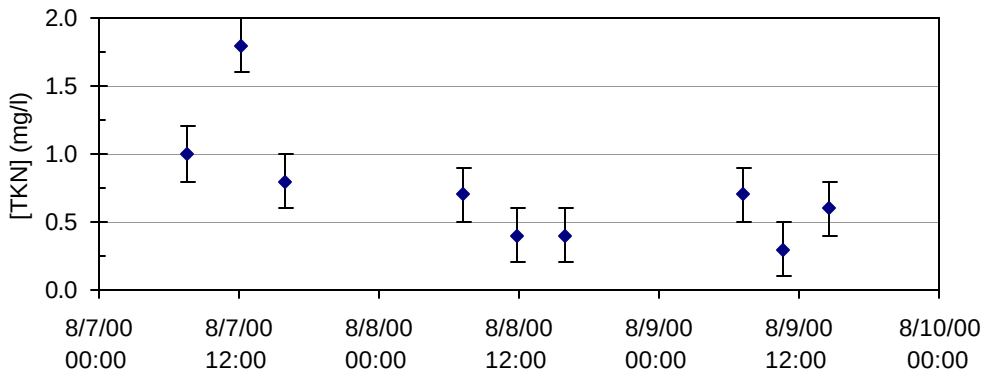
(b)

Figure H-12 Klamath River near Seiad Valley synoptic grab samples – June 5-7, 2000: (a) total phosphorous, (b) orthophosphate

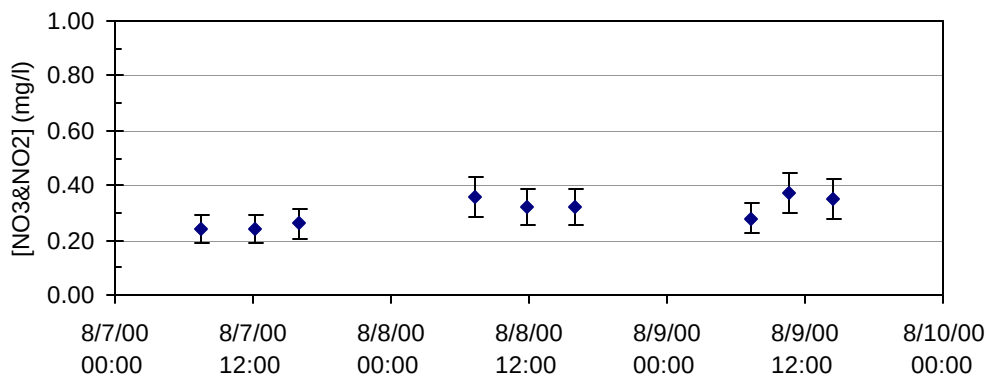
August 7-9, 2000 Synoptic



(a)

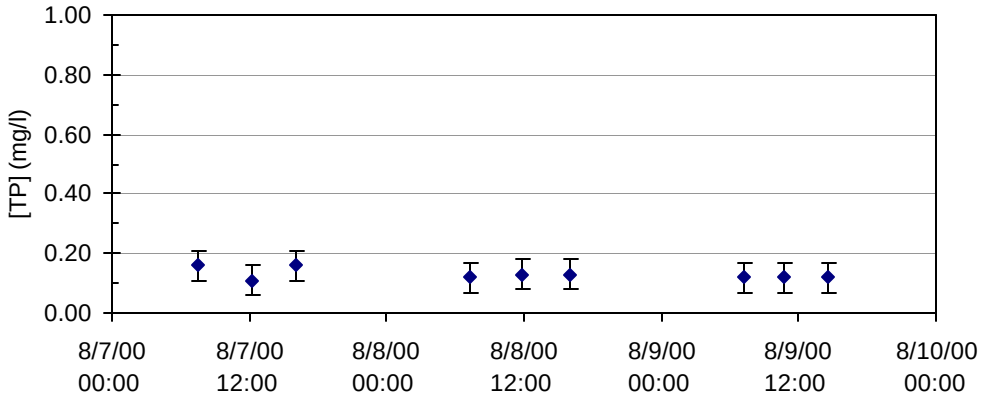


(b)

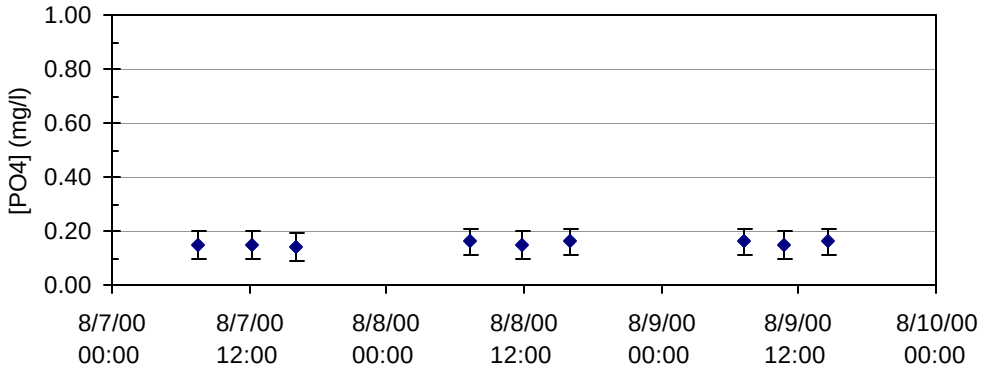


(c)

Figure H-13 Klamath River below Iron Gate Dam, synoptic grab samples – August 7-9, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate

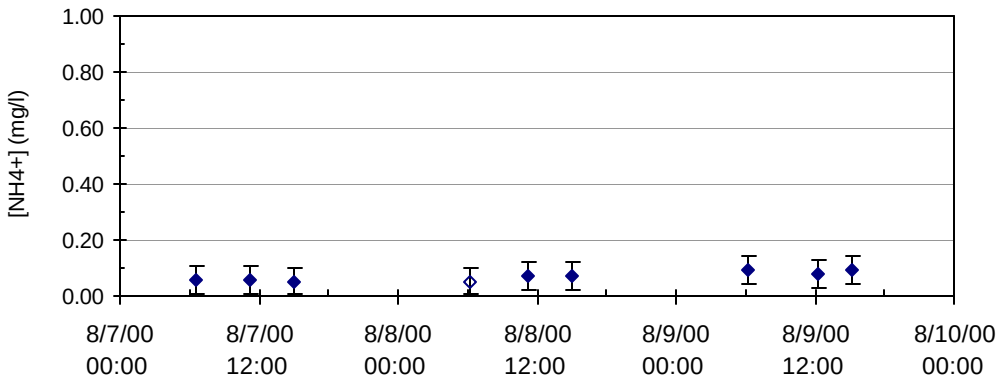


(a)

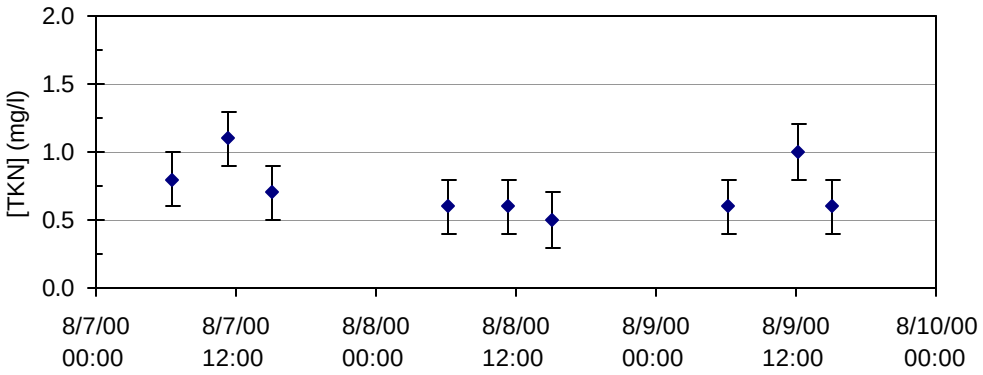


(b)

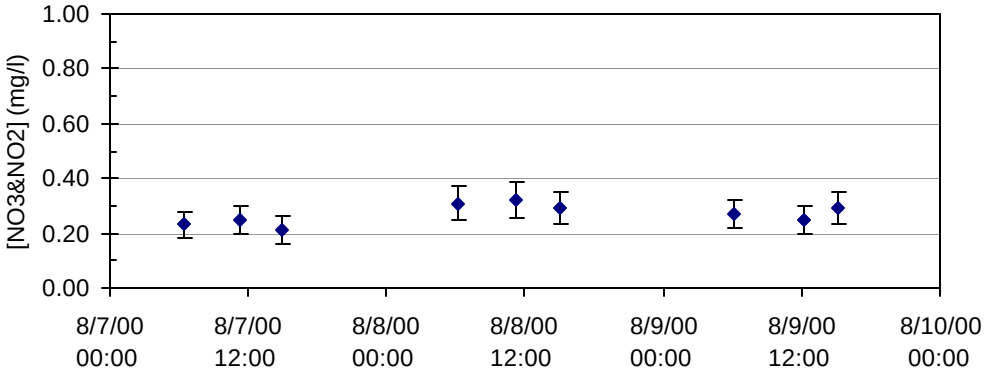
Figure H-14 Klamath River below Iron Gate Dam synoptic grab samples – August 7-9, 2000: (a) total phosphorous, (b) orthophosphate



(a)

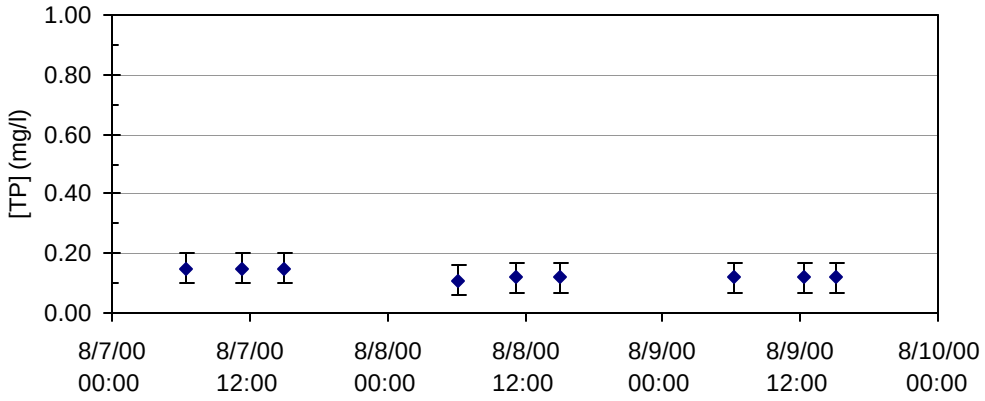


(b)

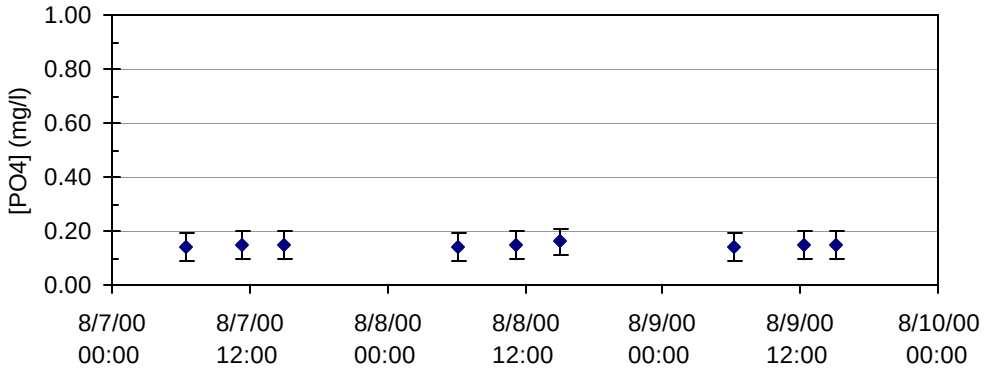


(c)

Figure H-15 Klamath River above Shasta River synoptic grab samples – August 7-9, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate

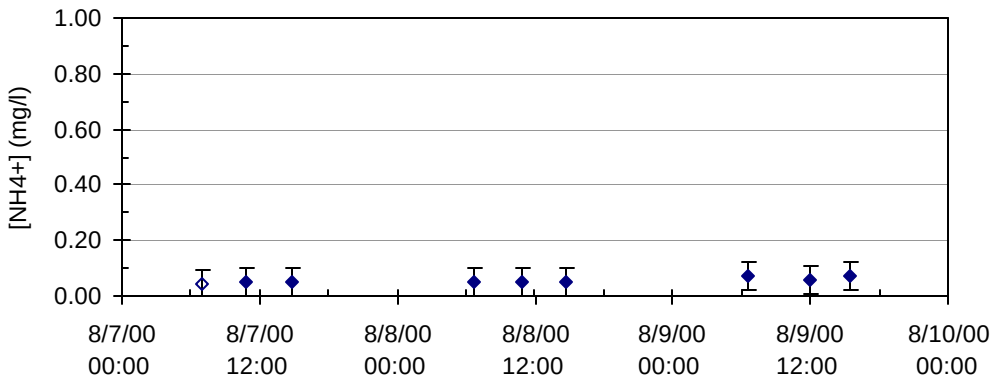


(a)

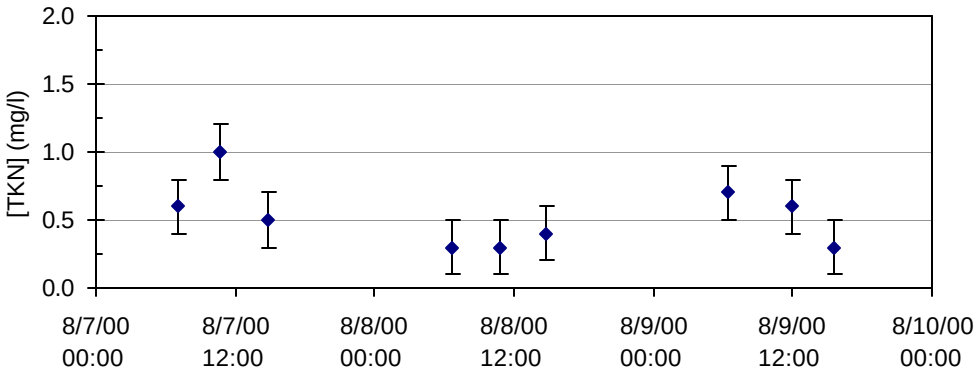


(b)

Figure H-16 Klamath River above Shasta River synoptic grab samples – August 7-9, 2000: (a) total phosphorous, (b) orthophosphate



(a)

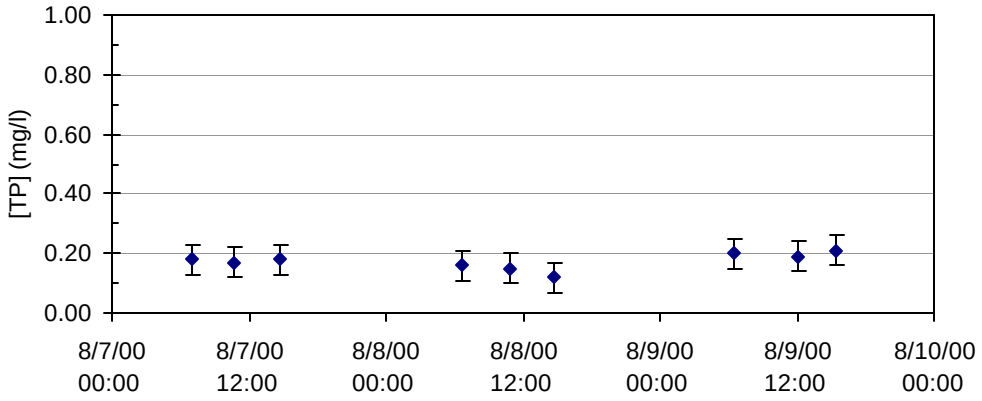


(b)

[less than Reporting Limit]

(c)

Figure H-17 Shasta River synoptic grab samples – August 7-9, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate



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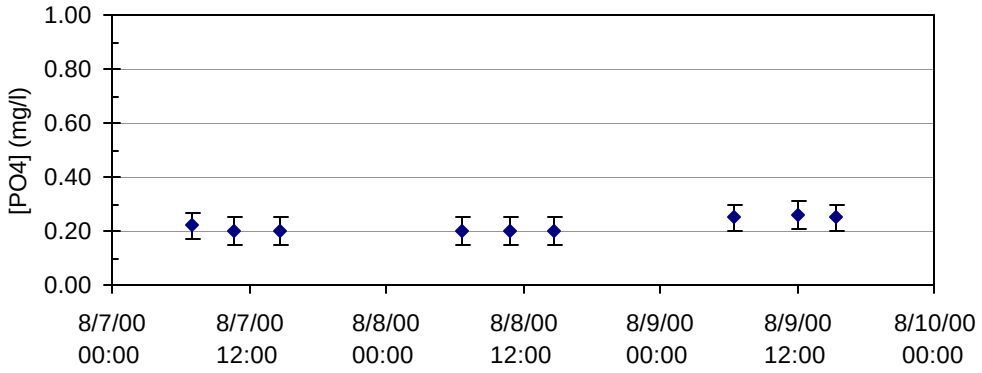
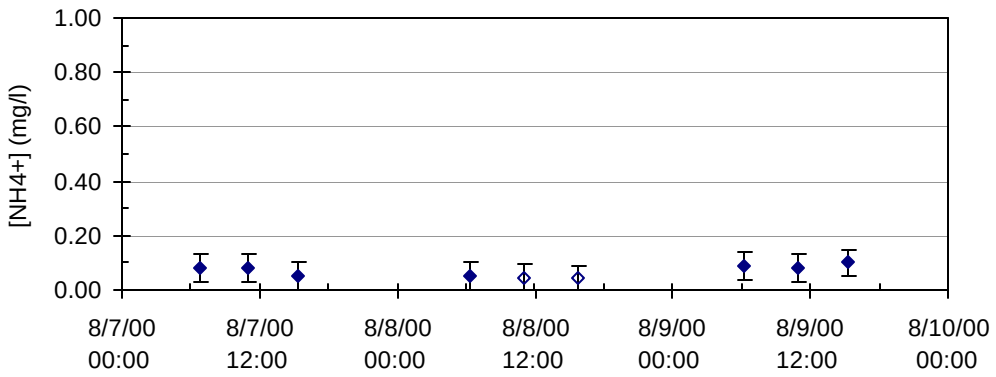
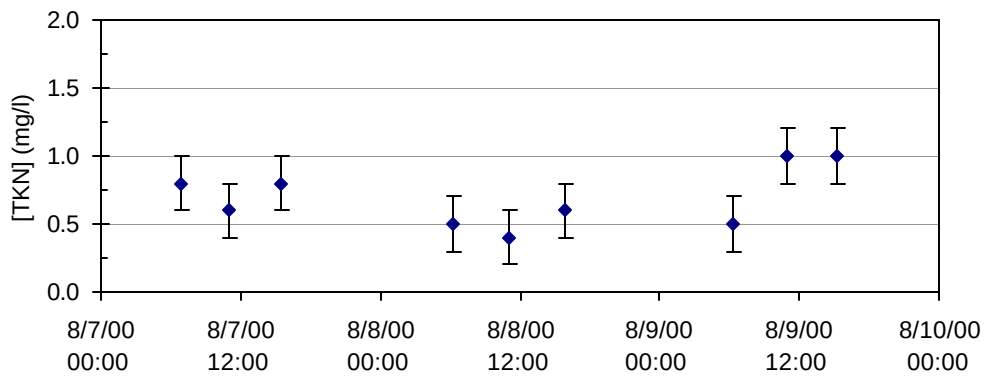


(b)

Figure H-18 Shasta River synoptic grab samples – August 7-9, 2000: (a) total phosphorous, (b) orthophosphate



(a)



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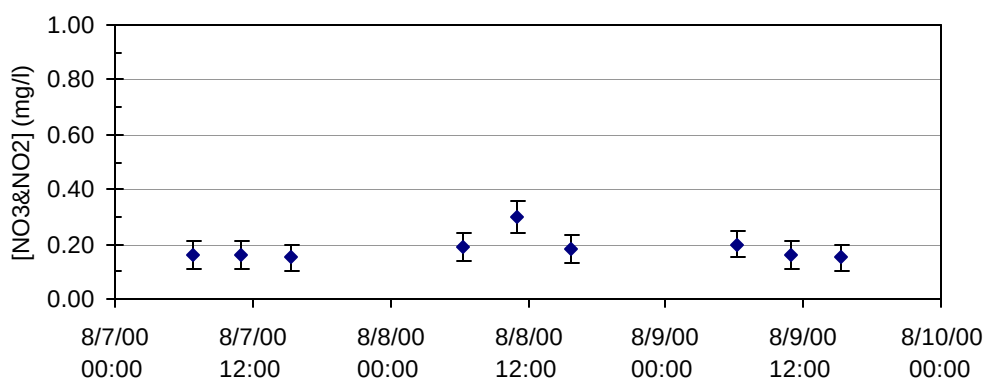
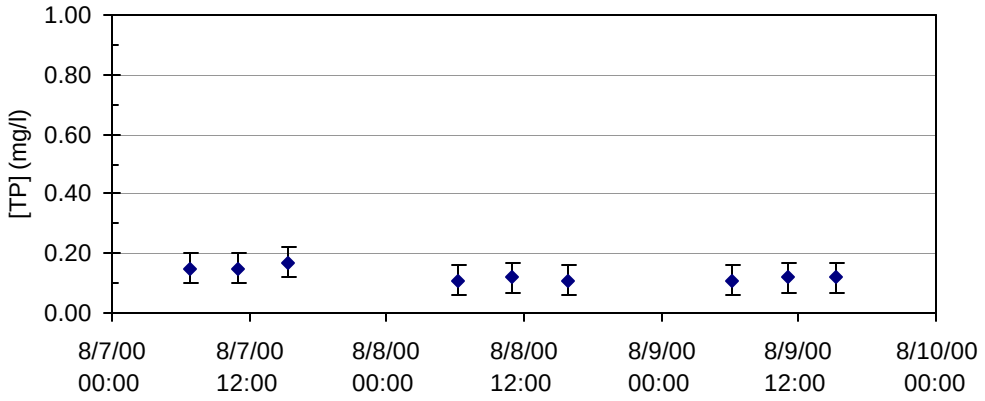
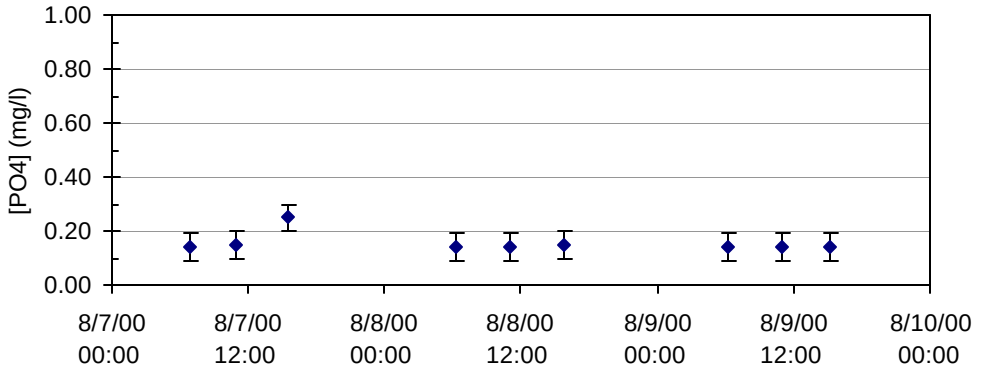


(c)

Figure H-19 Klamath River above Scott River synoptic grab samples – August 7-9, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate



(a)



(b)

Figure H-20 Klamath River above Scott River synoptic grab samples – August 7-9, 2000: (a) total phosphorous, (b) orthophosphate

[one data point]
(a)

[one data point]
(b)

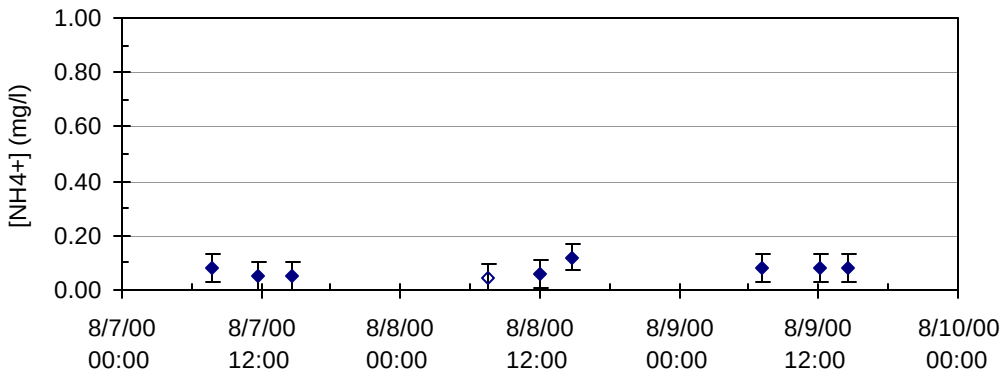
[less than Reporting Limit]
(c)

Figure H-21 Scott River (mouth) synoptic grab samples – August 7-9, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate

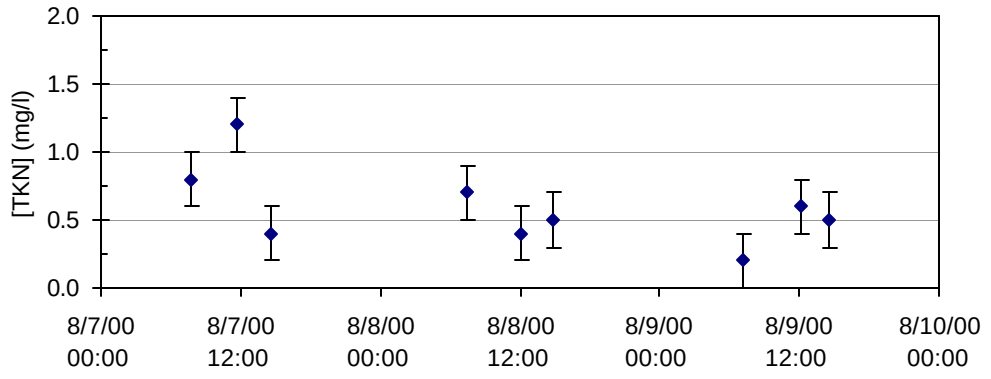
[one data point]
(a)

[less than Reporting Limit]
(b)

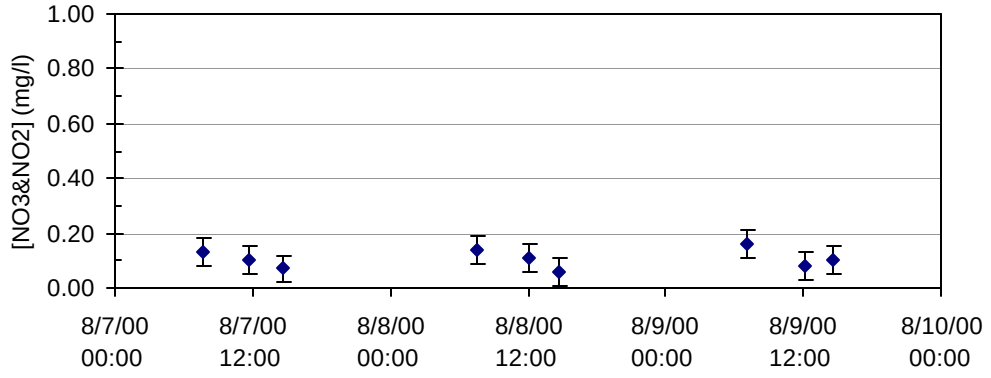
Figure H-22 Scott River (mouth) synoptic grab samples – August 7-9, 2000: (a) total phosphorous, (b) orthophosphate



(a)

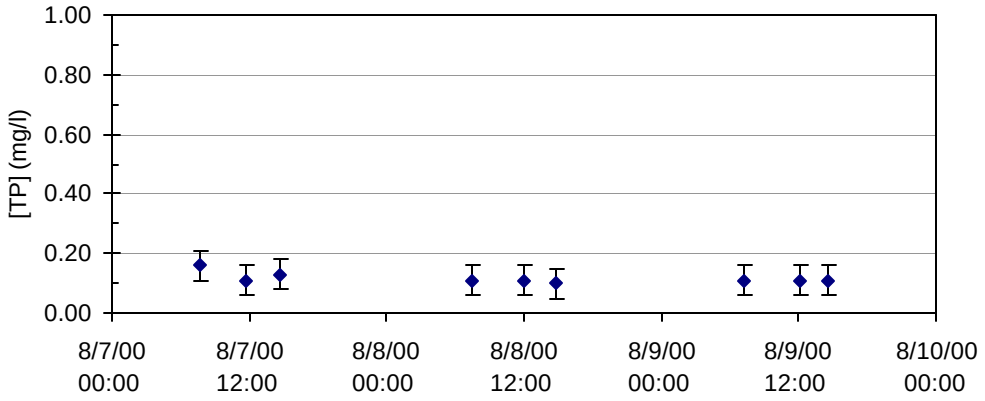


(b)

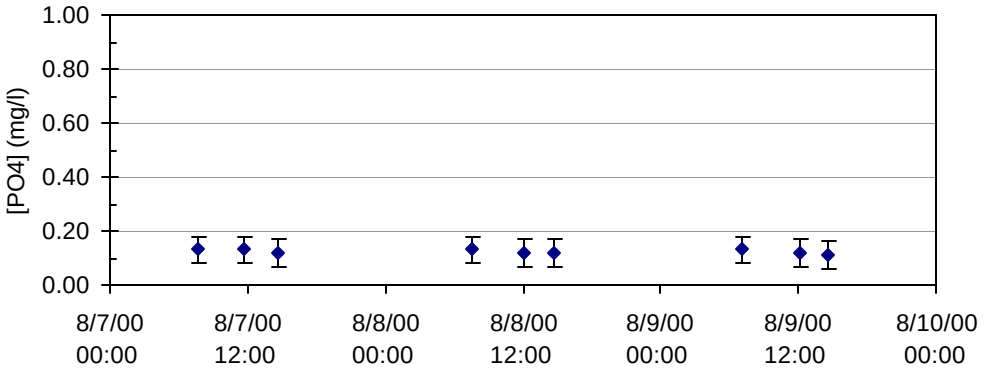


(c)

Figure H-23 Klamath River near Seiad Valley synoptic grab samples – August 7-9, 2000: (a) ammonia, (b) total Kjeldahl nitrogen, and (c) nitrate



(a)



(b)

Figure H-24 Klamath River near Seiad Valley synoptic grab samples – August 7-9, 2000: (a) total phosphorous, (b) orthophosphate

I SYNOPTIC SURVEY: DATASONDE RECORDS

During the synoptic surveys, datasonde (sondes) water quality probes were deployed at each sample location. These sondes recorded water temperature, pH, specific conductance, and dissolved oxygen. As noted above, two synoptic grab sampling surveys were completed: June 5-7 and August 7-9, 2000. A third synoptic using only water quality probes was completed on September 27-29, 2000. The data from these three sampling events is included herein. Beyond occasional missing data points due to sonde failure or data lost during replacement, the sonde above the Scott River for the June 5-7, 2000 deployment failed and all data were lost. Sonde recorded dissolved oxygen concentrations may suffer from biofouling. Instruments deployed at the

- Klamath River above the Shasta River
- Klamath River above the Shasta River
- Scott River (mouth)

show little impact of biofouling because they were only deployed for the periods when synoptic sampling was occurring. Probes at the remaining sites,

- Klamath River below Iron Gate Dam
- Shasta River
- Scott River at Ft. Jones
- Klamath River near Seiad Valley

show variable levels of biofouling. Both dissolved oxygen in mg/l and percent saturation are presented in the following graphs (percent saturation is the represented by a dashed line). Approximate sampling times for the June and August synoptic grab samples are shown on the graphs where applicable. For exact times refer to Appendix G.

Water temperature and dissolved oxygen data for June 5, 2000 for the Klamath River above the Scott River, the Scott River, and the USGS gage near Seiad Valley were collected with an Enviro-Safe® thermometer and a YSI model number 51B dissolved oxygen meter. This was primarily done because there was no DataSonde available for the Scott River location until the early afternoon. These spot measurements are summarized below.

Location	Time	Temperature	Dissolved Oxygen
		(°C)	(mg/l)
Klamath River above Scott River	6/5/00 8:40	17.5	8.6
Scott River	6/5/00 6:20	14.0	10.8
Klamath River at USGS near Seiad Valley	6/5/00 8:40	16.2	9.8
Klamath River above Scott River	6/5/00 12:05	18.1	9.2
Scott River	6/5/00 6:20	15.2	10.8
Klamath River at USGS near Seiad Valley	6/5/00 8:40	n/a	n/a

Synoptic Survey June 5-7, 2000

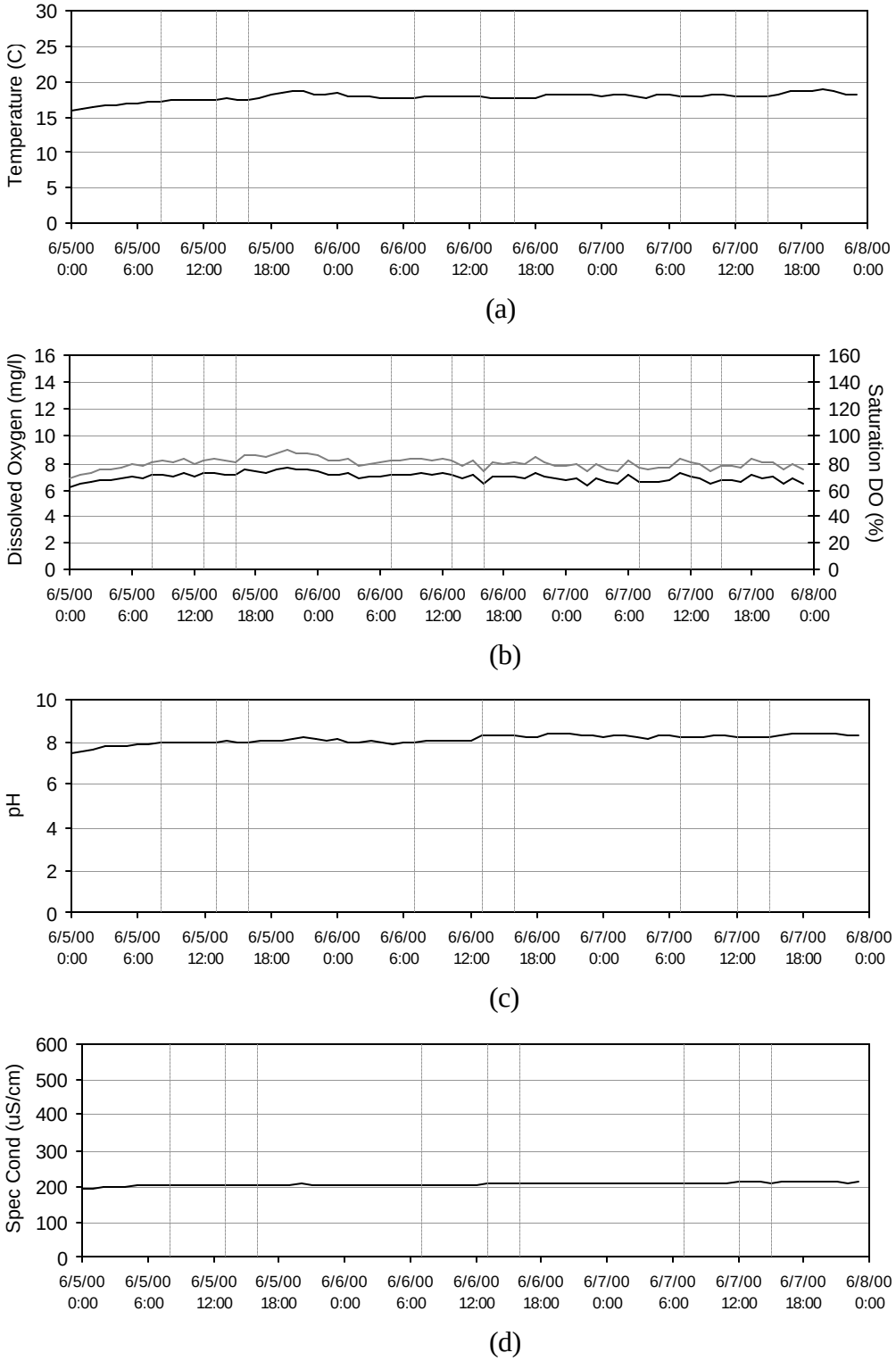


Figure I-1 Klamath River below Iron Gate Dam, June 5-7, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

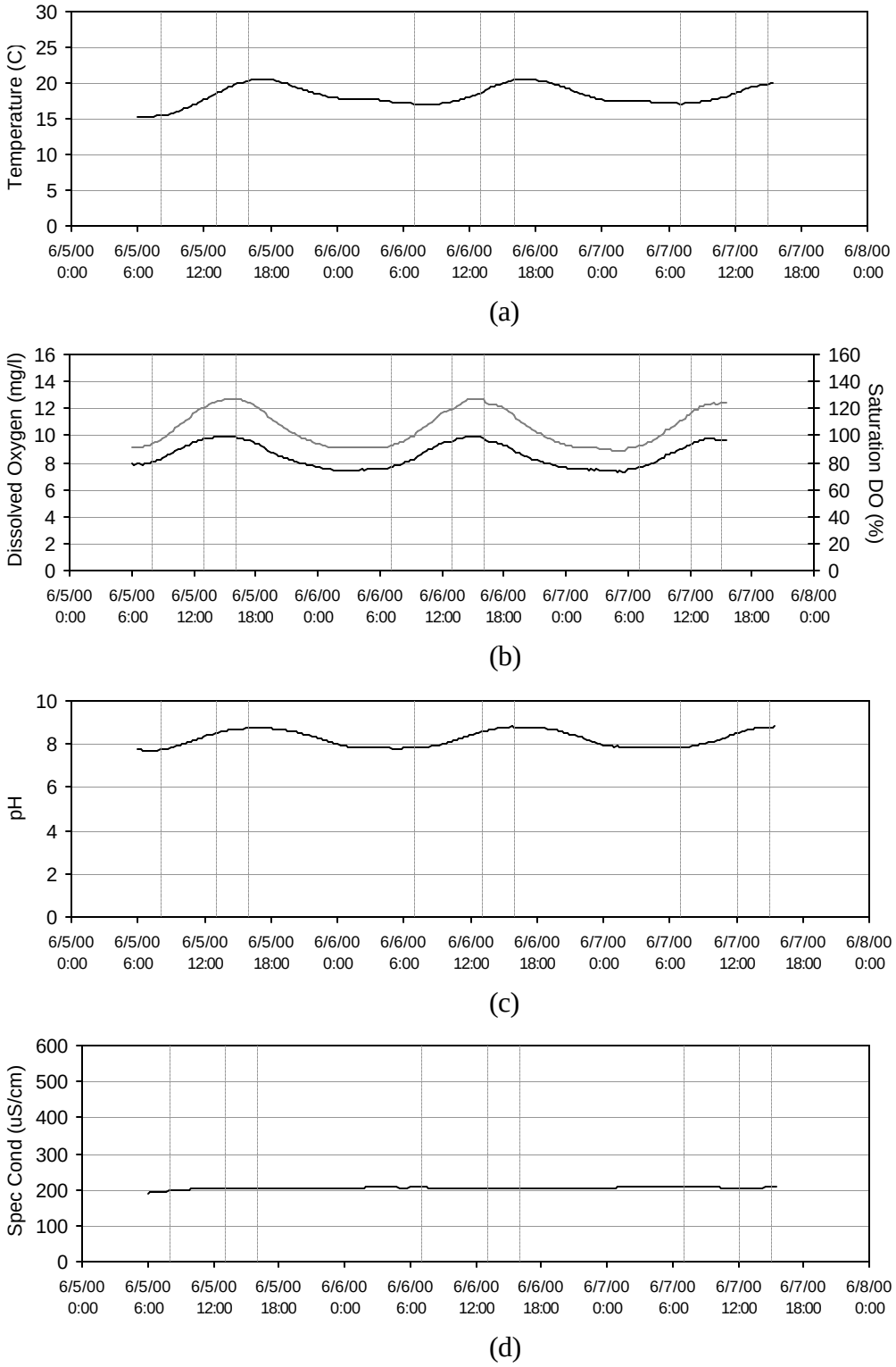


Figure I-2 Klamath River above Shasta River, June 5-7, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

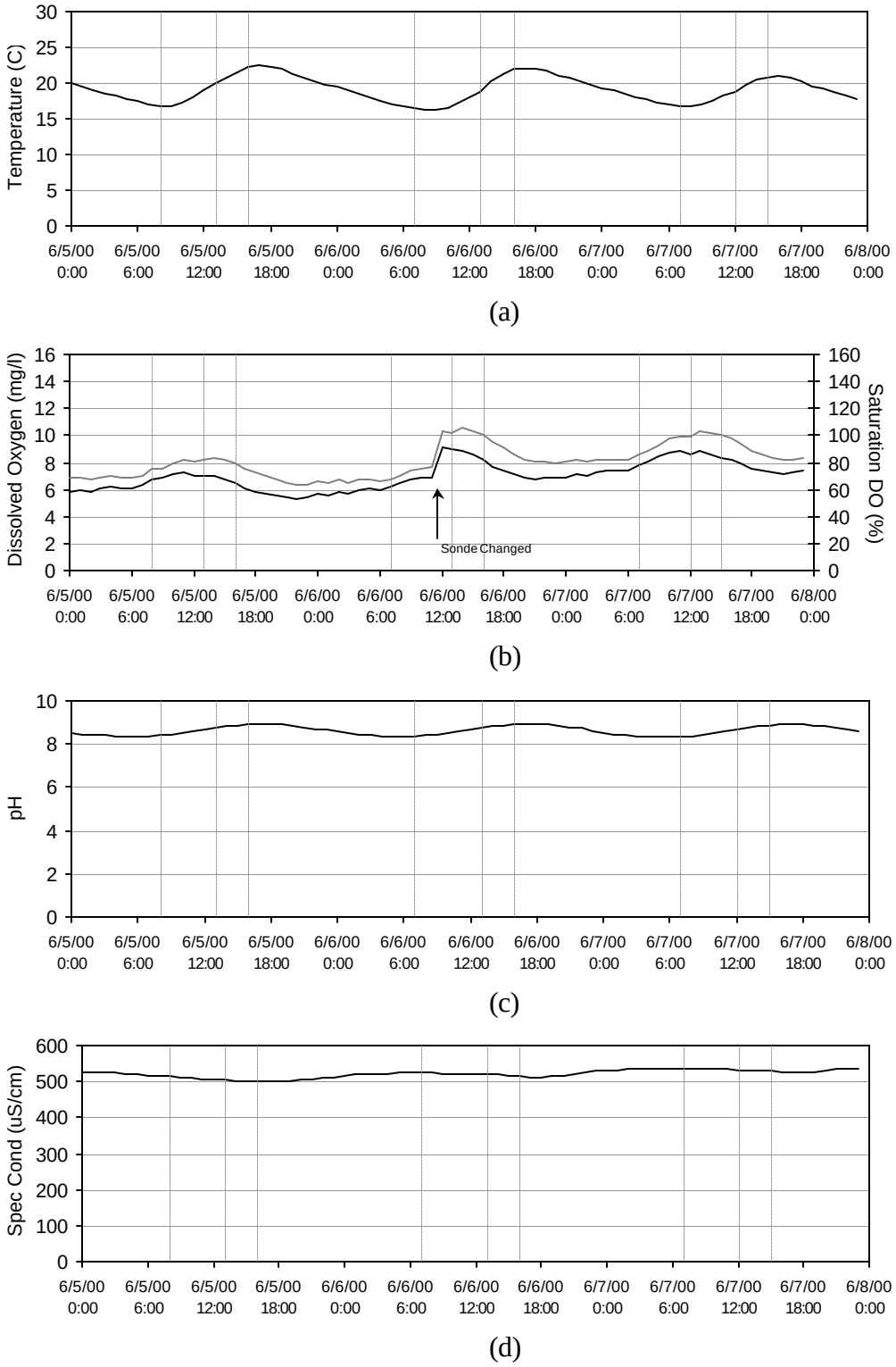


Figure I-3 Shasta River, June 5-7, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

[No Data]

(a)

[No Data]

(b)

[No Data]

(c)

[No Data]

(d)

Figure I-4 Klamath River above Scott River, June 5-7, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

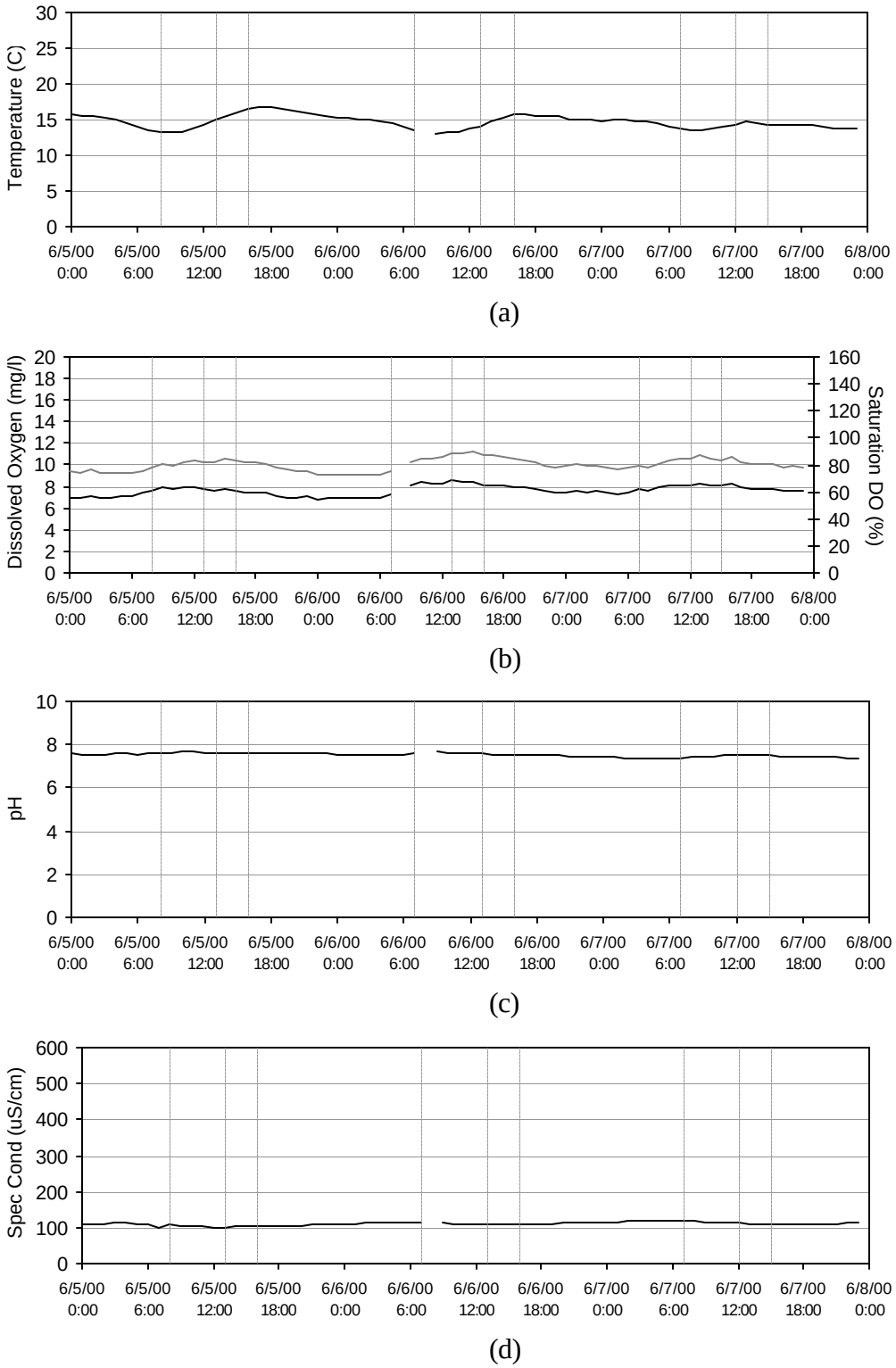


Figure I-5 Scott River at Ft. Jones, June 5-7, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

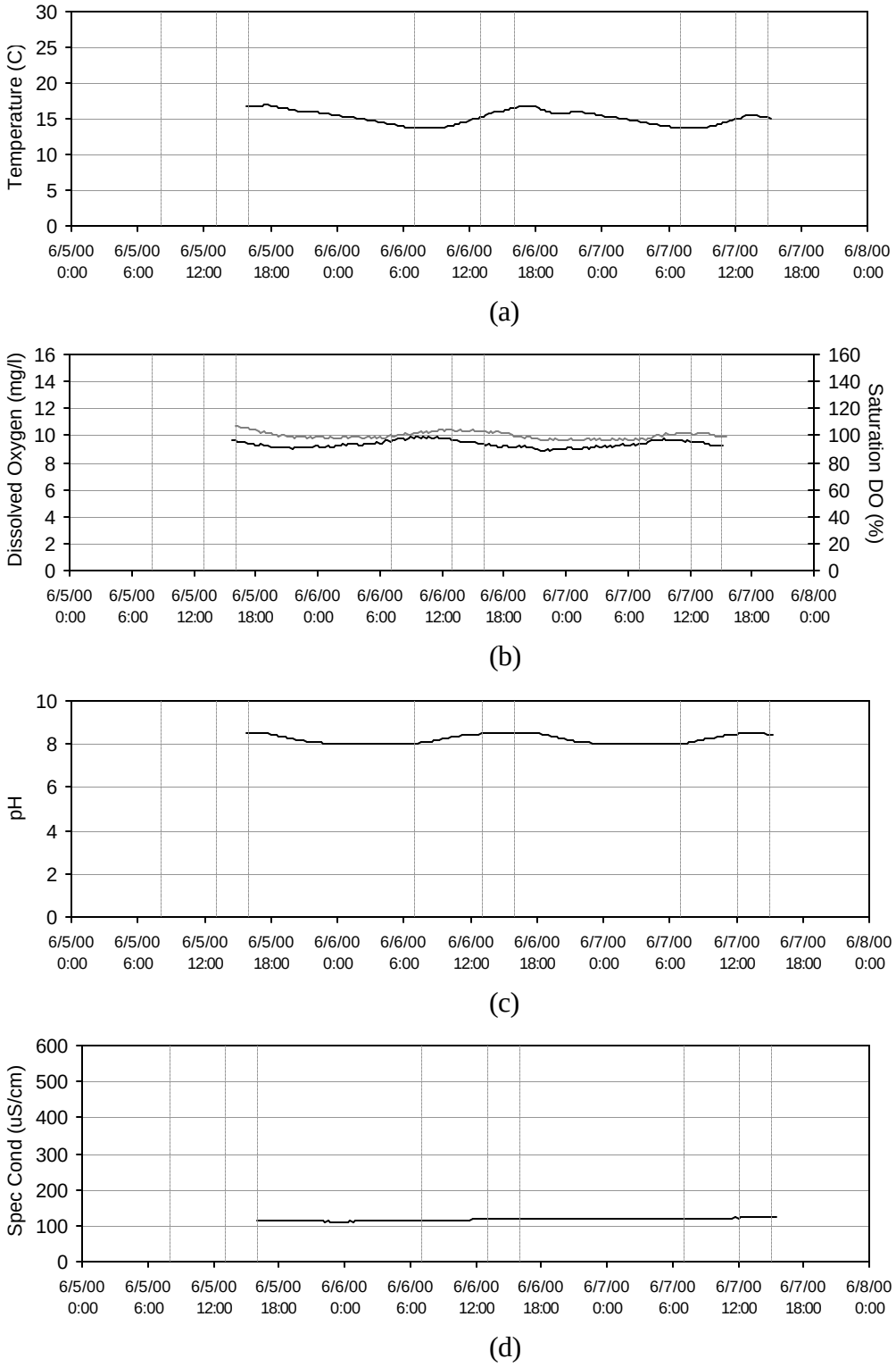


Figure I-6 Scott River at mouth, June 5-7, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

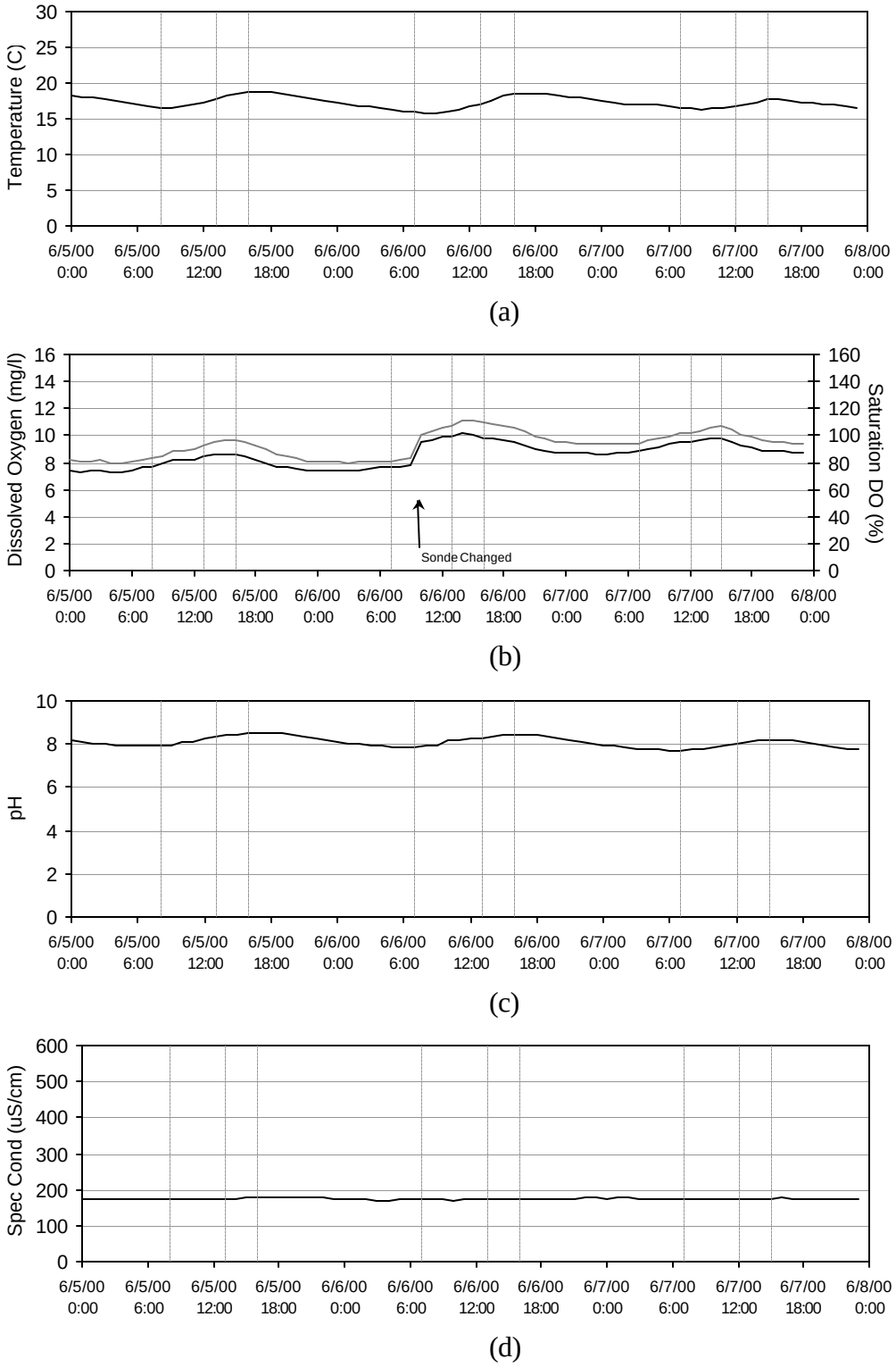


Figure I-7 Klamath River near Seiad Valley, June 5-7, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

Synoptic Survey August 7-9, 2000

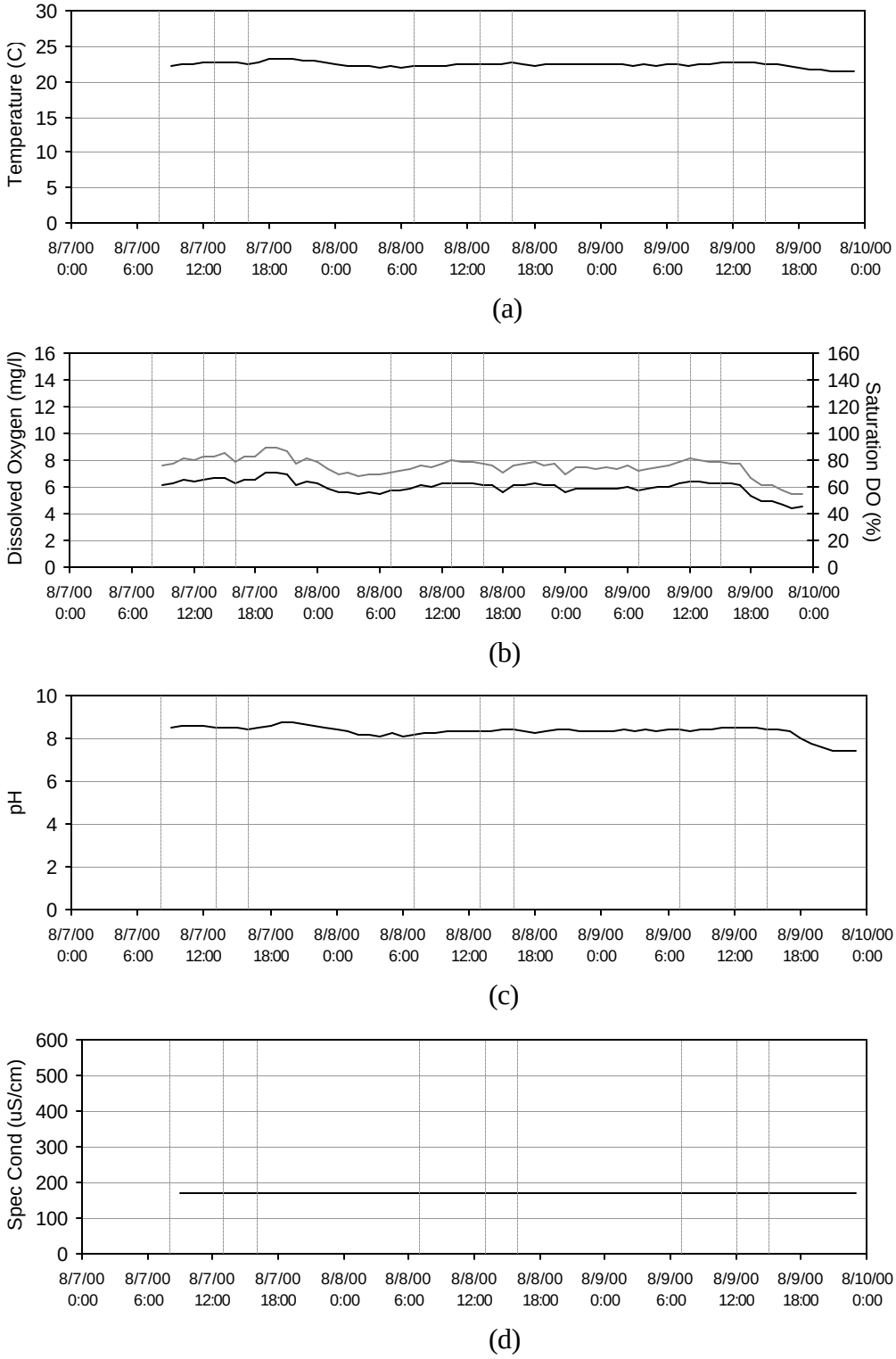


Figure I-8 Klamath River below Iron Gate Dam, August 7-9, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

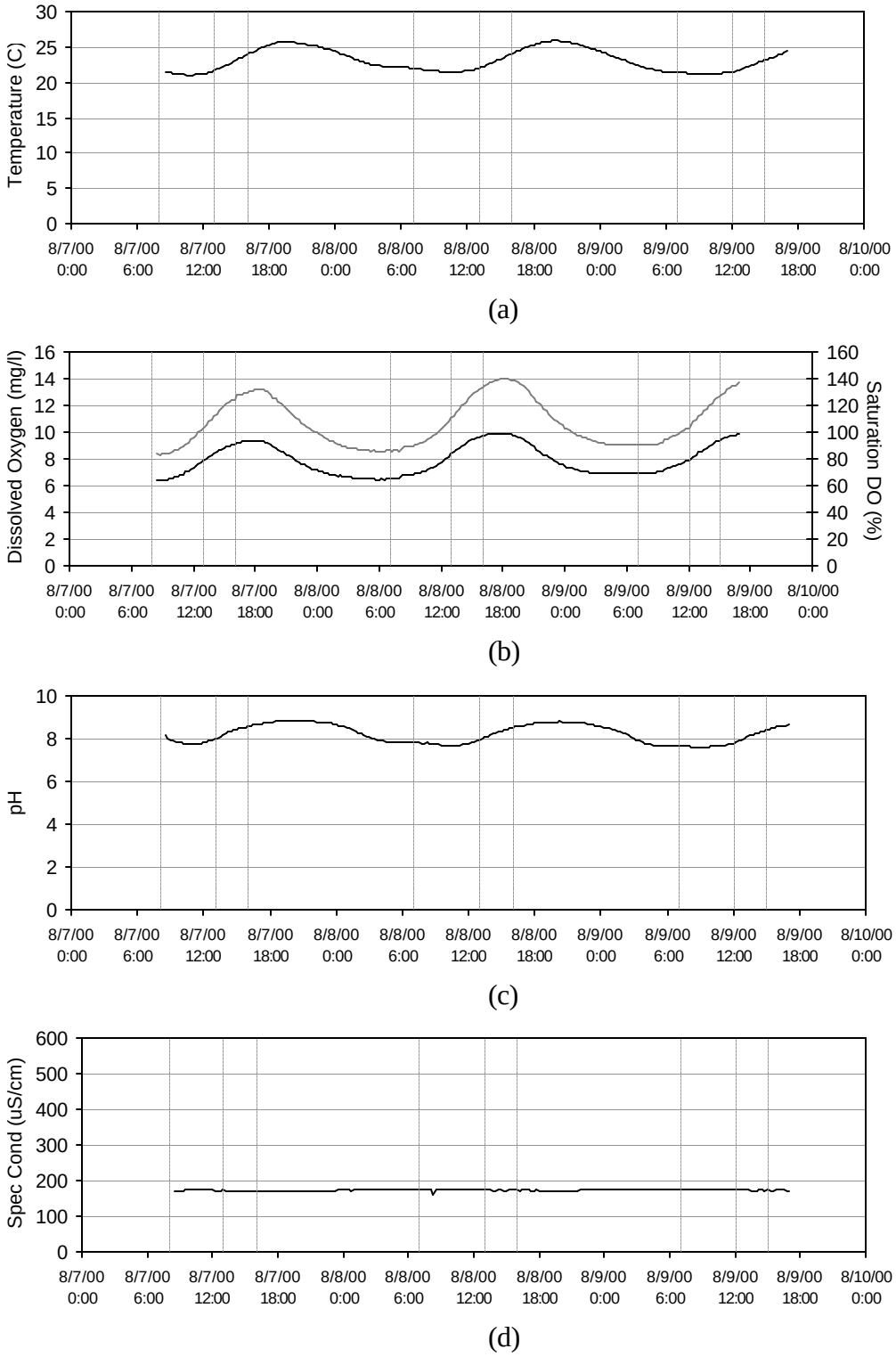


Figure I-9 Klamath River above Shasta River, August 7-9, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

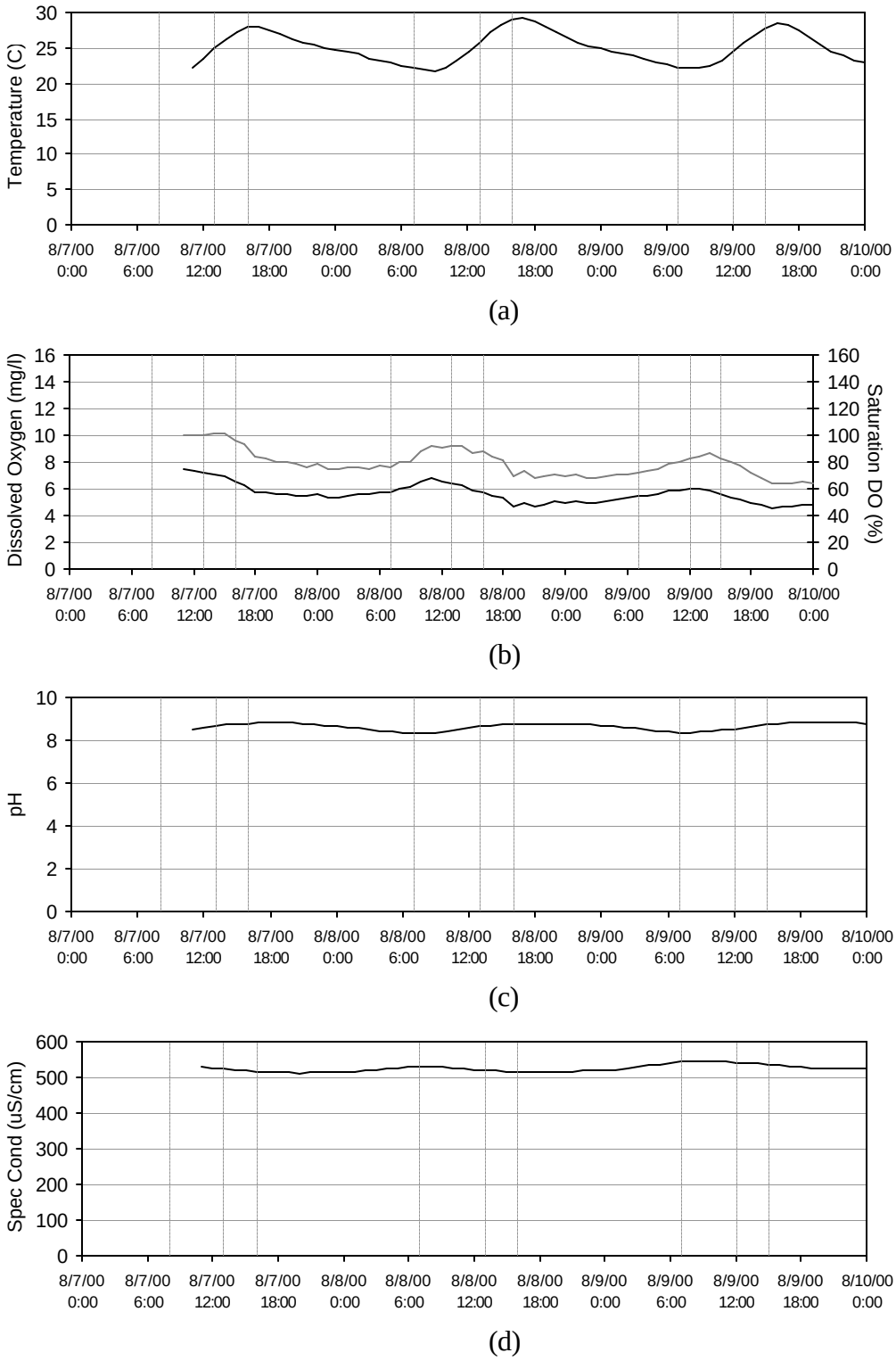


Figure I-10 Shasta River, August 7-9, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

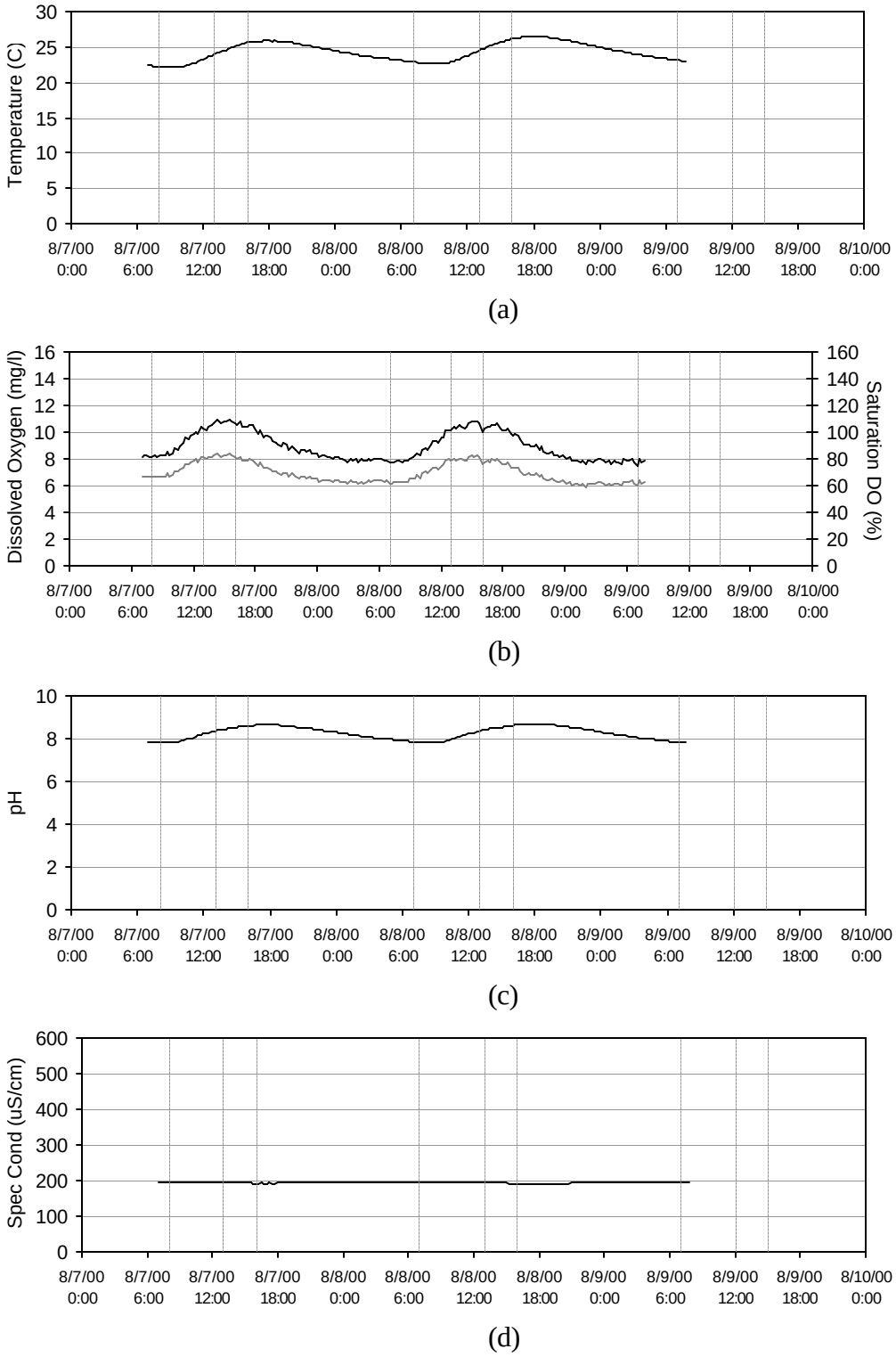


Figure I-11 Klamath River above Scott River, August 7-9, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

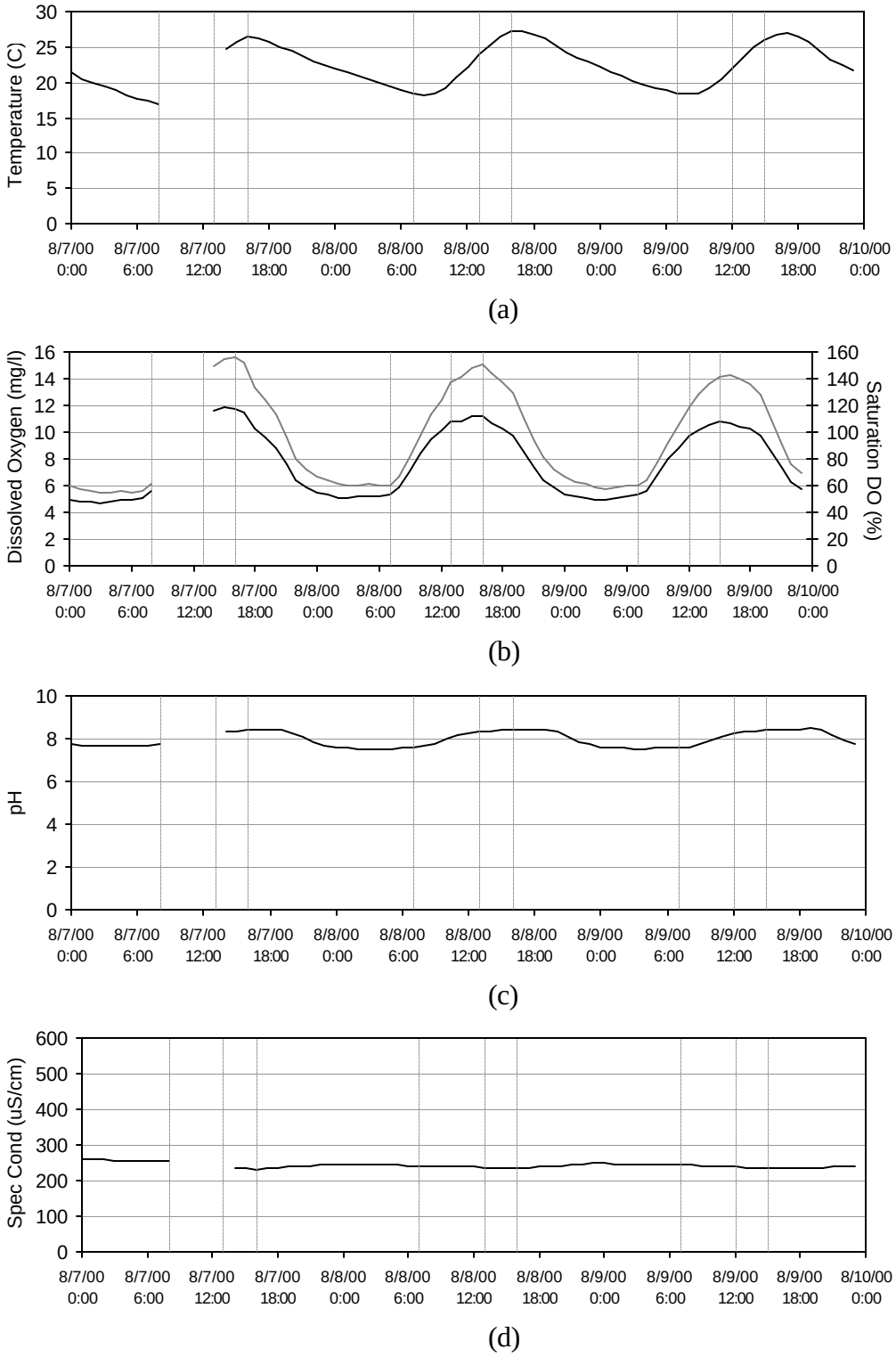


Figure I-12 Scott River at Ft. Jones, August 7-9, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

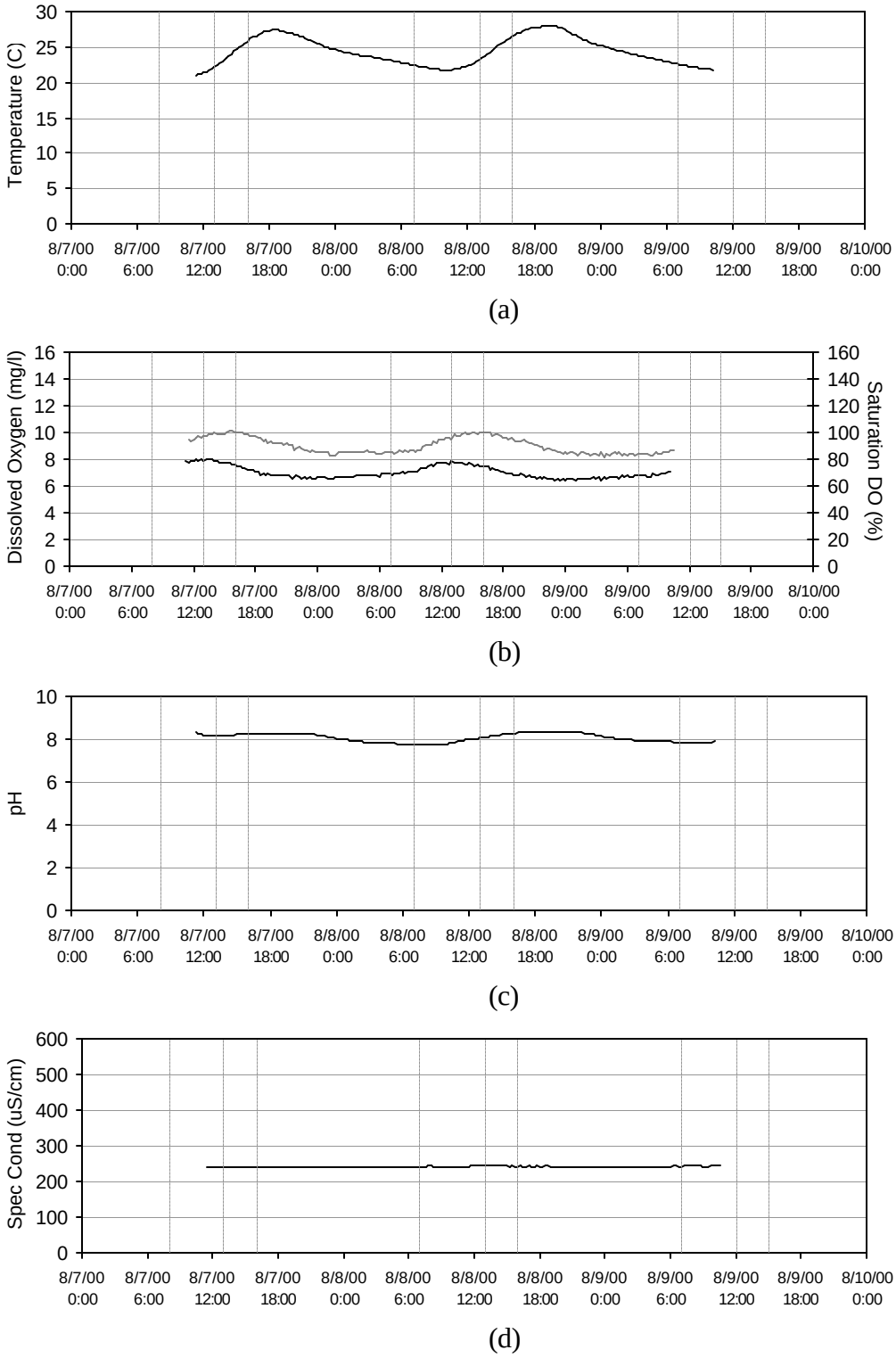


Figure I-13 Scott River at mouth, August 7-9, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

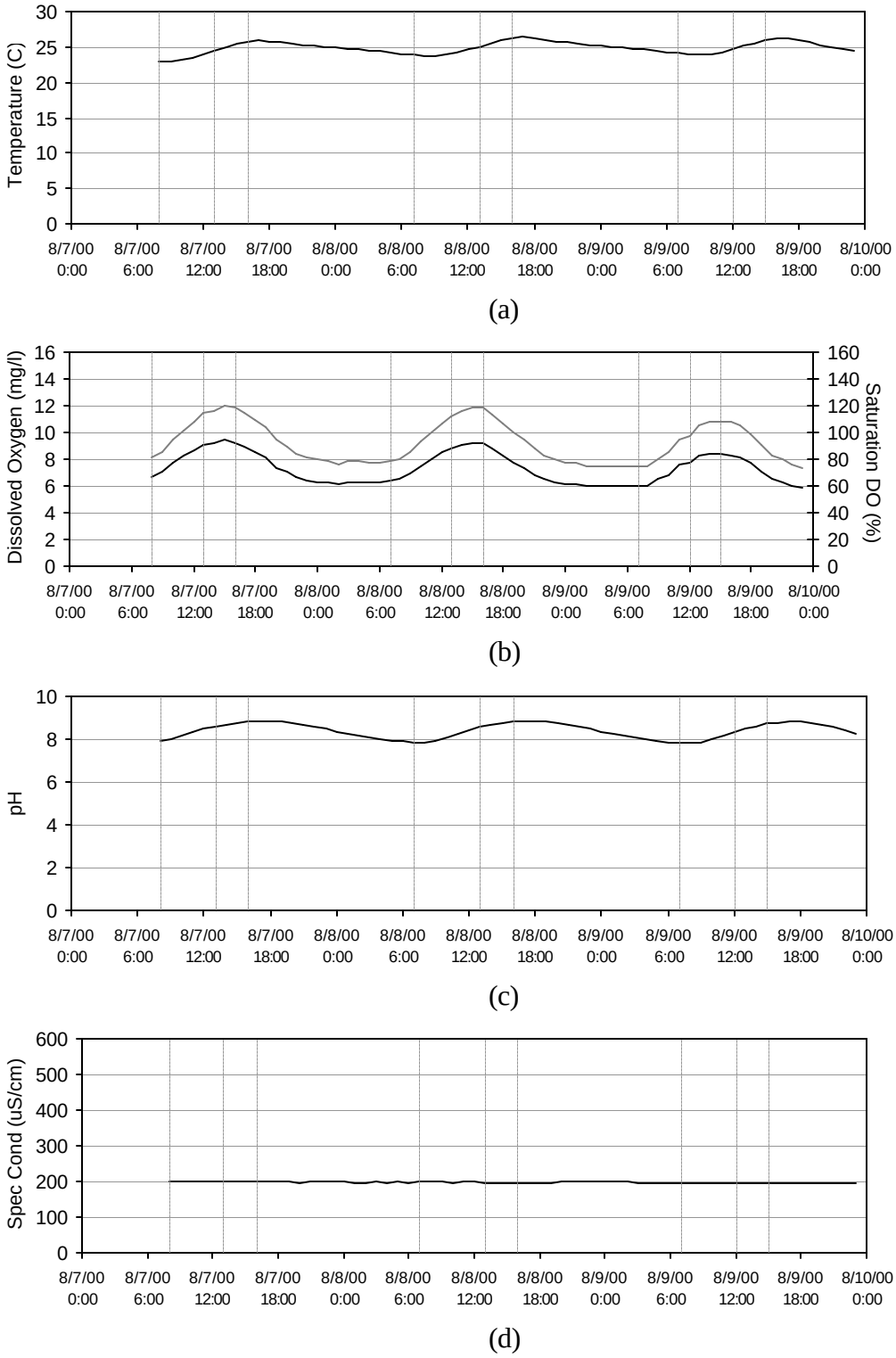


Figure I-14 Klamath River near Seiad Valley, August 7-9, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

Synoptic Survey September 26-29, 2000 (Sonde only)

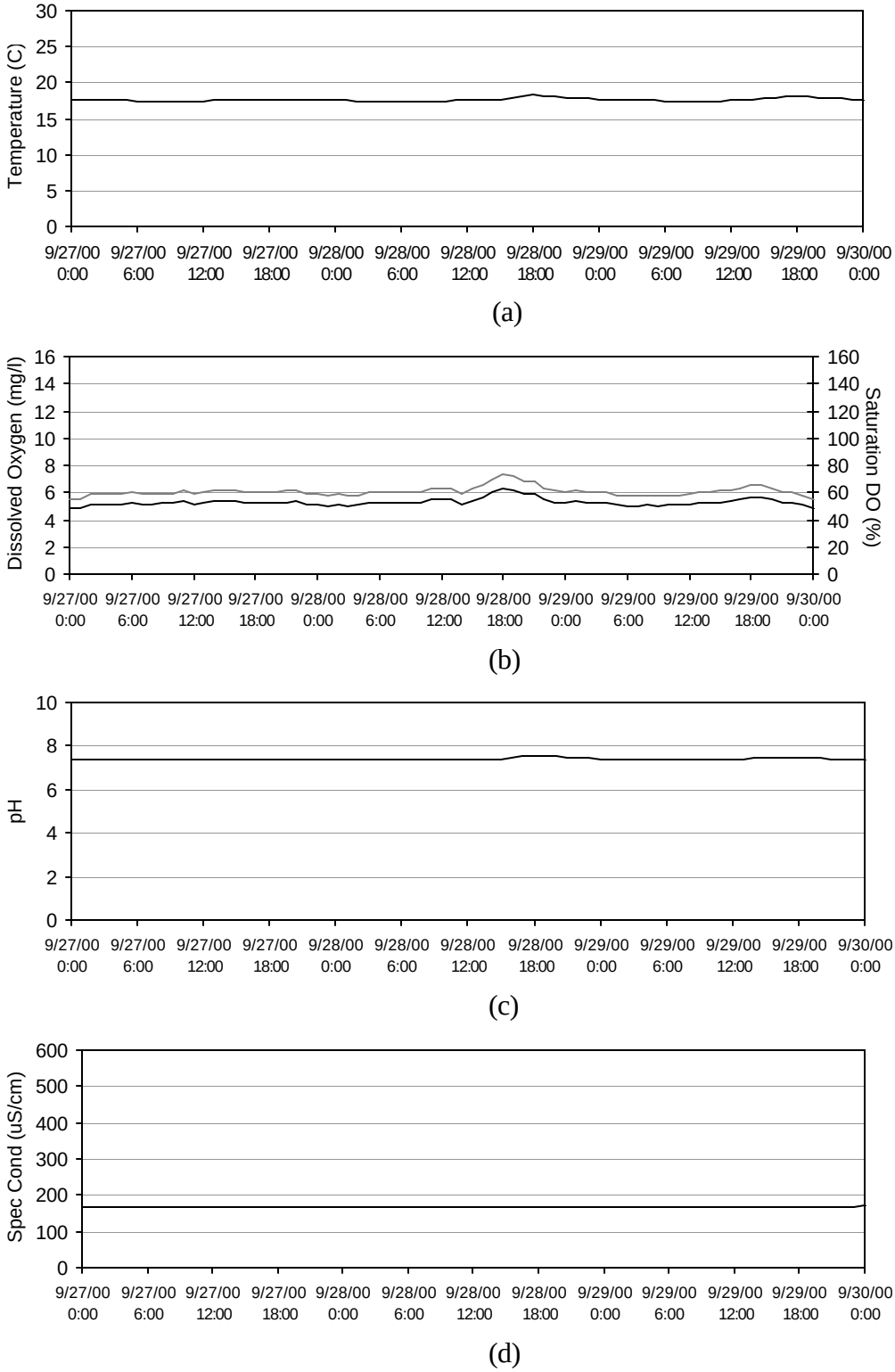


Figure I-15 Klamath River below Iron Gate Dam, September 27-29, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

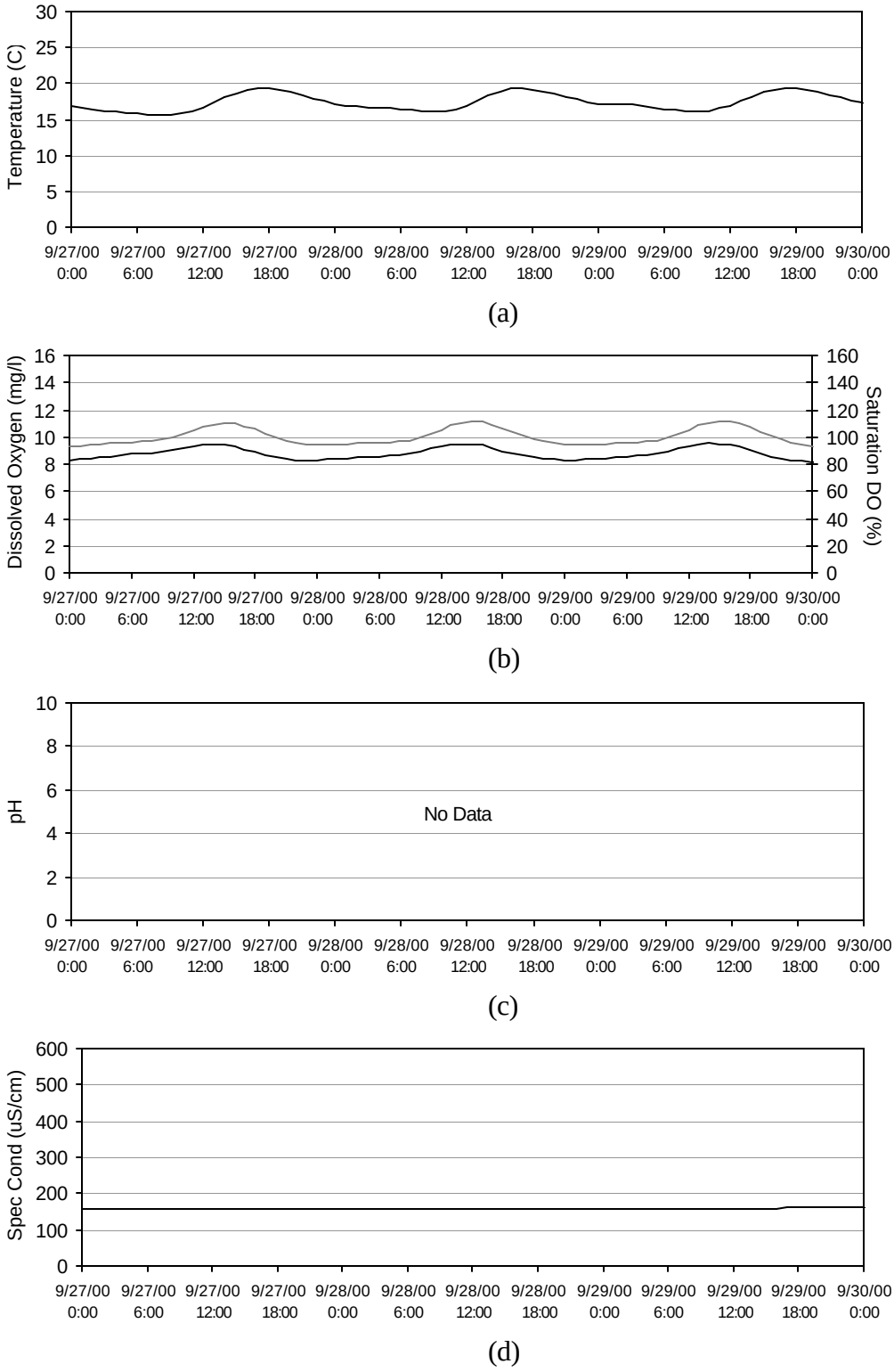


Figure I-16 Klamath River above Shasta River, September 27-29, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

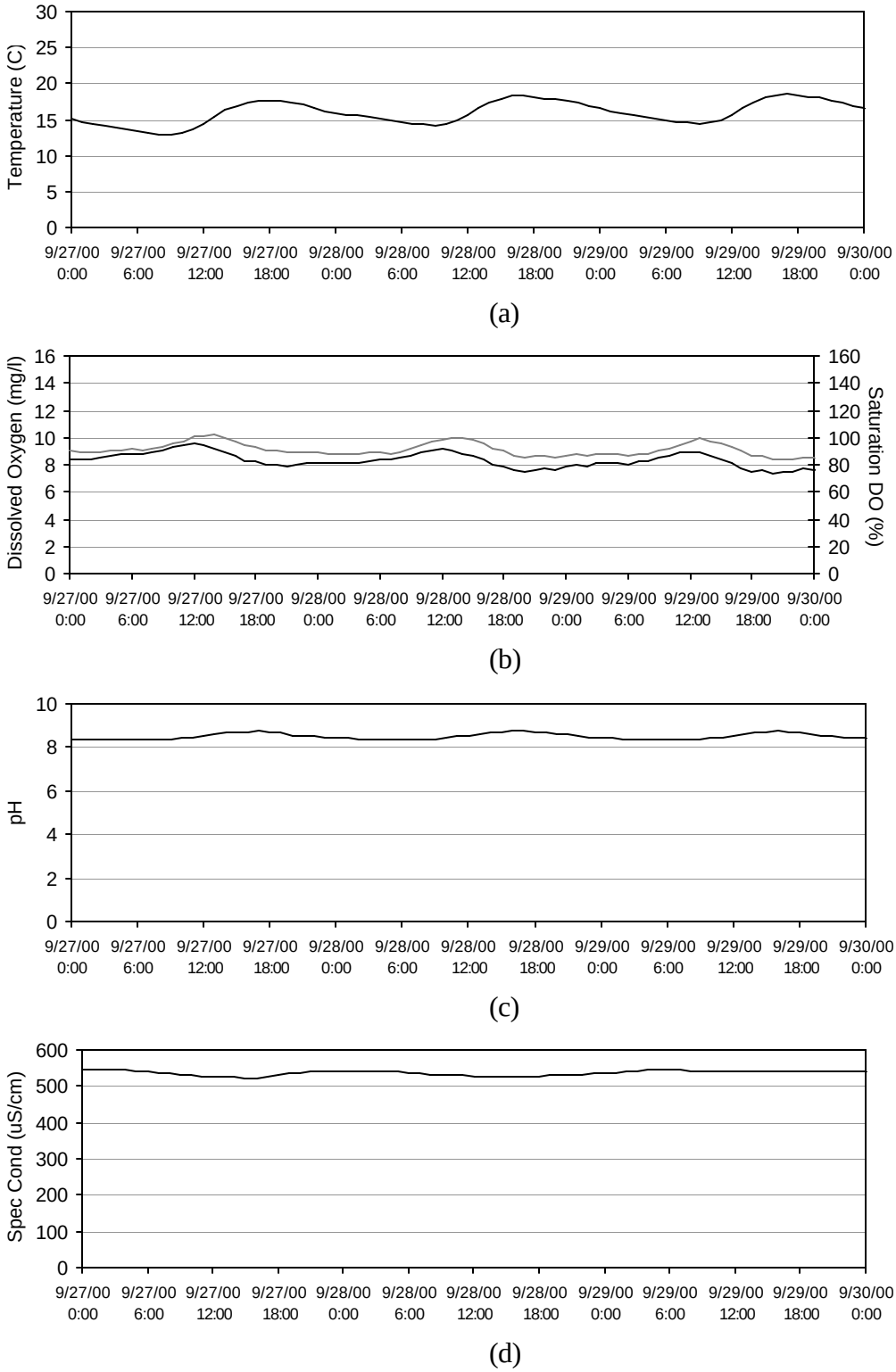


Figure I-17 Shasta River, September 27-29, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

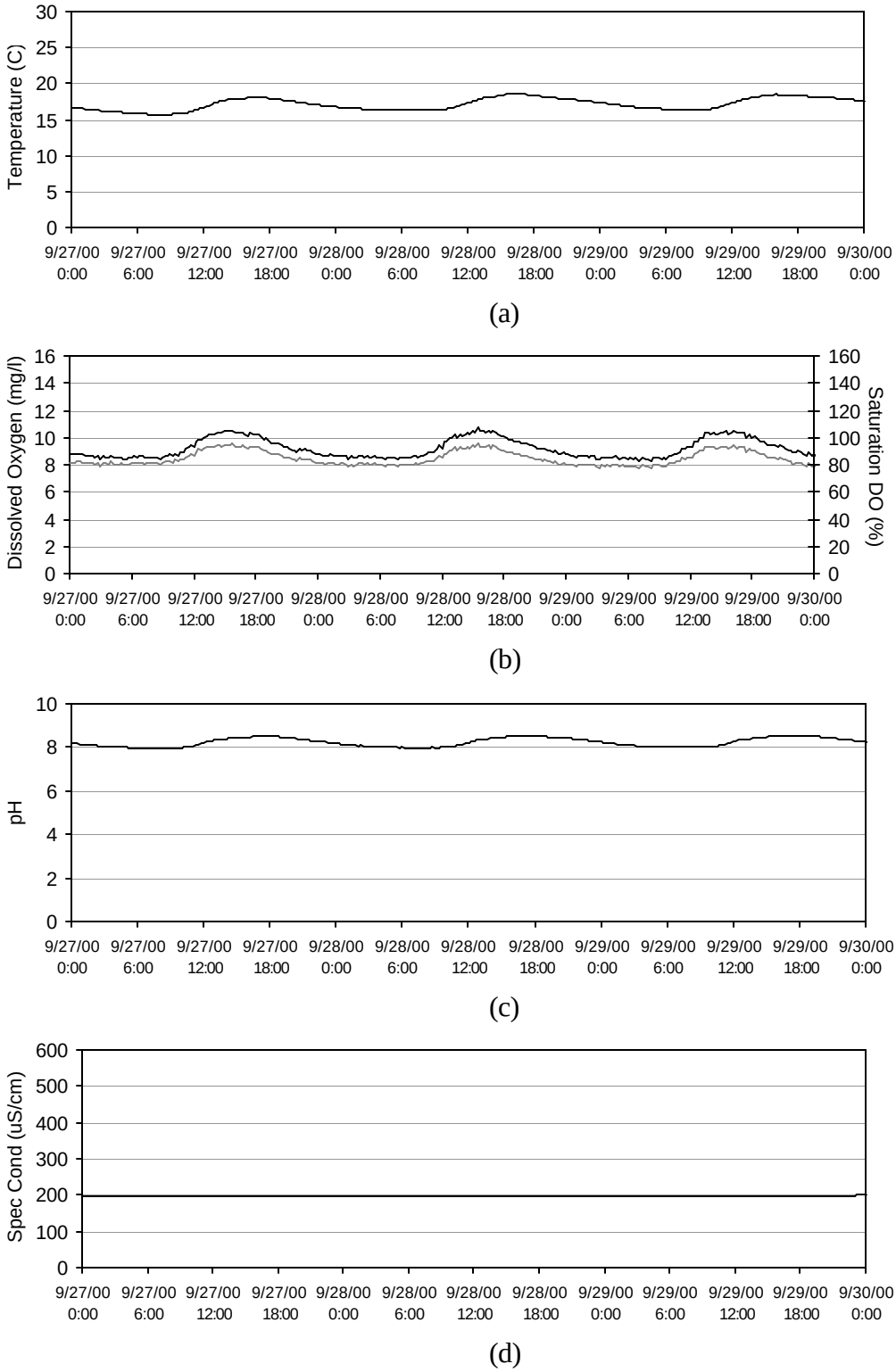


Figure I-18 Klamath River above Scott River, September 27-29, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

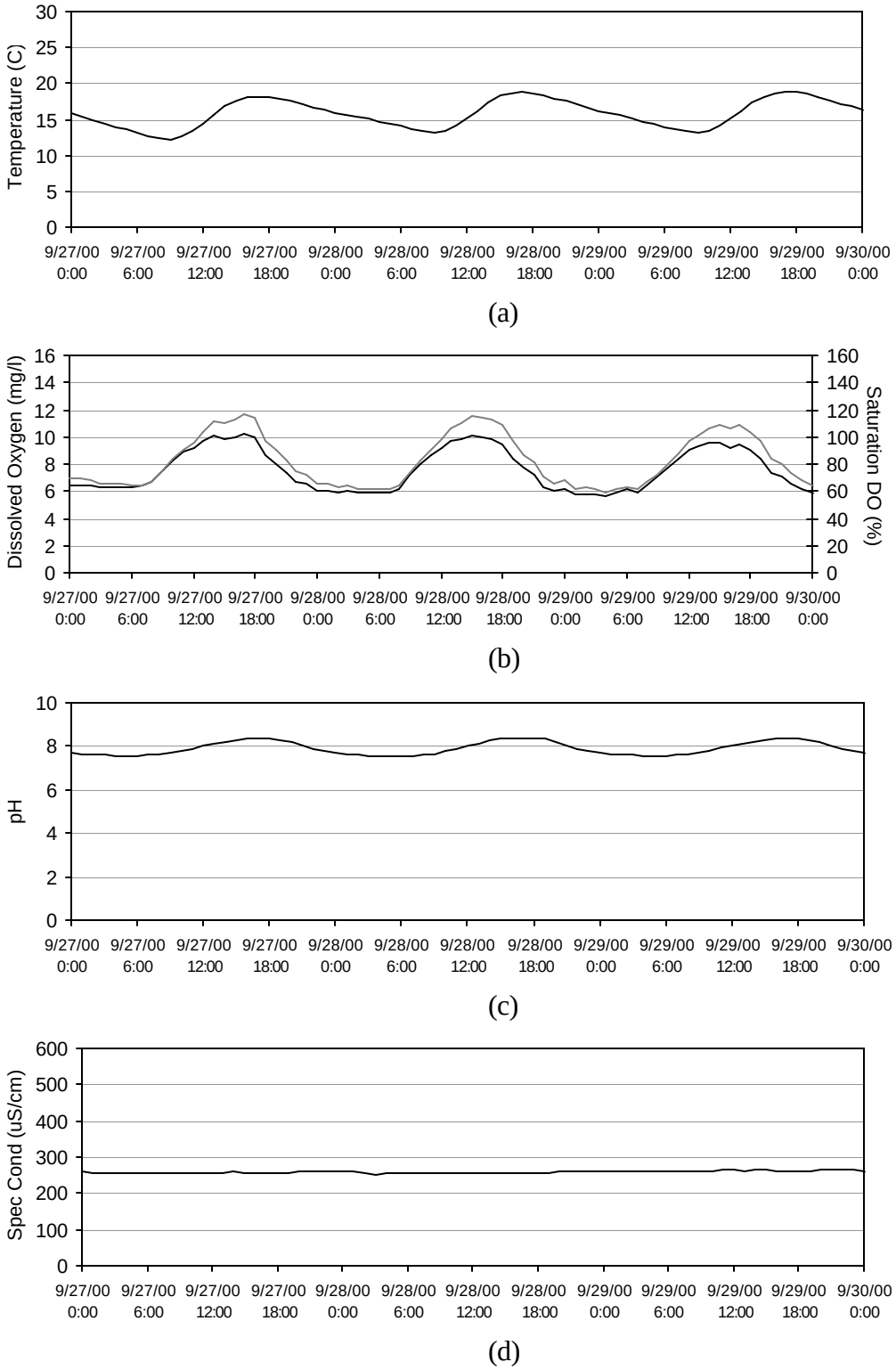


Figure I-19 Scott River at Ft. Jones, September 27-29, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

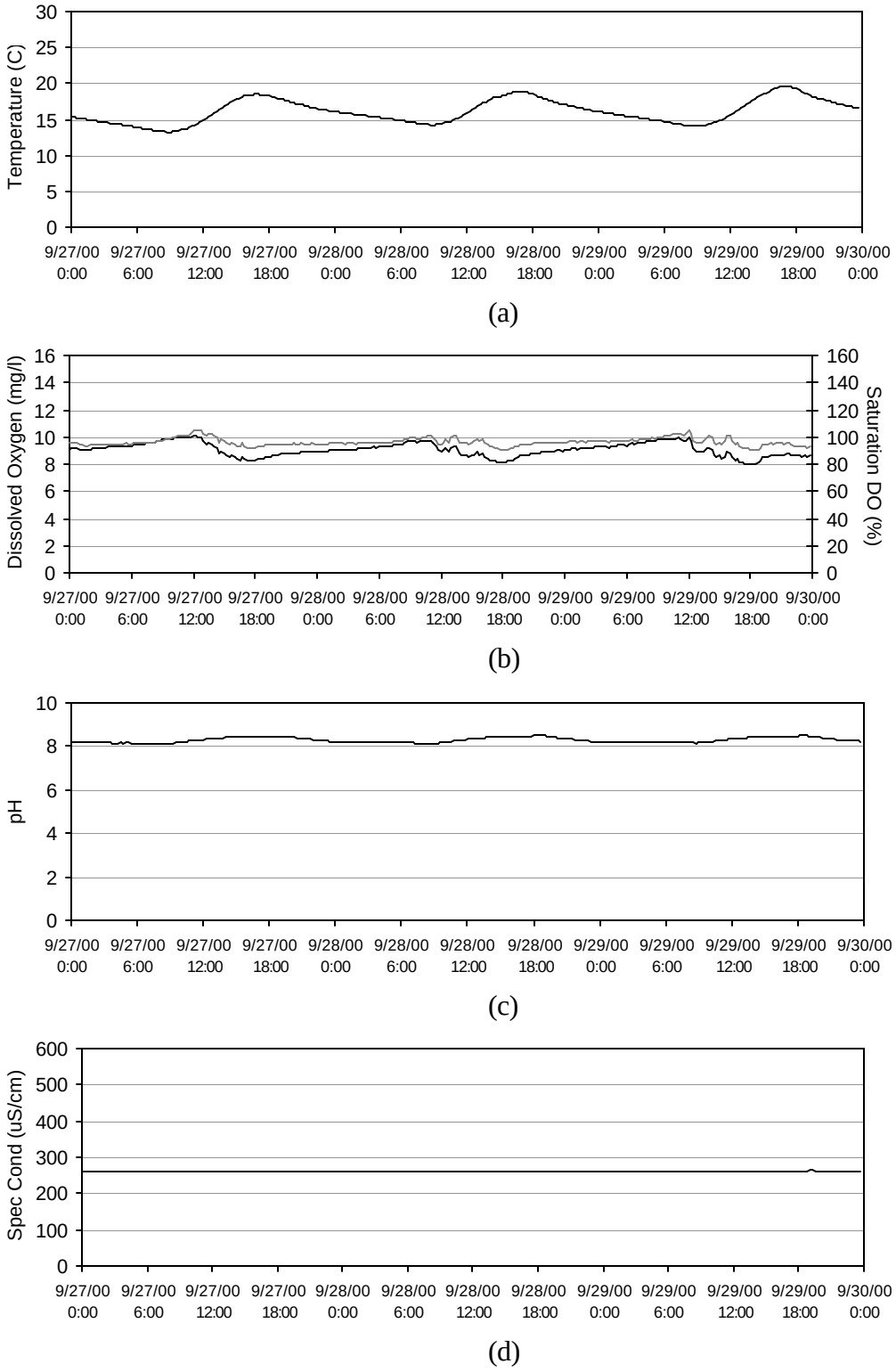


Figure I-20 Scott River at mouth, September 27-29, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

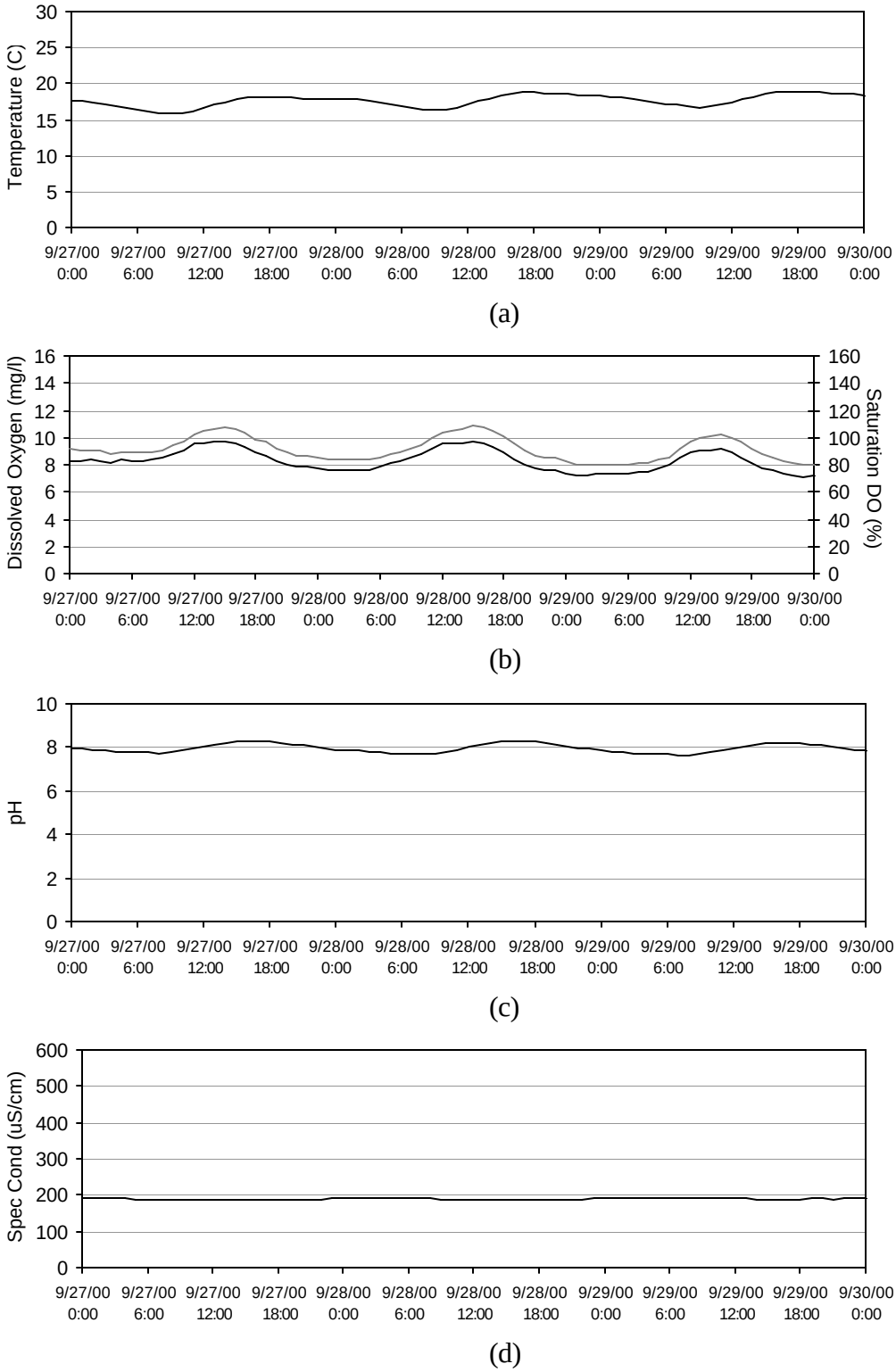


Figure I-21 Klamath River near Seiad Valley, September 27-29, 2000: (a) water temperature, (b) dissolved oxygen, (c) pH, and (d) specific conductance

J DATASONDE DATA

Datasonde data was collected at 13 locations outlined in Table J-1. It is apparent when reviewing the following graphs that water quality probe measurements suffer from biofouling and other probe related problems. The reader is referred to the discussion of water quality probe deployment in the main report. These are raw data sets that have not been processed beyond removing data that was sampled when the probes were not in the water.

Table J-1 Water quality probe deployment locations

Sampling Location	Latitude	Longitude
Klamath River at Miller Island	N42° 8.821’	W121° 50.904’
KSD @ Hwy 97	N42° 4.846’	W121° 50.833’
KSD @ Stateline Rd.	N41° 59.804’	W121° 46.676’
KSD @ Tule Lake Outlet Tunnel	N41° 55.795’	W121° 36.022’
Keno Bridge	N42° 7.627’	W121° 55.700’
Klamath River above Copco	N41° 57.910’	W122° 15.390’
Klamath River bel. Iron Gate Dam	N41° 55.894’	W122° 26.394’
Shasta River @ USGS Gage	N41° 49.393’	W122° 35.708’
Scott River @ USGS Gage	N41° 38.429’	W123° 0.867’
Klamath R. at Seiad Valley @ USGS Gage	N41° 50.247’	W123° 11.855’
Salmon River	N41° 22.615’	W123° 28.632’
Trinity River	N41° 3.023’	W123° 40.397’
Klamath River at Youngs Bar	N41° 14.797’	W123° 46.398’

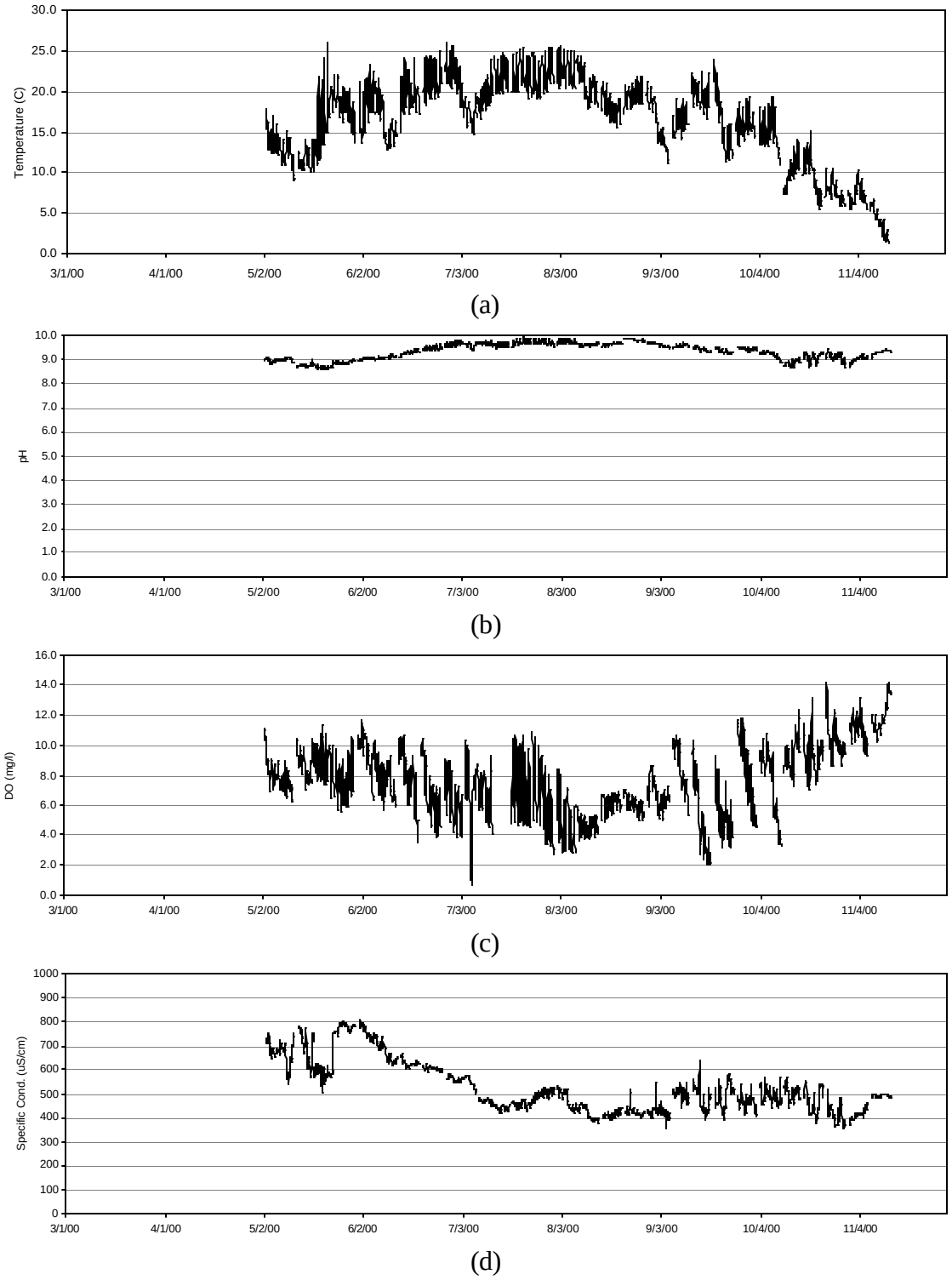
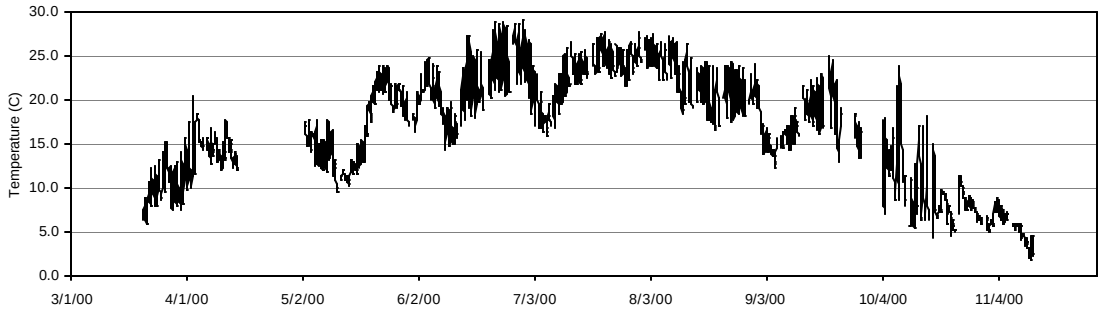
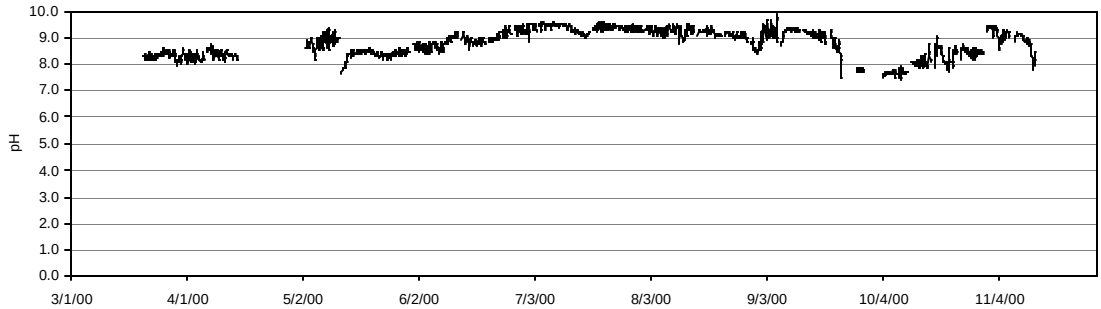


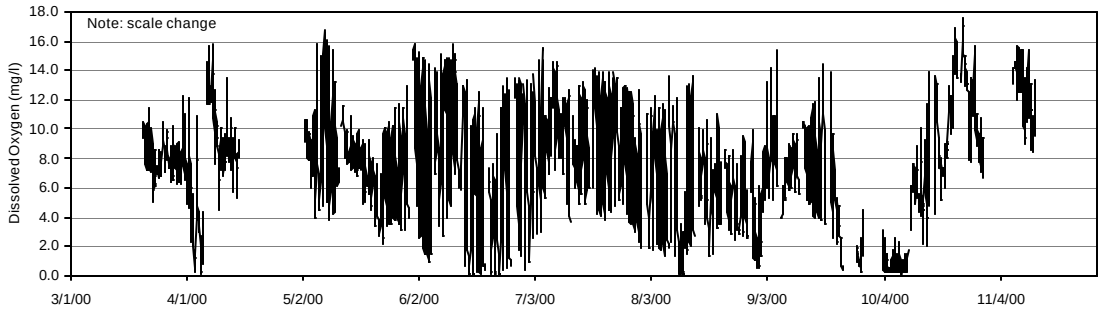
Figure J-1 Klamath Straight Drain at P-Canal (Tule Lake Outlet) hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



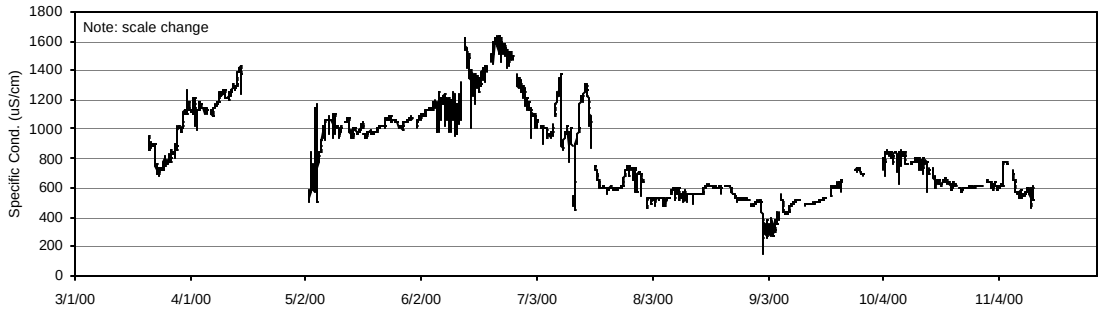
(a)



(b)

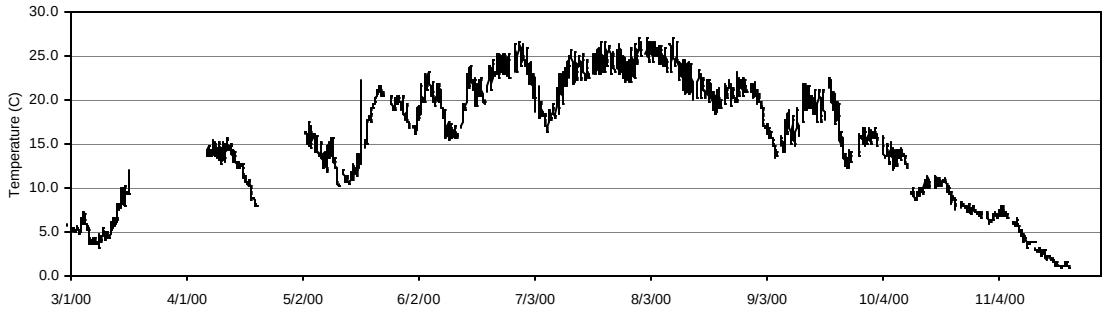


(c)

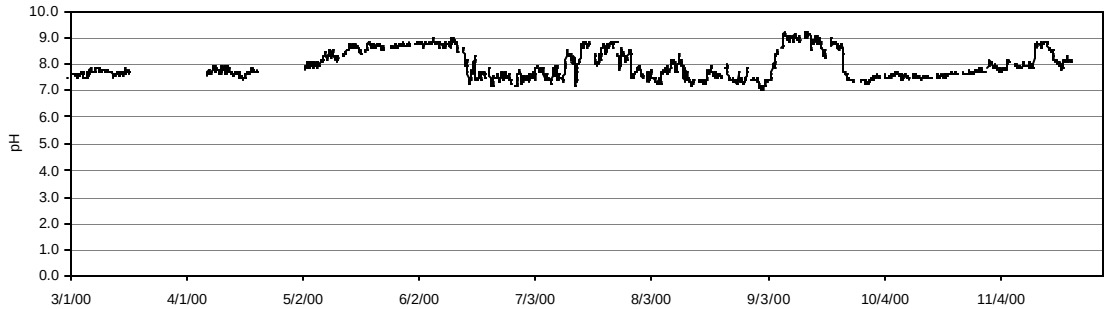


(d)

Figure J-2 Klamath Straight Drain at Stateline hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



(a)



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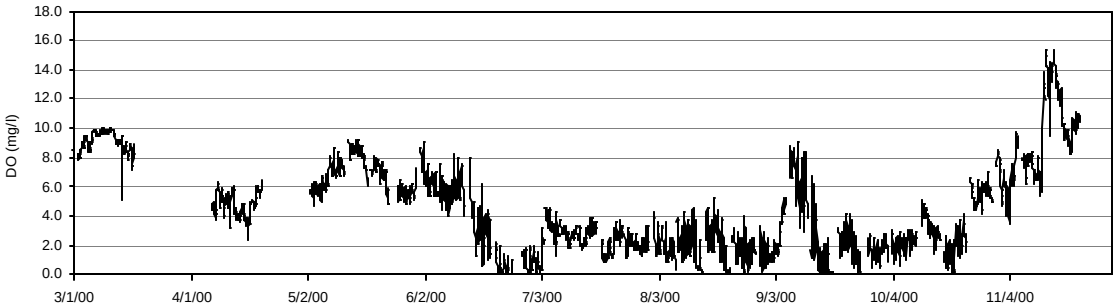
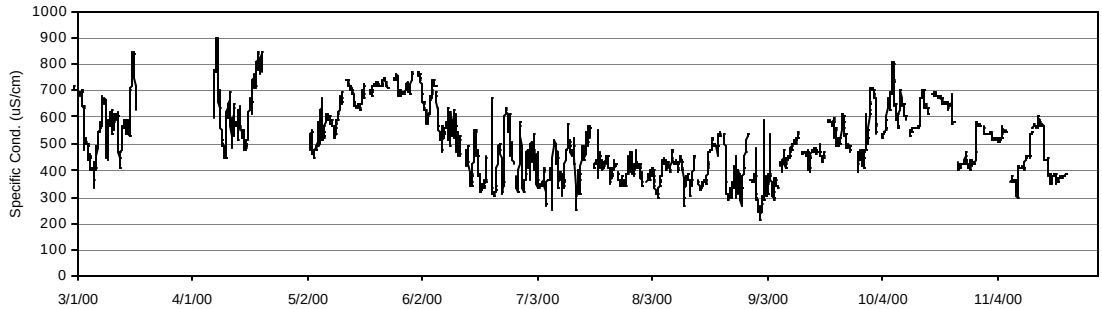
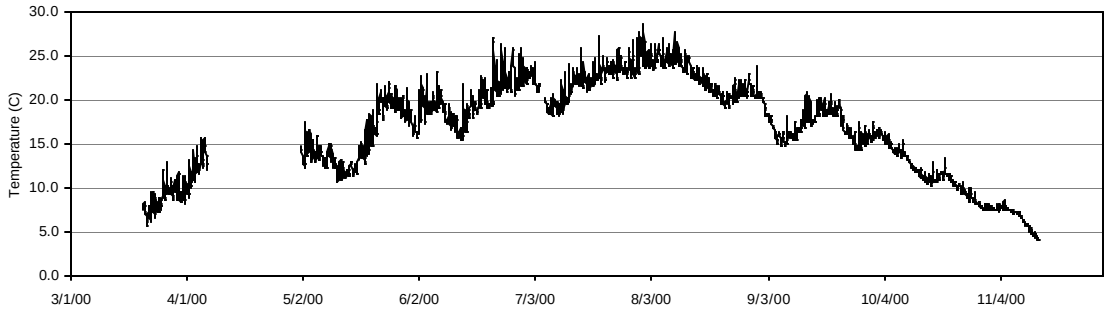


(c)

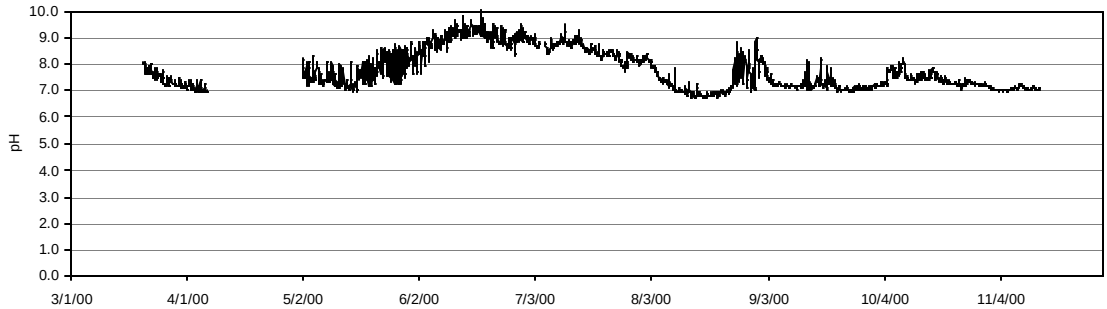


(d)

Figure J-3 Klamath Straight Drain at Highway 97 hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



(a)



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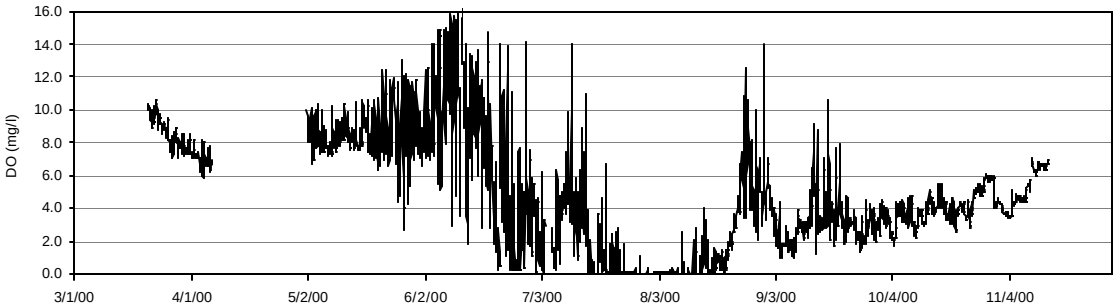
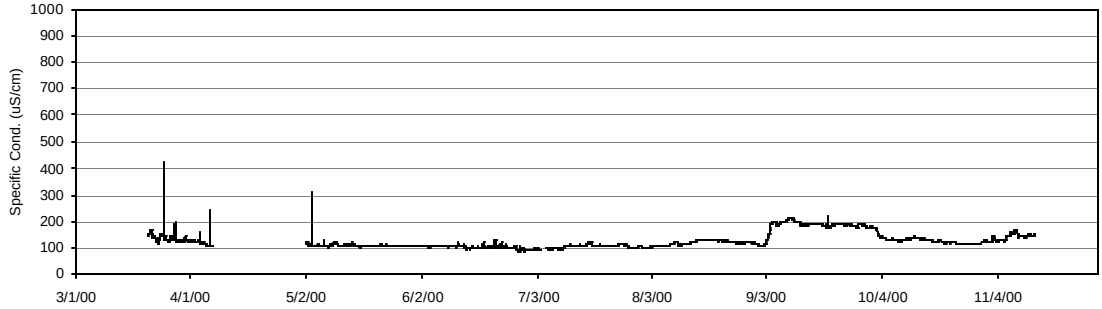


(c)



(d)

Figure J-4 Klamath River at Miller Island hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance

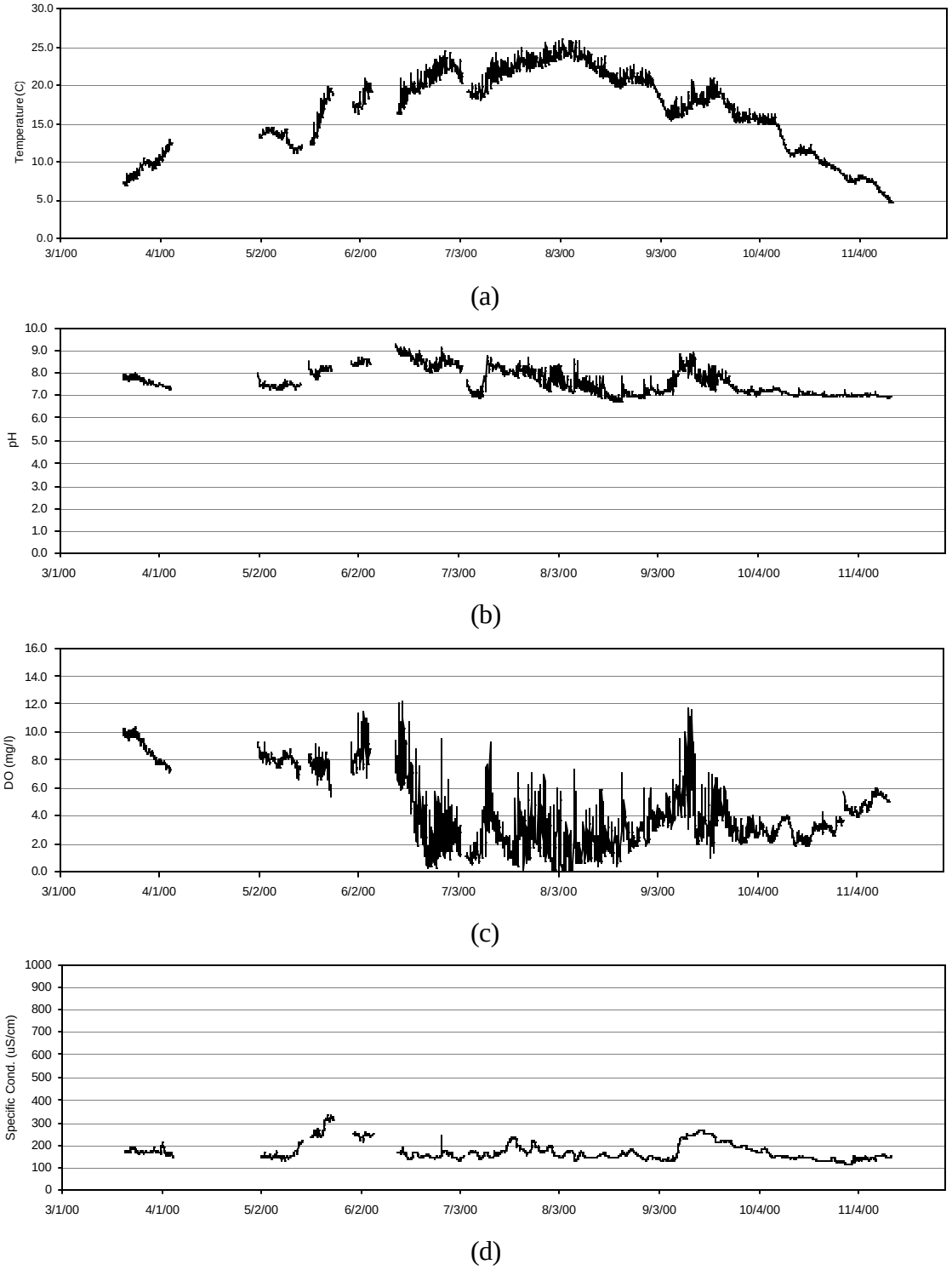
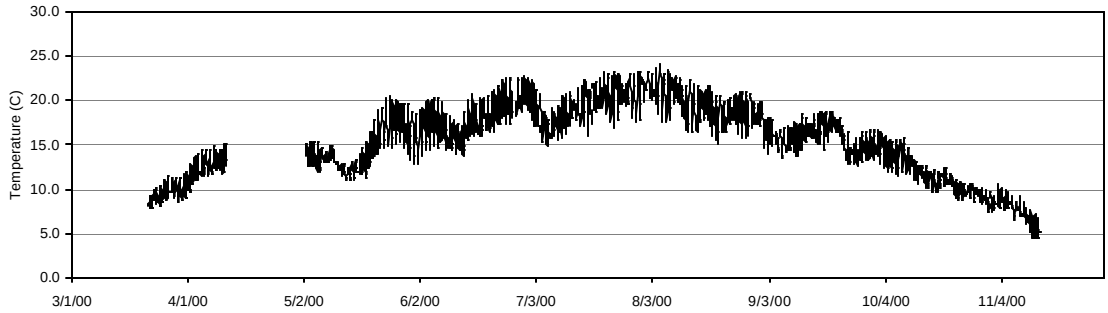
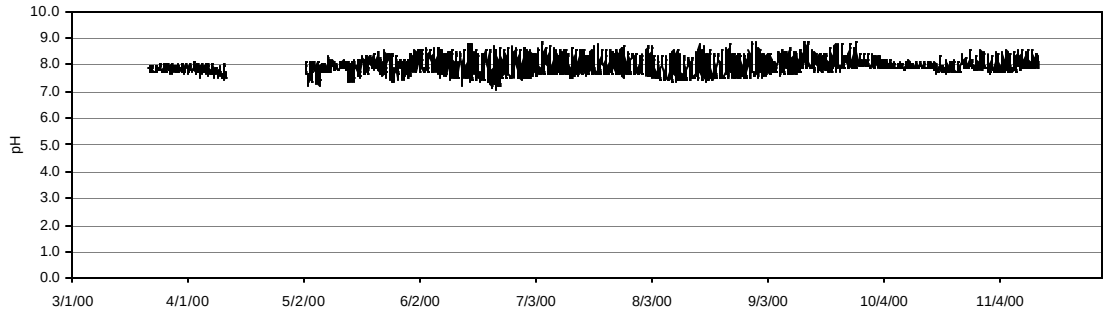


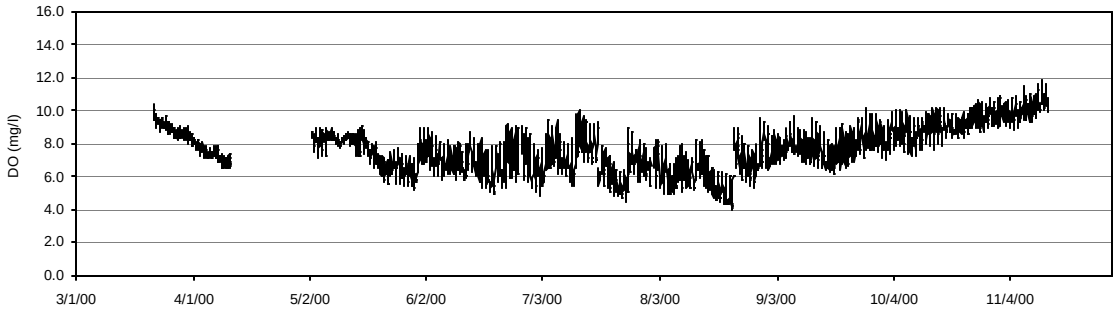
Figure J-5 Klamath River at Keno hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



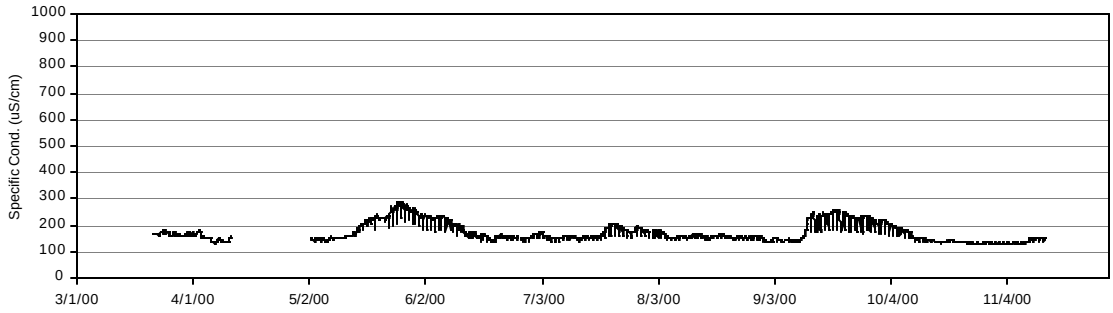
(a)



(b)

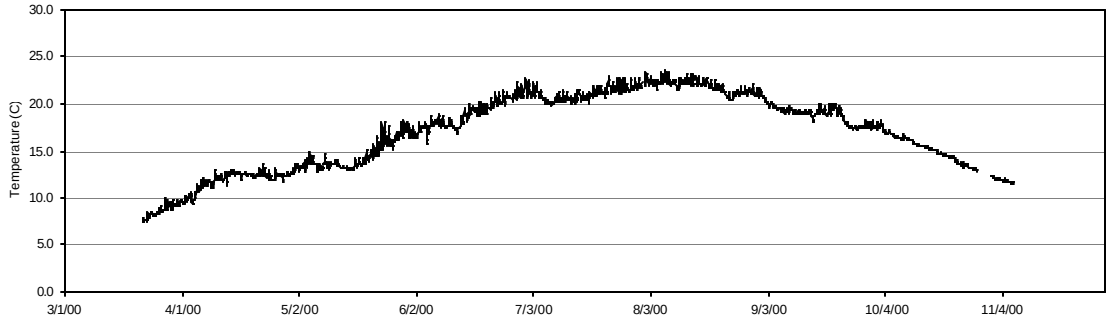


(c)

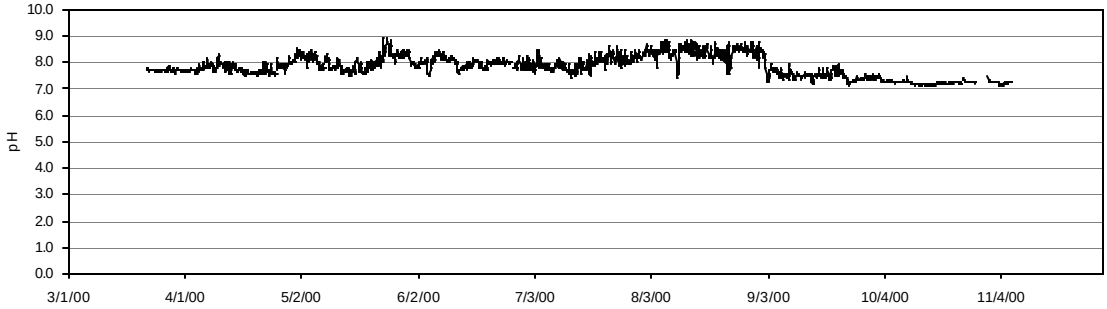


(d)

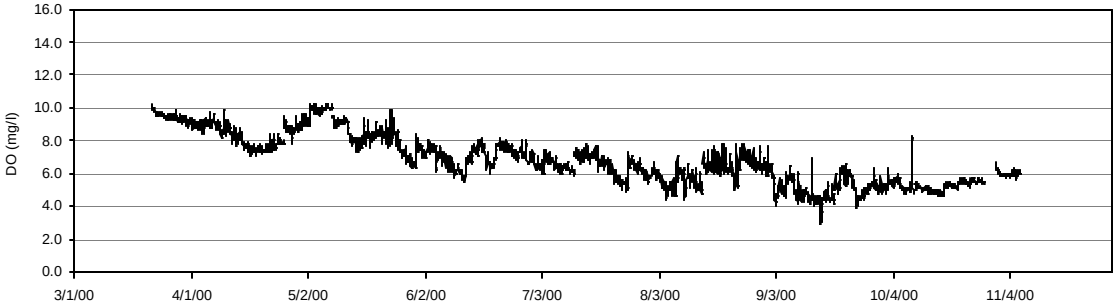
Figure J-6 Klamath River above Copco No. 1 Reservoir hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



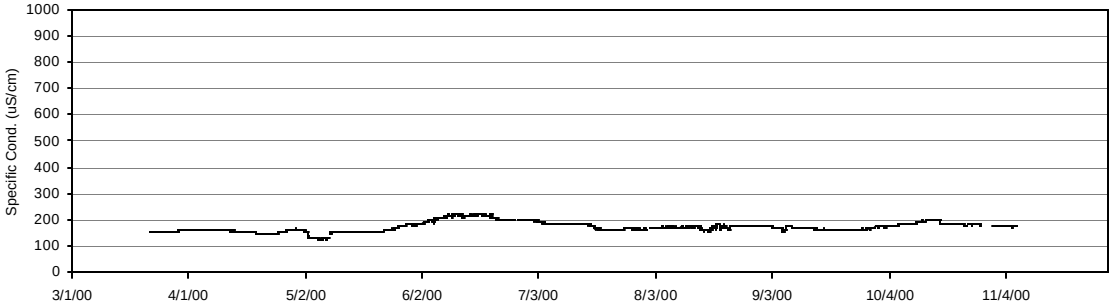
(a)



(b)

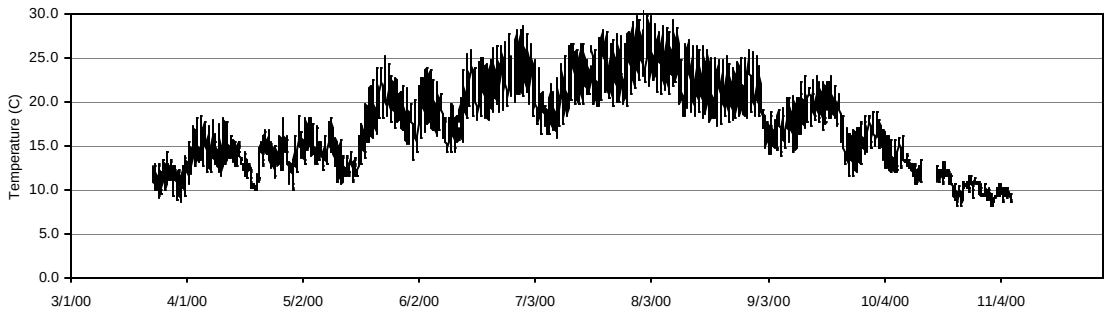


(c)

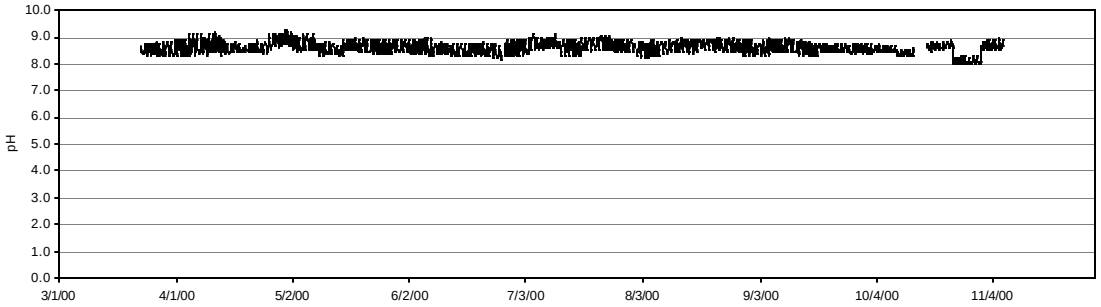


(d)

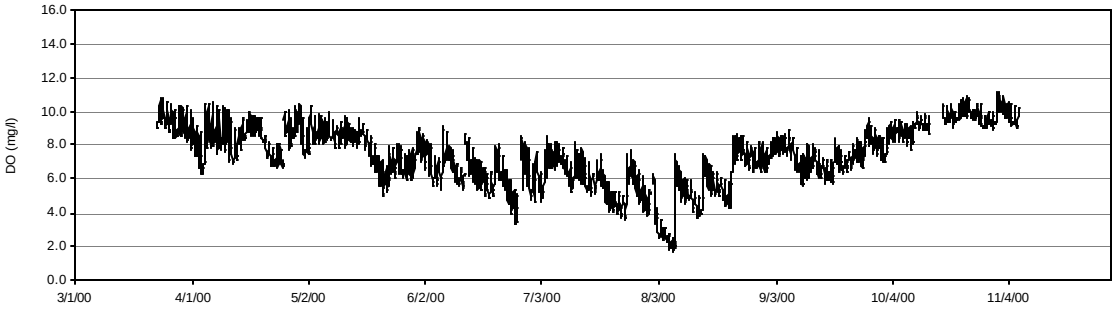
Figure J-7 Klamath River below Iron Gate Dam hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



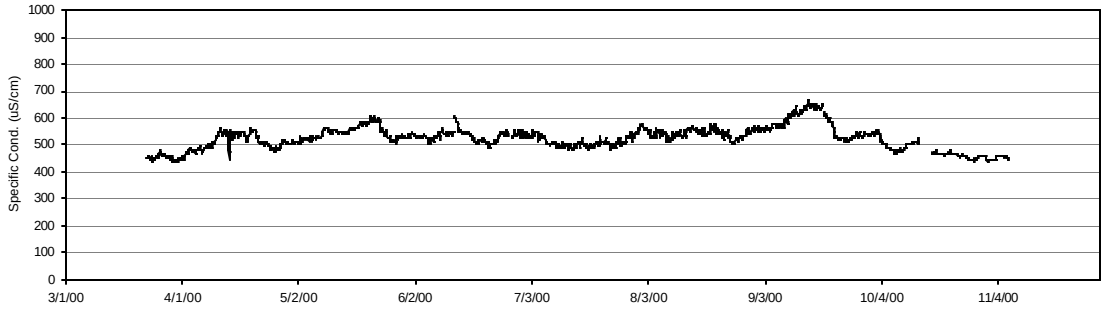
(a)



(b)

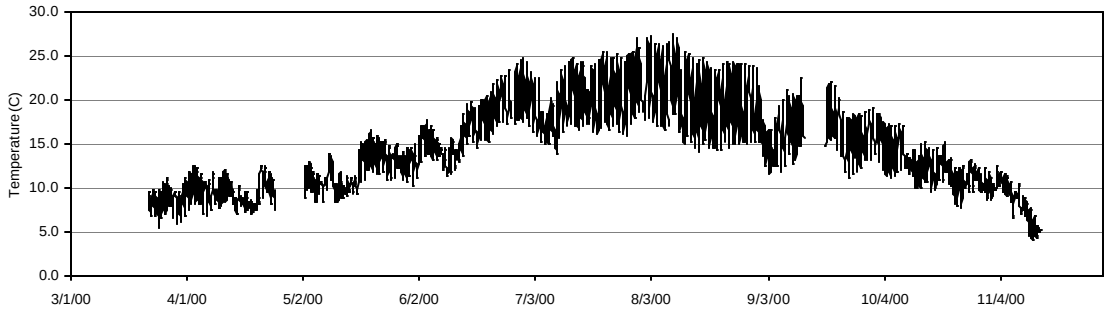


(c)

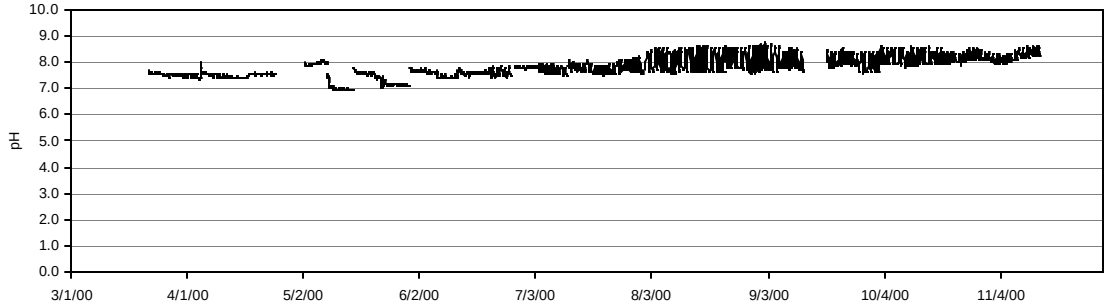


(d)

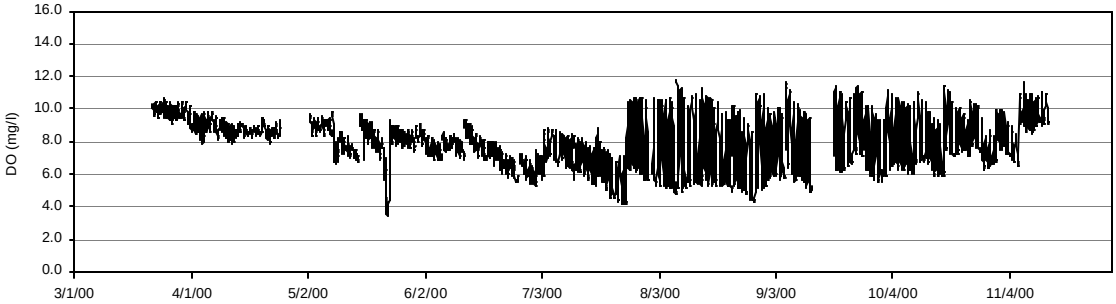
Figure J-8 Shasta River hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



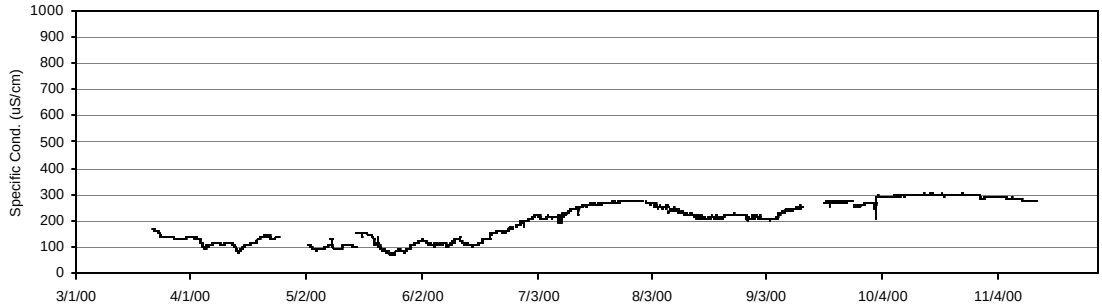
(a)



(b)

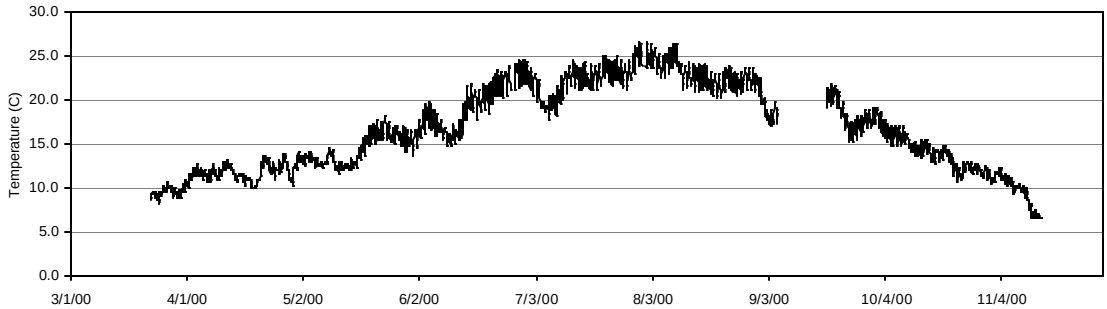


(c)

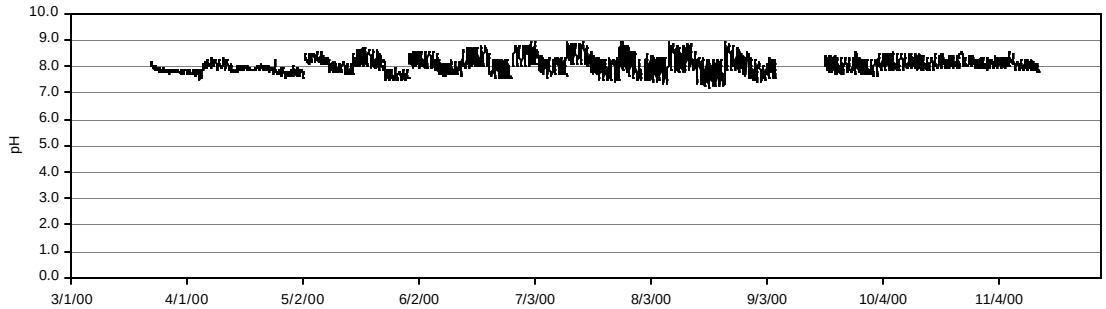


(d)

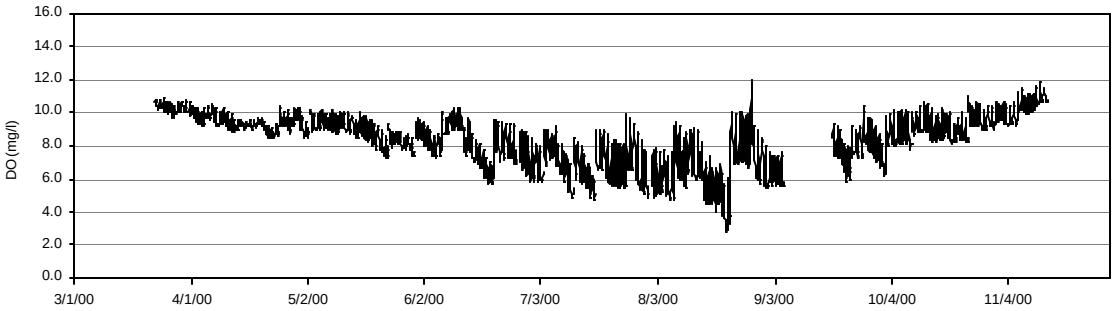
Figure J-9 Scott River near Ft. Jones hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



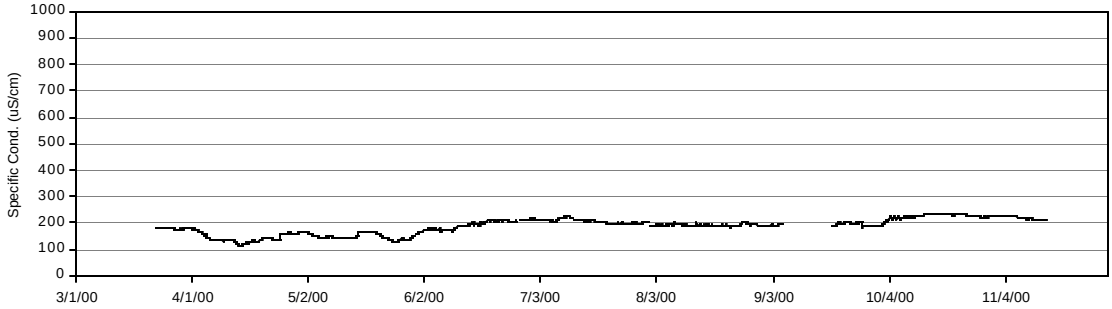
(a)



(b)

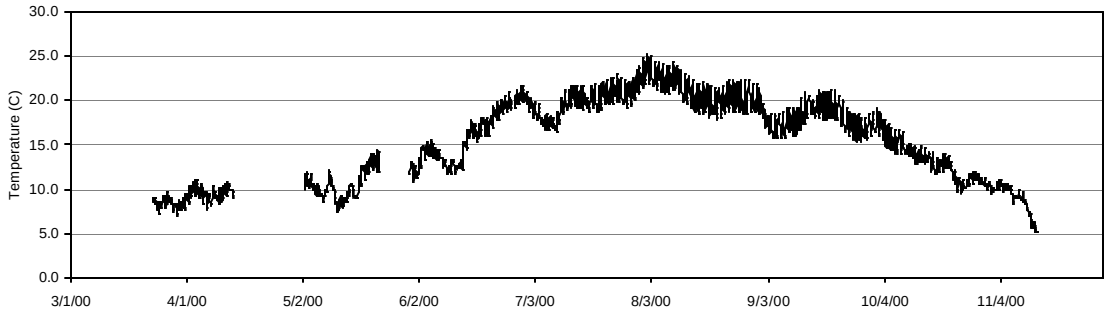


(c)

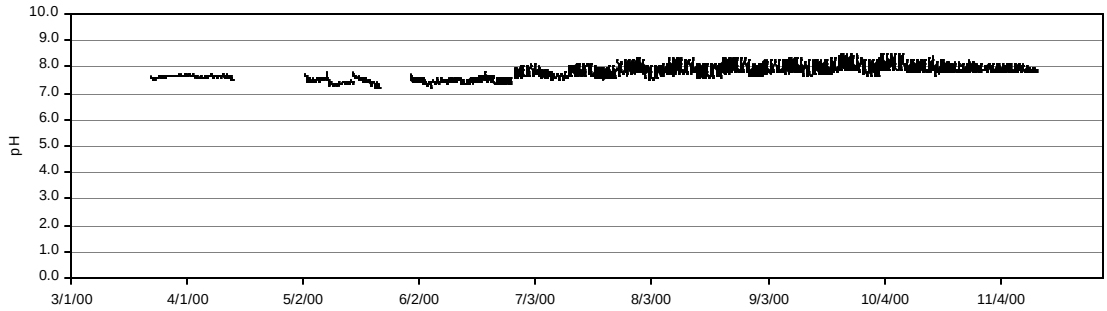


(d)

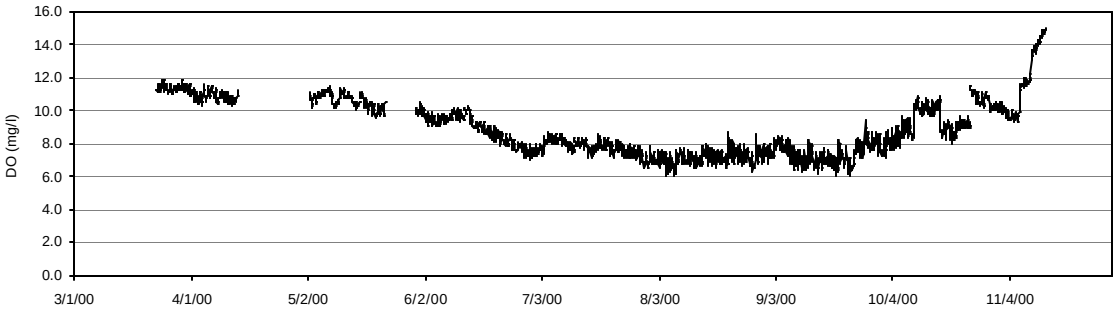
Figure J-10 Klamath River Near Seiad Valley hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



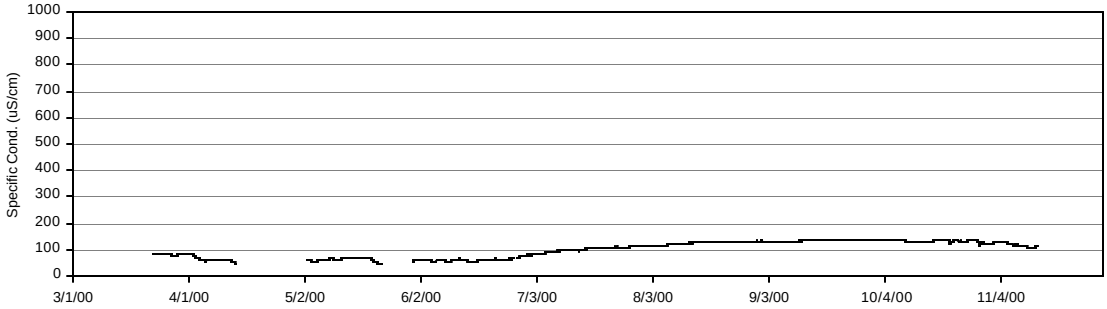
(a)



(b)



(c)



(d)

Figure J-11 Salmon River hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance

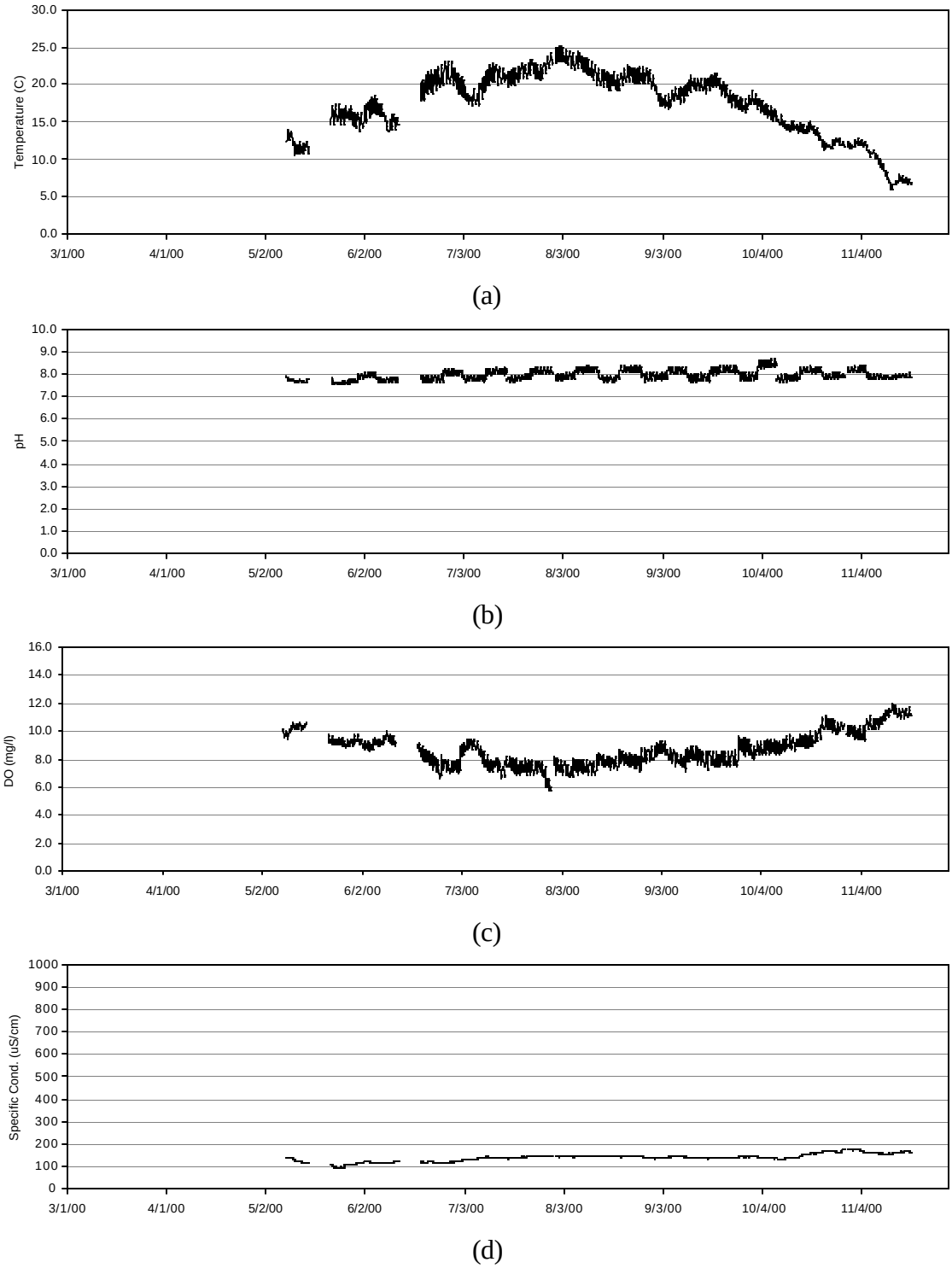
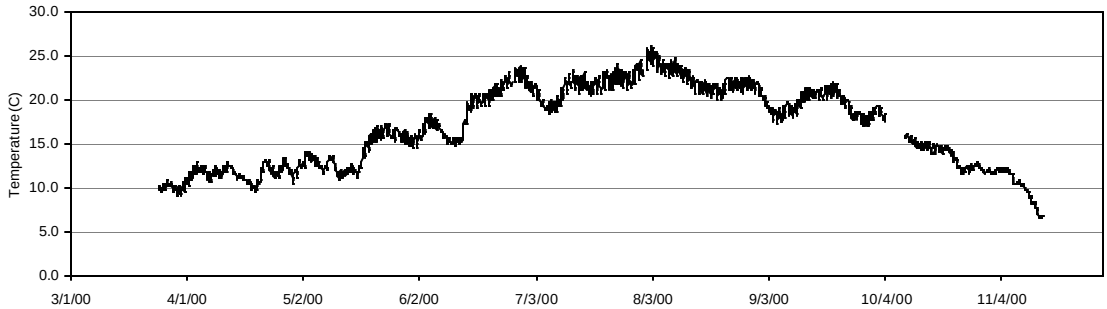
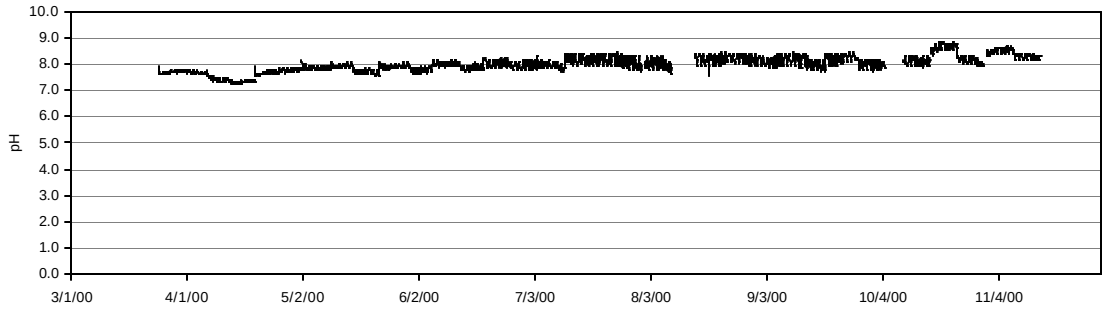


Figure J-12 Trinity River hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance



(a)



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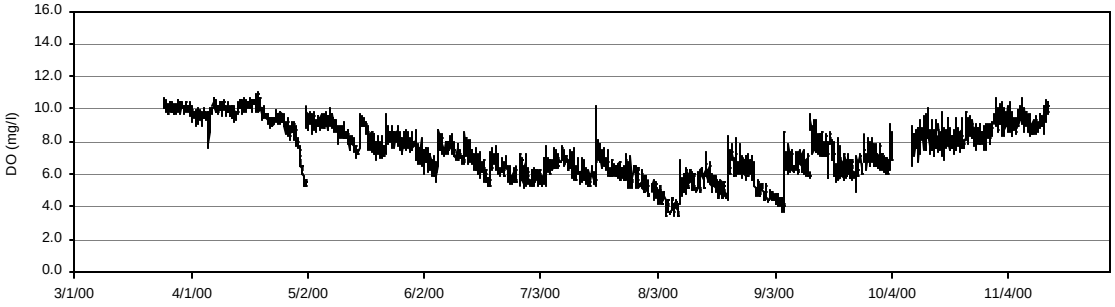

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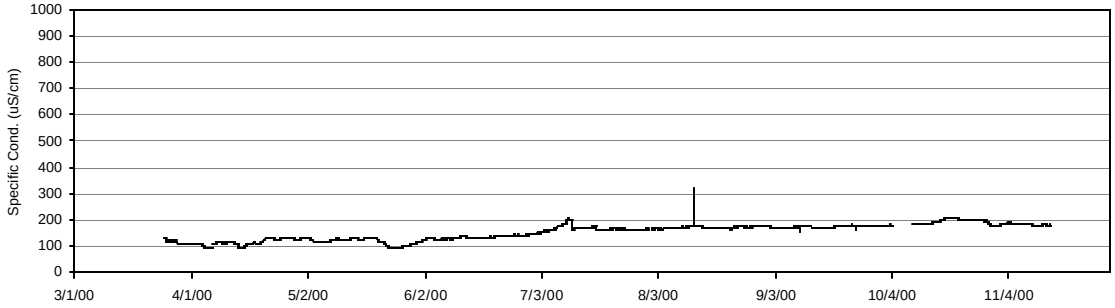
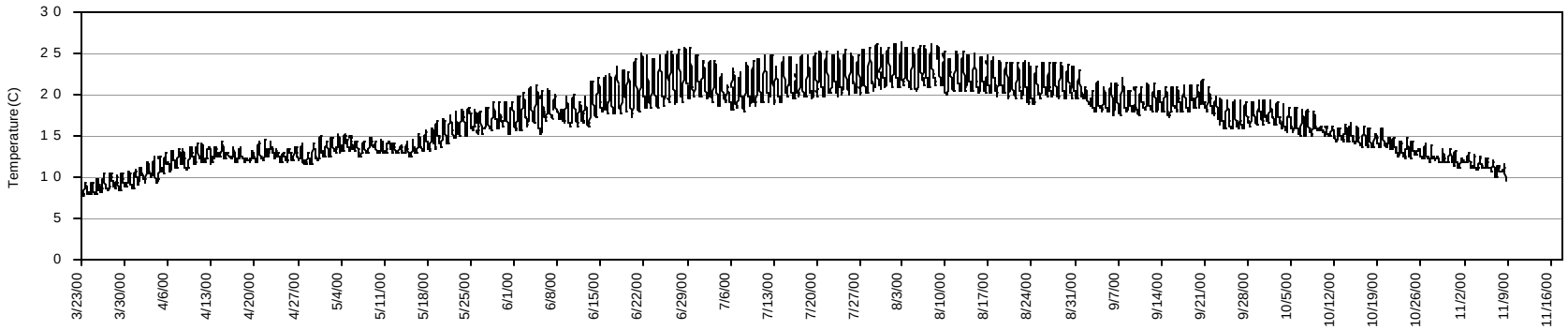


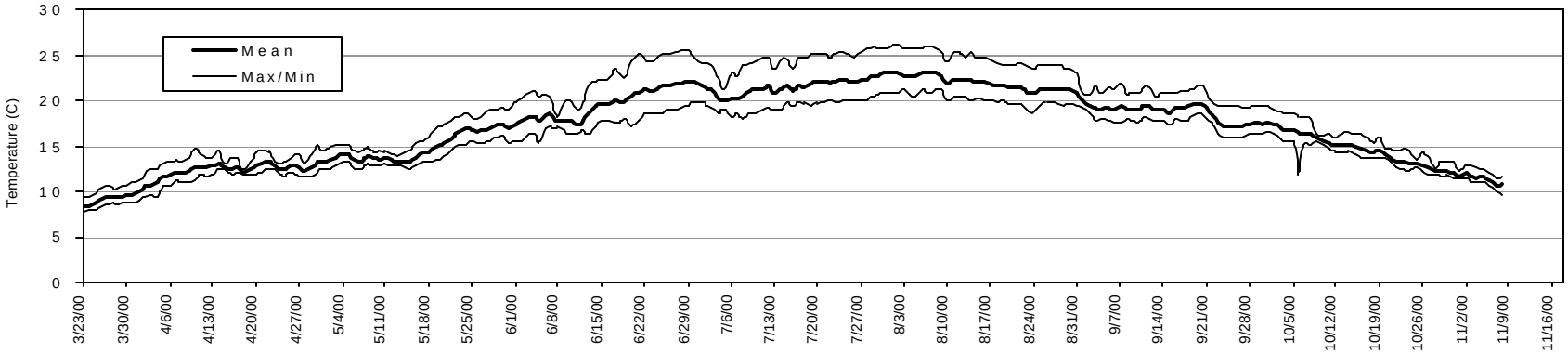
(d)

Figure J-13 Klamath River Near Youngs Bar hourly datasonde observations - 2000: (a) water temperature, (b) pH, (c) dissolved oxygen, and (d) specific conductance

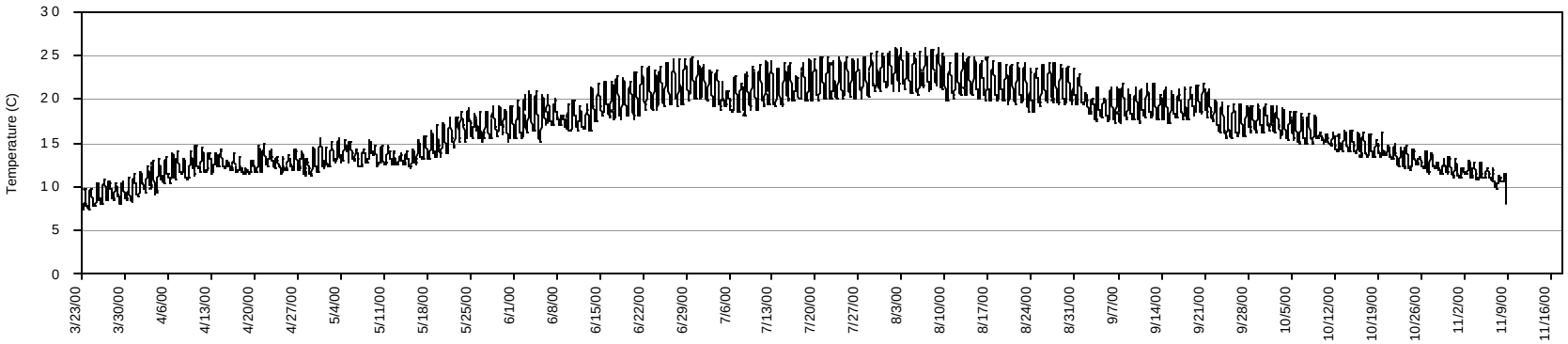
K WATER TEMPERATURE DATA



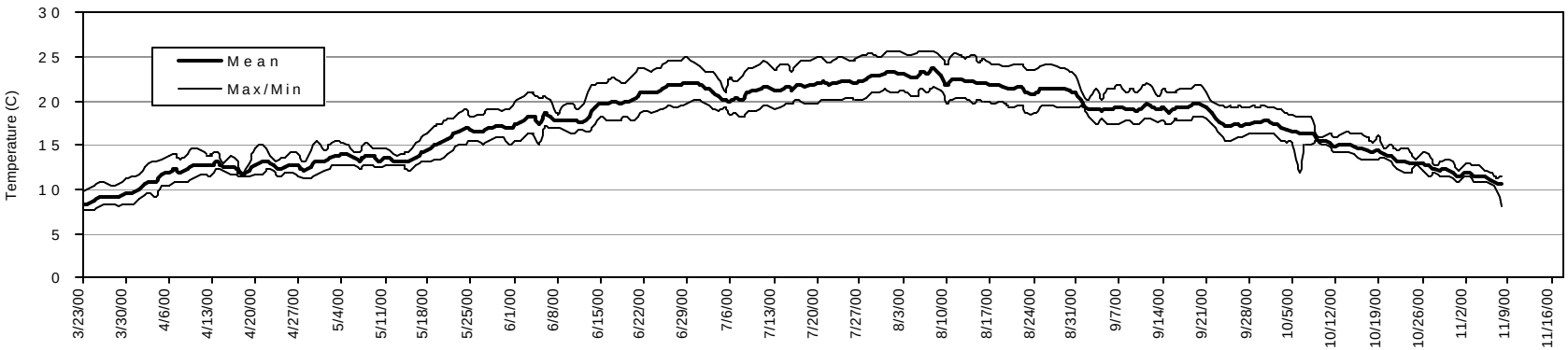
Klamath River observed hourly water temperature above Cottonwood Creek (RM 182)



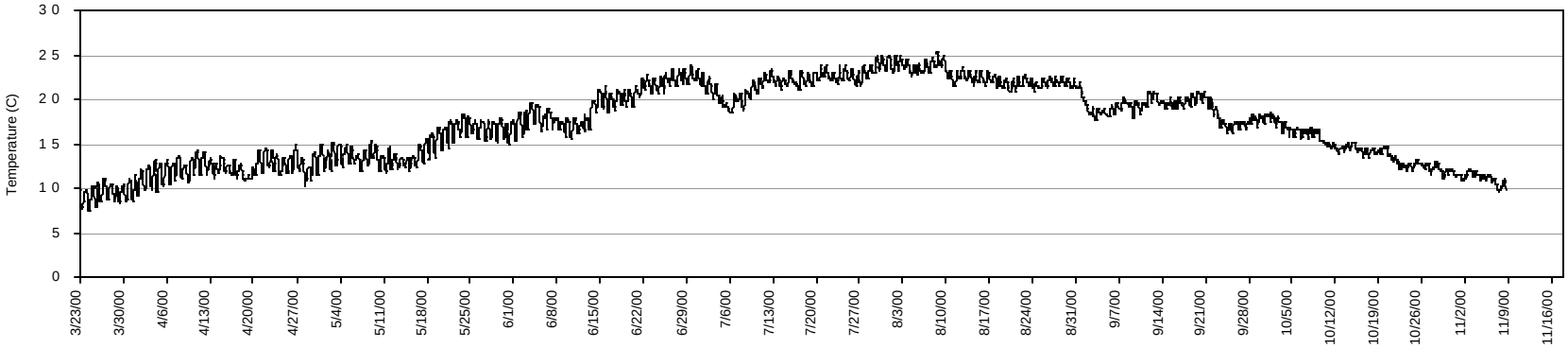
Klamath River observed daily mean, maximum, and minimum water temperature above Cottonwood Creek (RM 182)



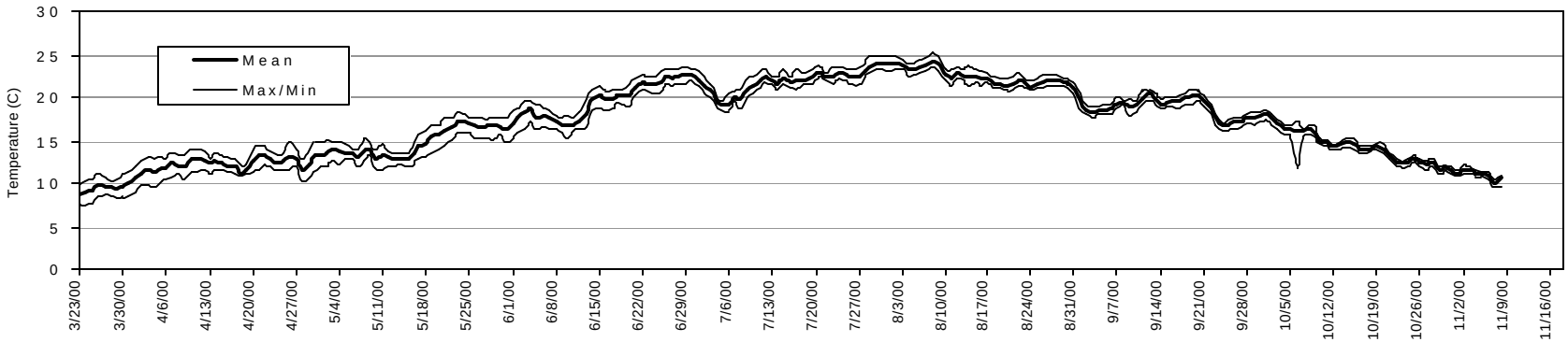
Klamath River observed hourly water temperature above Shasta River (RM 176.7)



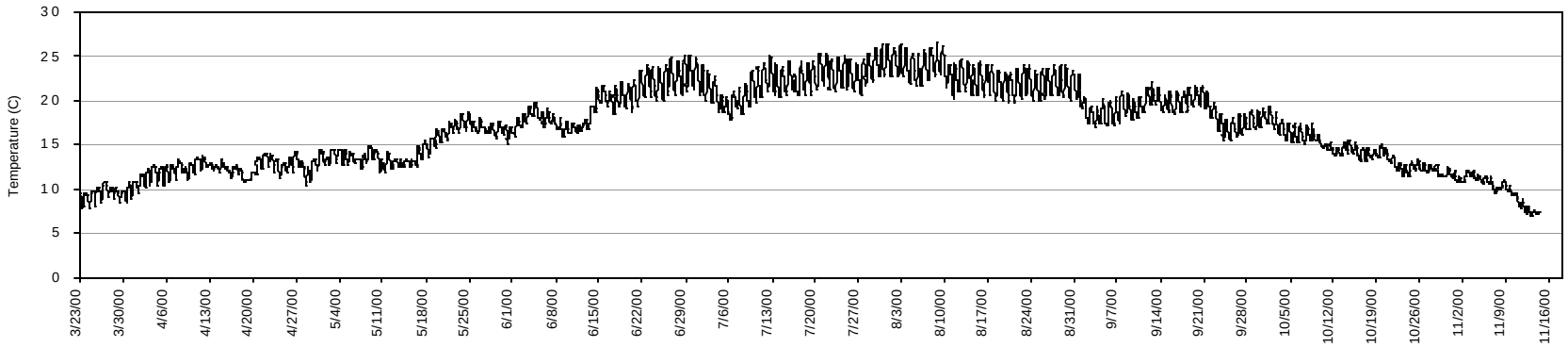
Klamath River observed daily mean, maximum, and minimum water temperature above Shasta River (RM 176.7)



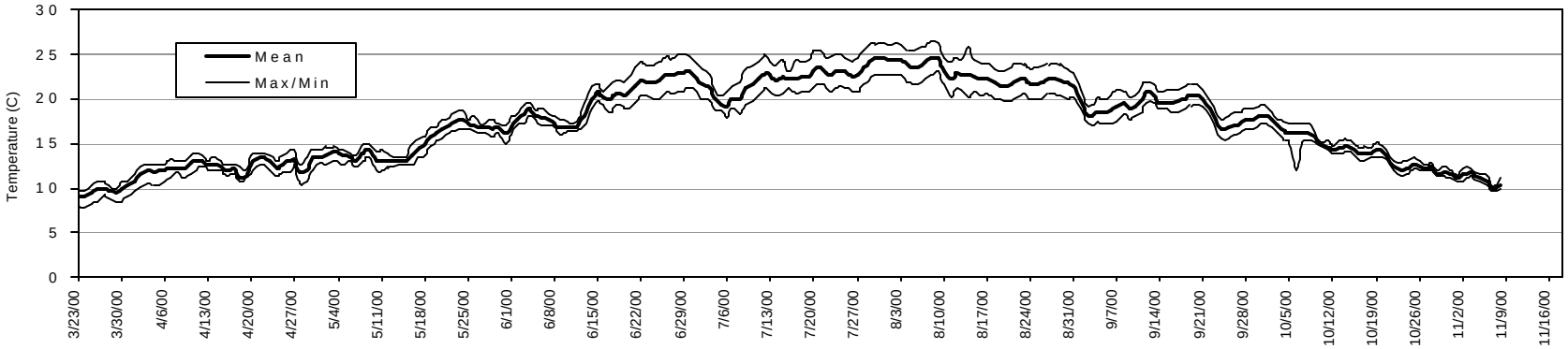
Klamath River observed hourly water temperature at Walker Road Bridge (RM 156)



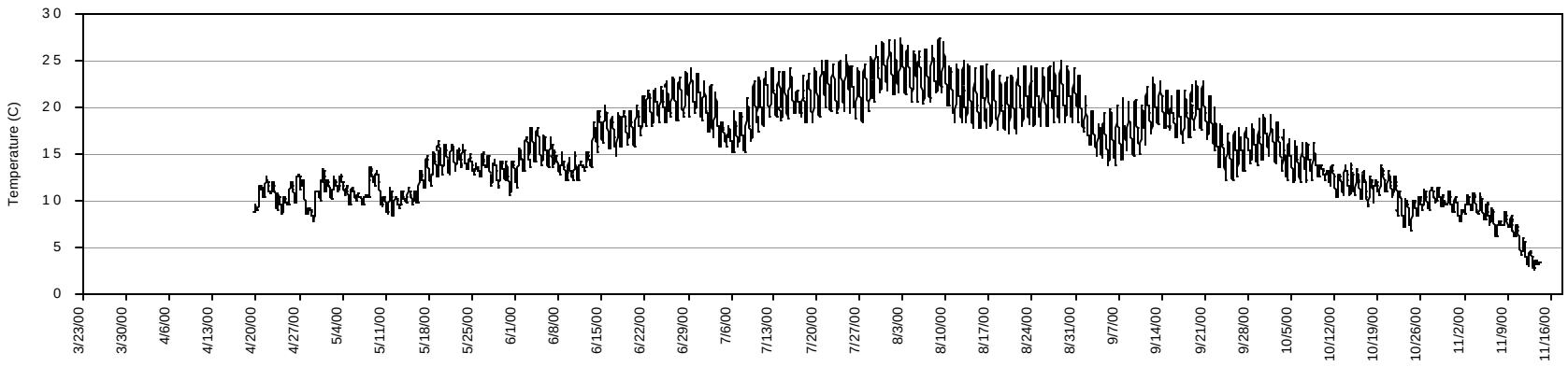
Klamath River observed daily mean, maximum, and minimum water temperature at Walker Road Bridge (RM 156.0)



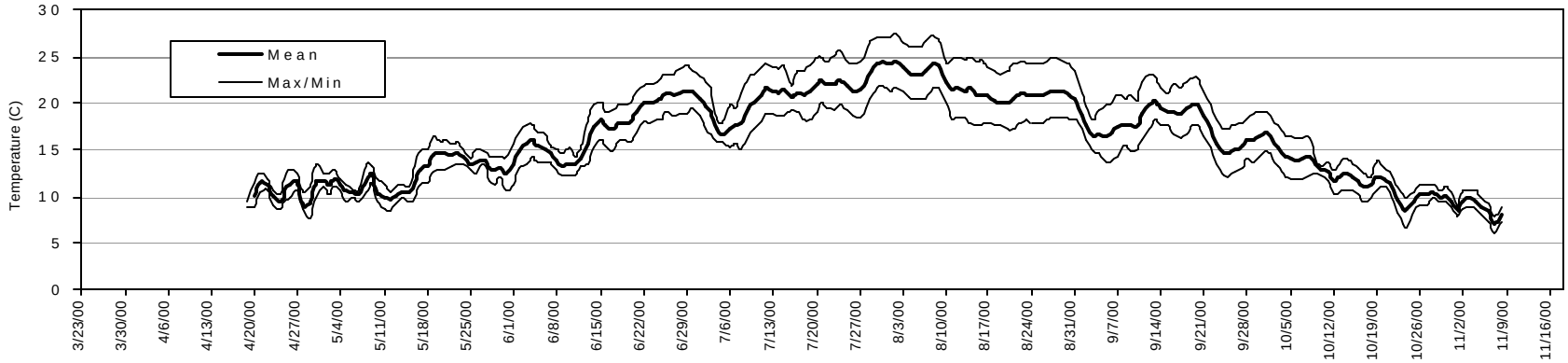
Klamath River observed hourly water temperature above Scott River (RM 143.5)



Klamath River observed daily mean, maximum, and minimum water temperature above Scott River (RM 143.5)



Scott River observed hourly water temperature, Scott River (RM 1)



Scott River observed daily mean, maximum, and minimum water temperature, Scott River (RM 1)

L TRACE ELEMENTS AND METALS DATA AND AQUATIC LIFE CRITERIA

Table L-1 Trace Elements and metals concentrations at screening locations: May 23, 2000

Parameter	KR @ Link Dam (mg/l)	FAL Criteria (mg/l)	KSD @ Hwy 97 (mg/l)	FAL Criteria (mg/l)	KR @ Keno (mg/l)	FAL Criteria (mg/l)	KR @ Iron Gate Dam (mg/l)	FAL Criteria (mg/l)
Aluminum	**0.2**	0.087	**0.53**	0.087	**0.29**	0.087	**0.14**	0.087
Antimony	<0.001	0.006**	<0.001	0.006**	<0.001	0.006**	<0.001	0.006**
Arsenic	0.0023	0.150	0.017	0.150	0.007	0.150	0.0031	0.150
Barium	0.0063	-	0.018	-	0.0096	-	0.0069	-
Cadmium*	<0.0005	0.001	<0.0005	0.0044	<0.0005	0.0024	<0.0005	0.0013
Calcium	7.8	-	43	-	20	-	11	-
Chromium*	<0.001	0.033	0.0015	0.16	<0.001	0.08	0.0014	0.044
Copper*	0.0011	0.0038	0.0033	0.02	0.0019	0.01	0.0026	0.005
Iron	0.21	1.0	0.51	1.0	0.31	1.0	0.16	1.0
Lead*	**<0.001**	0.00084	<0.001	0.007	0.002	0.003	**0.0014**	0.001
Magnesium	4.2	-	35	-	14	-	6.4	-
Mercury	**0.00013**	0.000012	**0.000013**	0.000012	**0.00017**	0.000012	0.000005	0.000012
Nickel*	0.0021	0.022	0.0054	0.113	0.0026	0.056	0.0034	0.031
Selenium	<0.001	0.005	<0.001	0.005	<0.001	0.005	<0.001	0.005
Silver*	**<0.001**	0.0006	<0.001	0.017	<0.001	0.0041	<0.001	0.0011
Thallium	<0.001	0.002	<0.001	0.002	<0.001	0.002	<0.001	0.002
Zinc*	<0.01	0.05	<0.01	0.25	<0.01	0.13	<0.01	0.068
Hardness	37	-	250	-	110	-	54	-

FAL Criteria – Freshwater Aquatic Life Criteria

Values in **BOLD** exceed FAL Criteria

* FAL criteria base on hardness (see: State of California, Regional Water Quality Control Board, Central Valley Region. 1998. *A Compilation of Water Quality Goals*. March)

Table L-2 Trace Elements and metals concentrations at screening locations: June 20, 2000

Parameter	KR @ Link Dam (mg/l)	FAL Criteria (mg/l)	KSD @ Hwy 97 (mg/l)	FAL Criteria (mg/l)	KR @ Keno (mg/l)	FAL Criteria (mg/l)	KR @ Iron Gate Dam (mg/l)	FAL Criteria (mg/l)
Aluminum	**0.20**	0.087	**0.17**	0.087	**0.14**	0.087	**0.10**	0.087
Antimony	<0.001	0.006**	<0.001	0.006**	<0.001	0.006**	<0.001	0.006**
Arsenic	0.0039	0.150	0.018	0.150	0.0059	0.150	0.005	0.150
Barium	0.0051	-	0.022	-	0.0066	-	0.0081	-
Cadmium*	<0.0005	0.00098	<0.0005	0.0036	<0.0005	0.0013	<0.0005	0.0018
Calcium	7.2	-	36	-	11	-	15	-
Chromium*	<0.001	0.03	0.0012	0.13	<0.001	0.043	0.0011	0.06
Copper*	0.002	0.0036	0.0031	0.016	0.0026	0.005	0.0033	0.007
Iron	0.31	1.0	0.65	1.0	0.24	1.0	0.1	1.0
Lead*	**0.0035**	0.0008	<0.001	0.005	<0.001	0.001	0.0012	0.002
Magnesium	3.9	-	25	-	6.0	-	9.5	-
Mercury	0.000012	0.000012	**0.00040**	0.000012	**0.00025**	0.000012	**0.000016**	0.000012
Nickel*	0.0032	0.021	0.0047	0.090	0.0029	0.030	0.0018	0.042
Selenium	<0.001	0.005	<0.001	0.005	<0.001	0.005	<0.001	0.005
Silver*	**<0.001**	0.0005	<0.001	0.01	<0.001	0.001	<0.001	0.0021
Thallium	<0.001	0.002	<0.001	0.002	<0.001	0.002	<0.001	0.002
Zinc*	<0.01	0.047	<0.01	0.200	<0.01	0.067	<0.01	0.095
Hardness	34	-	190	-	52	-	77	-

FAL Criteria – Freshwater Aquatic Life Criteria

Values in **BOLD** exceed FAL Criteria

* FAL criteria base on hardness (see: State of California, Regional Water Quality Control Board, Central Valley Region. 1998. *A Compilation of Water Quality Goals*. March)

Table L-3 Trace Elements and metals concentrations at screening locations: July 25, 2000

Parameter	KR @ Link Dam (mg/l)	FAL Criteria (mg/l)	KSD @ Hwy 97 (mg/l)	FAL Criteria (mg/l)	KR @ Keno (mg/l)	FAL Criteria (mg/l)	KR @ Iron Gate Dam (mg/l)	FAL Criteria (mg/l)
Aluminum	**0.21**	0.087	**0.30**	0.087	0.029	0.087	0.074	0.087
Antimony	0.0019	0.006*	<0.001	0.006*	<0.001	0.006*	<0.001	0.006*
Arsenic	0.0074	0.150	0.015	0.150	0.0093	0.150	0.0065	0.150
Cadmium*	<0.0005	0.00092	<0.0005	0.0021	<0.0005	0.0015	<0.0005	0.0015
Calcium	6.6	-	18	-	12	-	12	-
Chromium*	<0.001	0.028	<0.001	0.068	<0.001	0.05	<0.001	0.049
Copper*	0.0014	0.0032	0.0025	0.0082	0.0011	0.006	0.0010	0.006
Iron	0.29	1.0	0.65	1.0	0.11	1.0	0.049	1.0
Lead*	**<0.001**	0.0007	<0.001	0.002	<0.001	0.0015	<0.001	0.0014
Magnesium	3.4	-	11	-	7.6	-	7.2	-
Mercury	0.0000085	0.000012	0.0000067	0.000012	**0.000017**	0.000012	<0.000005	0.000012
Nickel*	<0.001	0.019	0.0028	0.048	0.0015	0.034	<0.001	0.034
Selenium	<0.001	0.005	<0.001	0.005	<0.001	0.005	0.0013	0.005
Silver*	**<0.001**	0.00043	<0.001	0.0029	<0.001	0.0014	<0.001	0.0014
Thallium	<0.001	0.002	<0.001	0.002	<0.001	0.002	<0.001	0.002
Zinc*	0.0038	0.042	0.0030	0.11	0.0080	0.077	0.0037	0.076
Hardness	30	-	90	-	61	-	60	-

FAL Criteria – Freshwater Aquatic Life Criteria

Values in **BOLD** exceed FAL Criteria

* FAL criteria base on hardness (see: State of California, Regional Water Quality Control Board, Central Valley Region. 1998. *A Compilation of Water Quality Goals*. March)

Table L-4 Trace Elements and metals concentrations at screening locations: September 26, 2000

Parameter	KR @ Link Dam (mg/l)	FAL Criteria (mg/l)	KSD @ Hwy 97 (mg/l)	FAL Criteria (mg/l)	KR @ Keno (mg/l)	FAL Criteria (mg/l)	KR @ Iron Gate Dam (mg/l)	FAL Criteria (mg/l)
Aluminum	**0.67**	0.087	**0.22**	0.087	**3.0**	0.087	0.052	0.087
Antimony	<0.001	0.006*	<0.001	0.006*	0.0018	0.006*	<0.001	0.006*
Arsenic	0.0071	0.150	0.013	0.150	0.0052	0.150	0.0058	0.150
Cadmium*	<0.0005	0.0011	<0.0005	0.0032	<0.0005	0.0019	<0.0005	0.0014
Calcium	8.5	-	32	-	17	-	12	-
Chromium*	0.0013	0.035	0.0018	0.11	0.0031	0.063	0.0014	0.047
Copper*	0.0015	0.004	0.0014	0.013	0.0024	0.007	<0.0003	0.005
Iron	<0.02	1.0	0.45	1.0	1.7	1.0	0.091	1.0
Lead*	<0.001	0.0009	<0.001	0.004	<0.001	0.002	<0.001	0.0013
Magnesium	4.5	-	19	-	9.8	-	6.8	-
Mercury	0.000011	0.000012	0.000012	0.000012	0.000010	0.000012	**0.000015**	0.000012
Nickel*	<0.001	0.024	0.0022	0.077	0.004	0.044	<0.001	0.032
Selenium	<0.001	0.005	<0.001	0.005	<0.001	0.005	<0.001	0.005
Silver*	**<0.001**	0.00071	<0.001	0.0077	<0.001	0.0025	<0.001	0.0013
Thallium	<0.001	0.002	<0.001	0.002	<0.001	0.002	<0.001	0.002
Zinc*	0.0024	0.054	0.0018	0.17	0.0054	0.098	<0.001	0.074
Hardness	40	-	160	-	83	-	58	-

FAL Criteria – Freshwater Aquatic Life Criteria

Values in **BOLD** exceed FAL Criteria

* FAL criteria base on hardness (see: State of California, Regional Water Quality Control Board, Central Valley Region. 1998. *A Compilation of Water Quality Goals*. March)

M BENTHIC ALGAE DATA

Benthic, or attached, algae data include two distinct types of information based on field methods used to determine algal growth rates. Both artificial substrate in the form of unglazed ceramic tiles and glass slides deployed in floating trays (floating periphyton sampler) were used. The ceramic tiles were attached to cinder blocks and placed on the streambed. Because of the high potential for grazing, floating periphyton samplers were also employed. The conditions of the ceramic tiles were likewise monitored and descriptions of conditions provided to augment the findings of the floating samplers

At each site three cinder blocks with two ceramic tiles each and three floating periphyton samplers with 8 slides each were deployed for two separate four week study periods in June and August. The two study sites included one above Cottonwood Creek and one below Iron Gate Dam.

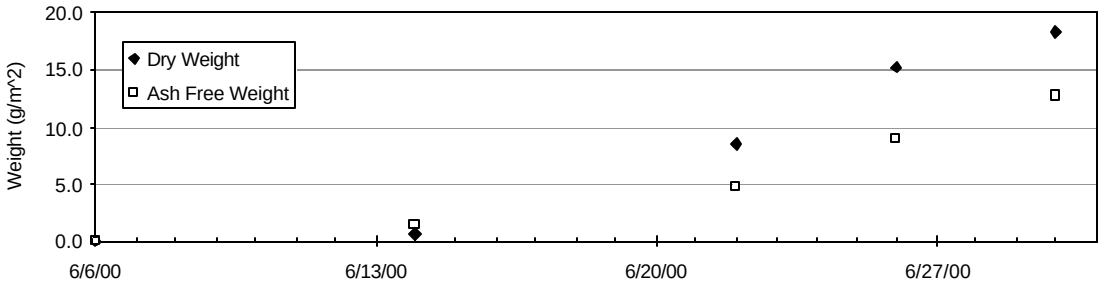
The slides from the floating samplers were collected at periods ranging from 3 days to 8 days and sent to Basic Laboratory in Redding, California for chlorophyll a, dry weight, and ash free weight analysis. The information for each study period at each site is presented in Table M-1 and M-2, and graphically in Figure M-1. Field note summaries associated with both the floating samplers and ceramic tiles are provided in the following sections.

Table M-1 Results for chlorophyll a, dry weight, and ash-free weight from floating periphyton sampler slides: June 2000

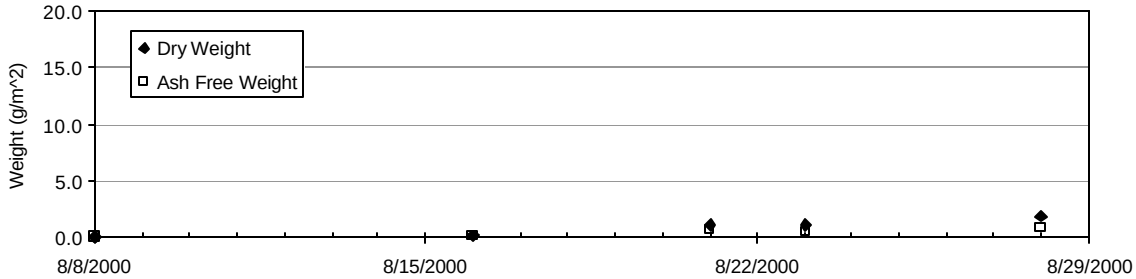
Date Sampled	Location	Chlorophyll A (mg/m^3)	Dry Weight (g/m^2)	Ash-Free Weight (g/m^2)
6/14/2000	KR @ Cottonwood Creek	0.6	0.9	0.5
6/14/2000	KR @ Cottonwood Creek (duplicate)	-	0.6	3.5
6/14/2000	KR @ Cottonwood Creek (triplicate)	-	0.4	0.2
6/22/2000	KR @ Cottonwood Creek	237.0	5.9	3.3
6/22/2000	KR @ Cottonwood Creek (duplicate)	-	9.8	5.6
6/22/2000	KR @ Cottonwood Creek (triplicate)	-	9.7	5.7
6/26/2000	KR @ Cottonwood Creek	135.0	16.4	9.3
6/26/2000	KR @ Cottonwood Creek (duplicate)	-	14.8	8.7
6/26/2000	KR @ Cottonwood Creek (triplicate)	-	14.2	8.9
6/30/2000	KR @ Cottonwood Creek	53.8	28.4	19.6
6/30/2000	KR @ Cottonwood Creek (duplicate)	-	17.9	12.2
6/30/2000	KR @ Cottonwood Creek (triplicate)	-	8.8	6.2
6/14/2000	KR below Iron Gate Dam	1.2	5.2	3.0
6/14/2000	KR below Iron Gate Dam (duplicate)	-	2.2	1.3
6/14/2000	KR below Iron Gate Dam (triplicate)	-	4.1	2.7
6/22/2000	KR below Iron Gate Dam	39.2	18.5	7.9
6/22/2000	KR below Iron Gate Dam (duplicate)	-	25.9	13.7
6/22/2000	KR below Iron Gate Dam (triplicate)	-	42.0	22.9
6/26/2000	KR below Iron Gate Dam	26.3	14.9	7.3
6/26/2000	KR below Iron Gate Dam (duplicate)	-	5.5	2.7
6/26/2000	KR below Iron Gate Dam (triplicate)	-	34.1	18.3
6/30/2000	KR below Iron Gate Dam	32.0	9.1	6.6
6/30/2000	KR below Iron Gate Dam (duplicate)		11.7	8.2
6/30/2000	KR below Iron Gate Dam (triplicate)		11.1	8.0

Table M-2 Results for chlorophyll a, dry weight, and ash-free weight from floating periphyton sampler slides: August 2000

Date Sampled	Location	Chlorophyll A (mg/m^3)	Dry Weight (g/m^2)	Ash-Free Weight (g/m^2)
8/16/2000	KR @ Cottonwood Creek	1.4	0.2	0.1
8/16/2000	KR @ Cottonwood Creek (duplicate)	-	0.0	0.0
8/16/2000	KR @ Cottonwood Creek (triplicate)	-	0.2	0.2
8/21/2000	KR @ Cottonwood Creek	8.2	1.2	0.7
8/21/2000	KR @ Cottonwood Creek (duplicate)	-	0.4	0.2
8/21/2000	KR @ Cottonwood Creek (triplicate)	-	1.8	1.0
8/23/2000	KR @ Cottonwood Creek	43.4	0.7	0.2
8/23/2000	KR @ Cottonwood Creek (duplicate)	-	1.2	0.5
8/23/2000	KR @ Cottonwood Creek (triplicate)	-	1.3	0.7
8/28/2000	KR @ Cottonwood Creek	14.2	1.2	0.6
8/28/2000	KR @ Cottonwood Creek (duplicate)	-	1.5	0.2
8/28/2000	KR @ Cottonwood Creek (triplicate)	-	3.2	1.6
8/16/2000	KR below Iron Gate Dam	4.6	0.5	0.3
8/16/2000	KR below Iron Gate Dam (duplicate)	-	0.3	0.2
8/16/2000	KR below Iron Gate Dam (triplicate)	-	0.3	0.3
8/21/2000	KR below Iron Gate Dam	33.8	1.3	0.2
8/21/2000	KR below Iron Gate Dam (duplicate)	-	5.5	2.2
8/21/2000	KR below Iron Gate Dam (triplicate)	-	2.8	1.5
8/23/2000	KR below Iron Gate Dam	32.8	9.2	2.6
8/23/2000	KR below Iron Gate Dam (duplicate)	-	10.9	4.2
8/23/2000	KR below Iron Gate Dam (triplicate)	-	16.5	4.2
8/28/2000	KR below Iron Gate Dam	101.0	12.5	5.3
8/28/2000	KR below Iron Gate Dam (duplicate)	-	10.6	3.6
8/28/2000	KR below Iron Gate Dam (triplicate)	-	14.8	5.8



(a)



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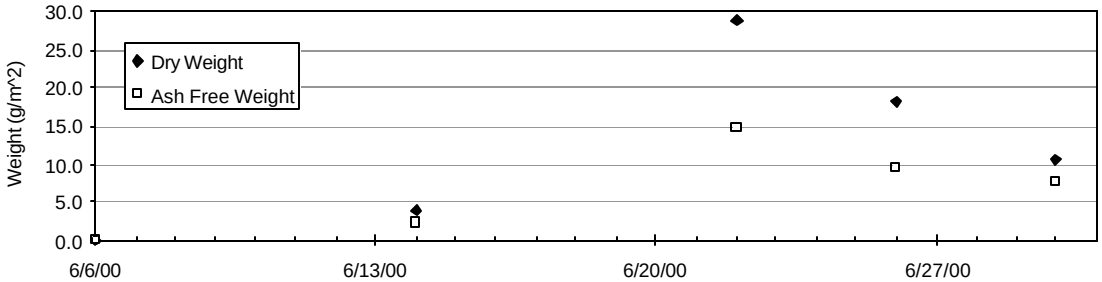
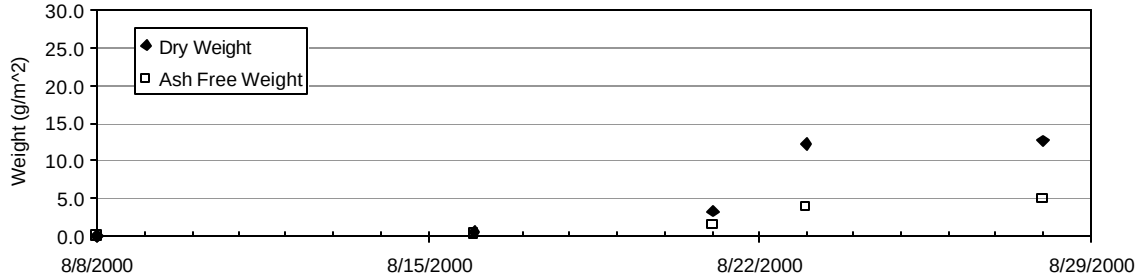




(c)
(d)

Figure M-1 Periphyton sample dry weight and ash free weight for (a) Cottonwood Creek: June, (b) Cottonwood Creek site: August, (c) Iron Gate Dam site: June, and (d) Iron Gate Dam site: August

M.1.1 Floating Periphyton Sampler: field notes summary

Cottonwood Creek Site

June 6, 2000: Deployment

June 14, 2000

Heavy macrophyte buildup on the samplers (from upstream reaches). Heavy load reduces light penetration and submerges sampler 3 to 4 inches. Only minimal growth noted on slides. Install t-post (remove weights) upstream of sampler to diminish impact of detached macrophyte buildup. Visit sampler more frequently to remove any buildup of material

June 22, 2000

Little or no macrophyte buildup (t-post successful in capturing much of the floating material). "Good" growth noted on slides. Two slides missing on one sampler. (Certain slides tended to move arrhythmically in the tray in response to local velocity field. It is postulated that these slides broke and fell out of the sampler). Minor grazing notes on select slides. One sampler had 12 snails. No other grazers noted. Snails removed.

June 26, 2000

Little or no macrophyte buildup. No grazing. Good growth.

June 29, 2000

Results varied from good to poor growth. Samplers are now accumulating appreciable growth (possibly affecting water flow and light to slide tray). Some snails present on one sampler – no grazing noted on slides. One sampler covered with debris and brown growth on slides.

Iron Gate Dam Site Deployment

June 6, 2000: Deployment

June 14, 2000

Minimal macrophyte buildup on samplers. Samplers sitting on surface. "good" growth notable on select slides. Install t-post to secure samplers

June 22, 2000

Most slides showed considerable growth. However, one tray had minimal growth and what was growing was brown in color. No grazing noted. Macrophyte buildup was minimal. There were chew marks on one of the sampler floats (possibly beaver, muskrat, or otter)

June 26, 2000

Wide range of conditions among three samplers. One experienced significant growth, one modest growth, and one poor growth. By visual inspection (and photographs) the sampler that exhibited poor growth appeared to have less algae than the previous week sample.

June 29, 2000
Experienced macrophyte buildup on one sampler. Conditions appear to have degraded. Algae dieback on many slides. Growth is arrested. Six snails found on one sampler. No grazing noted.

Cottonwood Creek Site
August 8, 2000: Deployment

August 16, 2000
No macrophyte buildup noted, although sampler shield eddy attracted several smaller types of algae (e.g., duckweed). Minimal growth noted.

August 21, 2000
No macrophyte buildup noted. Good growth noted. No snails, no sign of grazing observed.

August 23, 2000
No macrophyte buildup noted. Change in algal growth (brown), not as significant as during last visit. No snails, no sign of grazing observed.

August 28, 2000
Some macrophyte buildup on samplers. Growth appears to be slowing (brown). A few snails noted on one sampler, no clear evidence of grazing.

Iron Gate Dam Site Deployment
August 8, 2000: Deployment

August 16, 2000
No macrophyte buildup noted. Samplers completely covered with black fly larvae (1000's) and small colonies of caddis flies (?) All slides appear to be completely grazed.

August 21, 2000
No macrophyte buildup noted. Only remnant caddis fly populations. Old cases discarded. Effect of invertebrates still affecting growth, but certain slides show good growth.

August 23, 2000
No macrophyte buildup noted. Fewer invertebrates (<100 per tray). Good growth (brown) noted on all samplers.

August 28, 2000
No macrophyte buildup noted. Very few invertebrates. Significant growth continues (brown and some green).

M.1.2 Artificial Substrate: field notes summary

Cottonwood Creek Site

June 6, 2000: Deployment

Three cinder blocks with cleaned tiles were deployed in 2 to 3 feet of water (velocity 1-3 fps) approximately 25 feet from the left bank above the fishing weir. There was no potential shading from riparian vegetation (woody or herbaceous) at this location. The substrate consists predominantly of medium to large cobbles. Significant amounts of attached algae were already present in the river. Existing attached algae was removed and/or trimmed so as not to cover or abrade the artificial substrate.

June 14, 2000

The tile deployed under floating periphyton sampler moved two feet upstream due to shading from large amounts of algae that become tangled on the t-post to which the floating sampler is attached. Snails counts range from 14 to 70 per tile. No other benthic fauna present. Tiles are grazed clean, although they are "slick" to the touch and there is some staining (brown). No interference from attached algae external to the tile (those growing on the bed versus the tile).

June 22, 2000

Snails counts range from an estimate of 35 to over 75 per tile. Two limpets found on one artificial substrate. No other benthic fauna noted. Tiles are grazed clean, although they are "slick" to the touch and there is some staining (brown). One tile was affected by external attached algae washing over the surface. No interference from attached algae external to the tile (those growing on the bed versus the tile).

June 26, 2000

Snails counts for all tiles range are in excess of 75. No other grazers noted. Tiles are grazed clean, although they are "slick" to the touch.

June 29, 2000

Snails counts for all tiles range are in excess of 75. A few limpets noted. Tiles are grazed clean, although they are "slick" to the touch and there is some staining (brown).

Iron Gate Dam Site Deployment

June 6, 2000: Deployment

Three cinder blocks with cleaned tiles were deployed in 2 to 3 feet of water (velocity 1-3 fps) approximately 6 feet from the left bank below the fish hatchery raceways. There was minor potential shading from riparian vegetation (some trees present and herbaceous (cattail/bulrush) was present) at this location. The substrate consists predominantly of large cobbles. Significant amounts of attached algae were already present in the river. Existing attached algae was removed and/or trimmed so as not to cover or abrade the artificial substrate.

June 14, 2000

Snails counts range from 2 to 3 per tile (it is noted that they are "large" (>5 mm) – comparison presumed to be with those found at Cottonwood Creek (typically <5 mm)).

Benthic fauna include mayfly larvae and black fly larvae. Tiles are only modestly grazed. Growth on the substrate noted as "good." No interference from attached algae external to the tile (those growing on the bed versus the tile).

June 22, 2000
Snails counts range from an estimate of 6 to over 20 per tile. It is noted that there appear to be at least two separate species (1-11 mm). Up to 40 limpets (1-7 mm) found on artificial substrate. With flow change, some tiles are in faster moving water. Mayfly larvae present, with an apparent preference for that substrate in the slower water. Some tiles appear to be heavily grazed by mayfly larvae. Noted that there may be more than one species of algae colonizing substrate ("brown" and "green"). Even with grazing, growth continues to be described as "good." No interference from attached algae external to the tile (those growing on the bed versus the tile).

June 26, 2000
Snails counts range from an estimate of 2 to over 12 per tile. Up to 40 limpets found on artificial substrate. Small mayflies present. Noted that there may be more than one species of algae colonizing substrate ("brown" and "green"). Grazing has increased to the point where certain tiles are completely grazed, others partially grazed.

June 29, 2000
Those tiles in shallower water experienced greater limpet counts than snails. Limpets ranged were on the order of 20-30, while snails numbered less than 10. On the substrate in deeper water there were roughly 75 snails and limpets per tile in roughly equal proportion. The shallow water substrates had two observable type of algae (brown and green) and grazing ranged from almost none to moderate. The deeper water substrate was completely grazed clean.

Cottonwood Creek Site
August 8, 2000: Deployment
Tiles were cleaned and replaced in similar location as for June deployment. More attached algae present. Existing attached algae in vicinity was removed and/or trimmed so as not to cover or abrade the artificial substrate. Depths were slightly less and velocities were slower than June deployment.

August 16, 2000
Snails counts range from an estimate of 20 to 45 per tile. No other benthic fauna noted. Tiles are grazed clean. One cinder block was cracked and a small tile corner had broken off, but the artificial substrate was still useful. No interference from attached algae external to the tile (those growing on the bed versus the tile) is noted.

August 21, 2000
Snails counts range 25 to 35 per tile. No other benthic fauna noted. Tiles are heavily grazed, but there is greenish brown growth (slick to the touch) on some tiles. No interference from attached algae external to the tile (those growing on the bed versus the tile) is noted.

August 23, 2000
Snails counts range 10 to 15 per tile. Noted that fewer snails and limpets were present. No other benthic fauna noted. Tiles are heavily grazed, but there is greenish growth (slick to the touch) noted on some tiles. No interference from attached algae external to the tile is noted.

August 28, 2000
Snails counts range was generally greater than 50 per tile. No limpets were noted. No other benthic fauna noted. Tiles are heavily grazed, but there is greenish growth on some tiles and brownish on others. No interference from attached algae external to the tile is noted.

Iron Gate Dam Site
August 8, 2000: Deployment
Tiles were cleaned and replaced in similar location as for June deployment. More attached algae present. Existing attached algae in vicinity was removed and/or trimmed so as not to cover or abrade the artificial substrate. Depths were slightly less and velocities were slower than June deployment.

August 16, 2000
Snails counts range from an estimate of 5 to 15 per tile. Other benthic fauna included 3 water pennies, a few black fly larvae. Variable growth, including brown "spotting" and a brown/green slime forming on certain tiles. Some grazing present, but generally little growth. Some interference from attached algae external to the tile is noted for one cinder block. Where algae abrade, there is little growth.

August 21, 2000
About 30 snails and from 10-15 limpets, plus several water pennies present. No other benthic fauna noted. Some tiles were moderately grazed with preference to the margins (edges), while others were completely grazed. The mottled brown spotting first seen on 8/12 was present. No interference from attached algae external to the tile is noted.

August 23, 2000
Snails counts range 10 to 15 per tile. Noted that there were fewer snails and limpets. No other benthic fauna noted. Tiles are heavily grazed, but there is greenish growth (slick to the touch) noted on some tiles. No interference from attached algae external to the tile (those growing on the bed versus the tile) is noted.

August 28, 2000
Snails and limpets grazing ranged from modest (grazing the periphery of the tiles) to completely grazing certain substrate clean. Snails ranged in number from 25 to 35. Limpet numbers unreported. No other benthic fauna reported. No interference from attached algae external to the tile (those growing on the bed versus the tile) is noted.

N RESERVOIR WATER QUALITY DATA: GRAB SAMPLES

In addition to the grab samples collected primarily by USBR and supported staff, PacifiCorp collected grab samples in the mainstem reservoirs: JC Boyle, Copco, and Iron Gate. Samples were collected at approximately monthly intervals at two depths in JC Boyle (with the exception of the first sampling period), and at three depths in Copco and Iron Gate Reservoirs. The near surface and near bottom samples in JC Boyle are termed epilimnion and hypolimnion respectively, even though this reservoir experiences weak stratification. The three depths in Copco and Iron Gate Reservoirs are termed epilimnion, metalimnion and hypolimnion, respectively.

The constituents sampled include ammonia, total Kjeldahl nitrogen, nitrate+nitrite, total phosphorous, orthophosphate, and BOD. Chlorophyll a samples were collected, but laboratory performance was unsatisfactory and data should be used with caution. Unlike the larger Klamath River sampling program, there were insufficient few data points (sampling days) to estimate values below the reporting limit or to estimate meaningful statistics. There are only a few dates where nutrient data are below the reporting limit, when plotted in Appendix O, these values are plotted at the reporting limit. During the field sampling events, physical data were collected with a water quality probe (see also *Reservoir Water Quality Data: Physical Profiles.* Tabulated reservoir grab sample data are included below.

Table N-1 JC Boyle Reservoir grab sample data: May – November 2000

Site	Date	Depth (m)	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^-+NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor a (mg/m^3)	T_W (C)	DO (mg/L)	EC (uS/cm)	pH	Redox mV
JCB-E	05/09/00	1.0	0.21	1.0	0.19	0.20	0.24	<3.0	2.67j	13.63	9.88	151	7.93	-
JCB-E	06/06/00	1.0	0.16	1.5	0.64	0.38	0.33	<3.0	20.0	19.34	9.72	251	8.77	-
JCB-E	08/08/00	0.9	0.16	1.0	1.36	0.29	0.28	<3.0	0j	24.35	7.83	154	7.67	-
JCB-E	09/27/00	1.0	0.14	1.4	0.62	0.24	0.20	<3.0	0j	15.50	7.56	261	8.45	-
JCB-E	10/18/00	1.0	0.16	1.1	0.60	0.16	0.09	<3.0	3j	10.58	10.59	157	7.52	-
JCB-E	11/14/00	1.0	0.14	1.2	0.78	0.06	0.07	<3.0	2j	3.87	9.28	156	7.66	-
JCB-M	05/09/00	4.0	0.42	0.7	0.18	0.21	0.21	<3.0	2.00j	13.63	9.83	151	7.98	-
JCB-H	05/09/00	8.0	0.56	0.6	0.21	0.30	0.18	<3.0	1.67j	13.16	9.43	150	7.86	-
JCB-H	06/06/00	7.0	0.21	1.0	0.63	0.22	0.34	<3.0	4.38j	19.15	8.23	259	8.54	-
JCB-H	08/08/00	7.6	0.30	1.7	1.55	0.27	0.23	<3.0	0j	22.83	2.10	154	6.94	-
JCB-H	09/27/00	9.0	0.17	1.4	0.59	0.25	0.21	4.0	2j	15.50	6.69	257	8.35	-
JCB-H	10/18/00	7.0	0.15	1.2	0.63	0.16	0.09	<3.0	0j	10.66	10.04	160	7.61	-
JCB-H	11/14/00	5.0	0.14	0.9	0.79	0.06	0.07	<3.0	2j	3.91	8.90	159	7.64	-

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) No data available

Table N-2 Copco Reservoir grab sample data: May – November 2000

Site	Date	Depth (m)	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^-+NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor a (mg/m^3)	T_W (C)	DO (mg/L)	EC (uS/cm)	pH	Redox mV
COP-E	05/09/00	1.0	0.39	0.7	0.06	0.18	0.16	<3.0	6.14j	14.29	11.52	148	8.55	-
COP-E	06/06/00	1.0	0.10	1.2	0.40	0.36	0.31	<3.0	9.88j	19.24	11.97	245	8.91	-
COP-E	08/08/00	1.0	0.05	0.9	0.47	0.17	0.23	<3.0	11j	23.41	13.08	168	9.05	-
COP-E	09/27/00	1.0	<0.05	2.1	0.25	0.26	0.10	15.0	31j	17.50	7.94	195	8.75	-
COP-E	10/18/00	1.0	0.12	0.7	0.55	0.20	0.14	<3.0	0j	13.56	10.47	201	7.66	-
COP-E	11/14/00	1.0	0.09	0.6	0.57	0.09	0.09	<3.0	0j	8.26	8.50	141	8.45	-
COP-M	05/09/00	12.0	0.73	0.5	0.15	0.17	0.19	<3.0	5.34j	13.28	9.31	147	7.95	-
COP-M	06/06/00	14.0	0.32	0.9	0.42	0.26	0.29	<3.0	0.53j	14.26	5.81	221	7.61	-
COP-M	08/08/00	17.0	0.17	0.5	0.62	0.29	0.29	<3.0	2j	19.95	2.10	172	7.13	-
COP-M	09/27/00	15.0	0.29	1.1	0.34	0.22	0.21	<3.0	1j	16.00	3.42	217	8.18	-
COP-M	10/18/00	15.0	0.11	0.8	0.56	0.17	0.11	<3.0	1j	12.35	10.19	182	7.74	-
COP-M	11/14/00		0.10	0.6	0.59	0.08	0.08	<3.0	0j	7.84	0.07	143	7.90	-
COP-H	05/09/00	25.0	0.51	1.2	0.29	0.55	0.35	<3.0	2.93j	10.16	2.36	162	7.23	24
COP-H	06/06/00	25.0	0.68	1.1	0.97	0.51	0.42	<3.0	<0.01j	11.54	0.48	195	7.14	-
COP-H	08/08/00	28.0	0.99	1.3	1.11	0.65	0.54	<3.0	1j	12.78	0.34	180	6.84	-
COP-H	09/27/00	29.0	1.60	2.6	<0.05	0.78	0.61	11.0	1j	14.70	0.10	210	7.80	-
COP-H	10/18/00	25.0	0.10	0.7	0.56	0.16	0.10	<3.0	1j	11.89	12.27	173	7.90	-
COP-H	11/14/00	26.0	0.08	0.6	0.59	0.08	0.07	<3.0	2j	7.13	4.87	146	7.76	-

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) No data available

Table N-3 Iron Gate Reservoir grab sample data: May – November 2000

Site	Date	Depth (m)	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^-+NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)	Chlor a (mg/m^3)	T_W (C)	DO (mg/L)	EC (uS/cm)	pH	Redox mV
IG-E	05/09/00	1.0	0.07	0.9	0.10	0.13	0.18	<3.0	4.54j	14.26	10.71	147	8.42	-
IG-E	06/06/00	1.0	0.28	0.9	0.28	0.34	0.24	<3.0	9.35j	19.65	11.90	225	8.83	-
IG-E	08/08/00	1.0	<0.05	1.2	<0.05	0.13	0.13	5.0	46	25.25	15.85	162	9.46	-
IG-E	09/27/00	1.0	<0.05	0.8	0.58	0.17	0.15	<3.0	3j	18.40	7.50	176	7.58	-
IG-E	10/18/00	1.0	0.06	0.5	0.53	0.19	0.14	<3.0	2j	14.93	6.46	210	7.50	-
IG-E	11/14/00	1.0	0.12	0.3	0.69	0.12	0.12	<3.0	3j	9.84	6.55	155	7.70	-
IG-M	05/09/00	15.0	0.73	0.8	0.26	0.16	0.19	<3.0	1.07j	11.33	8.40	148	7.61	14
IG-M	06/06/00	13.0	0.07	0.6	0.24	0.15	0.24	<3.0	<0.01j	12.28	7.38	169	7.63	-
IG-M	08/08/00	17.0	0.06	<0.2	0.31	0.11	0.12	<3.0	0j	16.44	2.36	207	7.10	-
IG-M	09/27/00	15.0	0.11	0.7	0.57	0.17	0.16	<3.0	0j	16.67	1.84	4.7	7.31	-
IG-M	10/18/00	25.0	0.11	0.3	0.16	0.24	0.20	<3.0	4j	9.87	2.61	191	7.30	-
IG-M	11/14/00		0.09	0.5	0.66	0.07	0.12	<3.0	0j	9.80	0.09	156	7.61	-
IG-H	05/09/00	30.0	0.13	0.6	0.38	0.23	0.21	<3.0	<0.01j	6.28	7.27	171	7.35	-
IG-H	06/06/00	30.0	0.05	0.5	0.49	0.25	0.29	<3.0	<0.01j	6.43	5.25	172	7.14	-
IG-H	08/08/00	30.0	0.06	<0.2	0.52	0.12	0.12	<3.0	0j	7.07	0.43	157	6.71	-
IG-H	09/27/00	30.0	0.12	0.7	0.38	0.17	0.17	<3.0	1j	7.74	0.33	192	6.89	-
IG-H	10/18/00	30.0	0.21	0.5	0.28	0.21	0.17	<3.0	2j	8.02	1.65	194	7.12	-
IG-H	11/14/00	30.0	0.09	0.6	0.56	0.07	0.12	<3.0	1j	9.16	6.83	150	7.55	-

(<) less than reporting limit
(j) below reporting limit of 40 ug/l
(-) No data available

O RESERVOIR WATER QUALITY DATA: GRAB SAMPLES, GRAPHICAL REPRESENTATION BY SITE

Unlike the large Klamath River sampling program, there were too few data points (sampling days) to estimate values below the reporting limit or to estimate meaningful statistics. There are only a few dates where nutrient data are below the reporting limit, these values are plotted at the reporting limit (denoted with an open symbol).

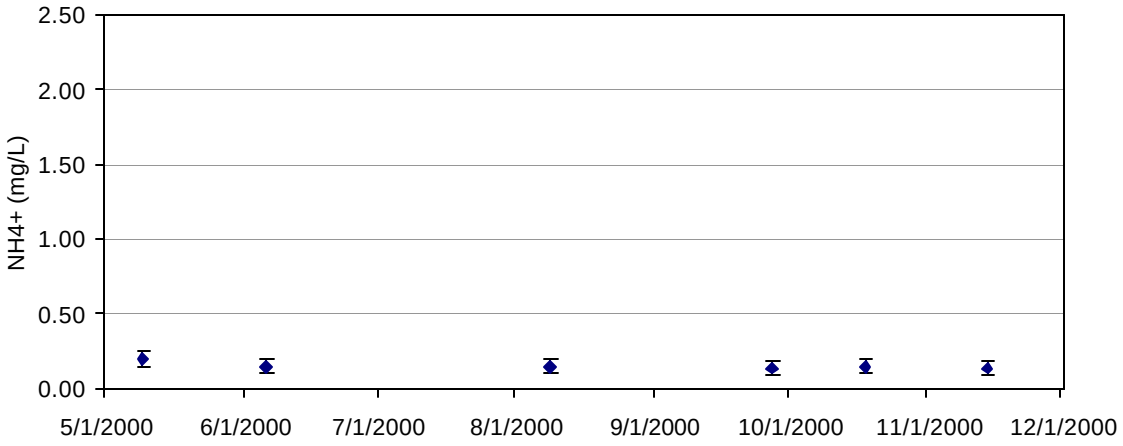


Figure O-1 JC Boyle Reservoir epilimnion, ammonia concentration, May – November 2000

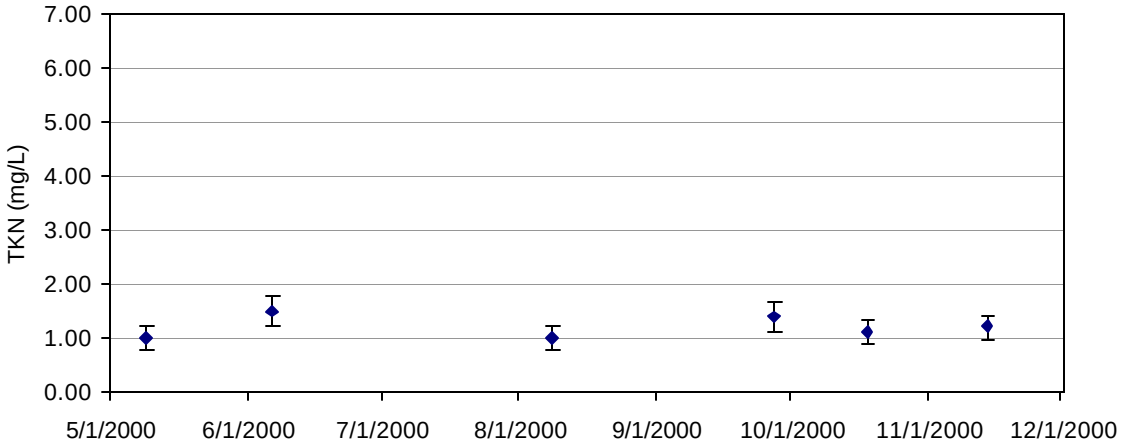


Figure O-2 JC Boyle Reservoir epilimnion, total Kjeldahl nitrogen concentration, May – November 2000

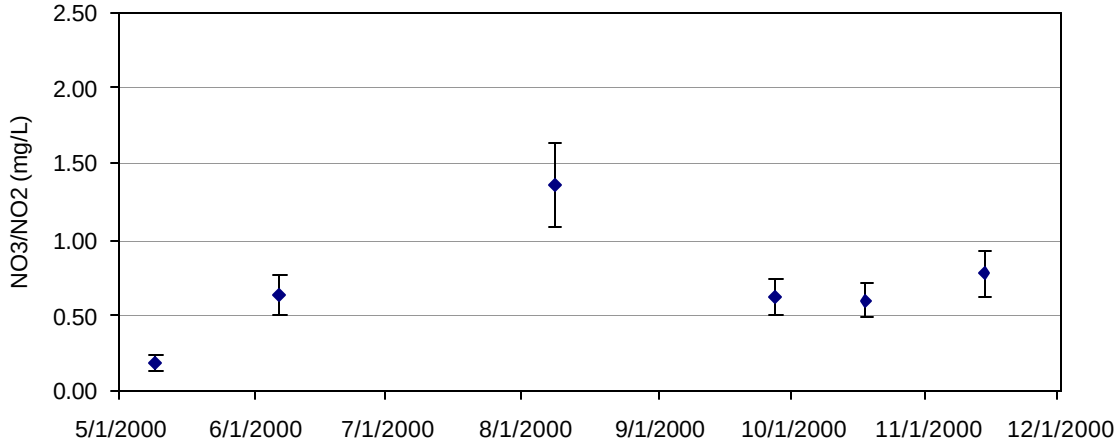


Figure O-3 JC Boyle Reservoir epilimnion, nitrite plus nitrate concentration, May – November 2000

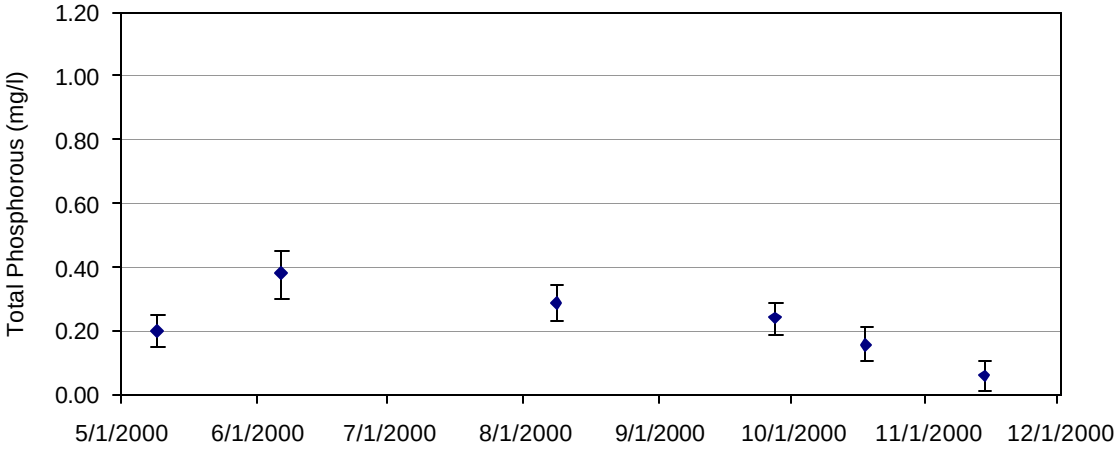


Figure O-4 JC Boyle Reservoir epilimnion, total phosphorous concentration, May – November 2000

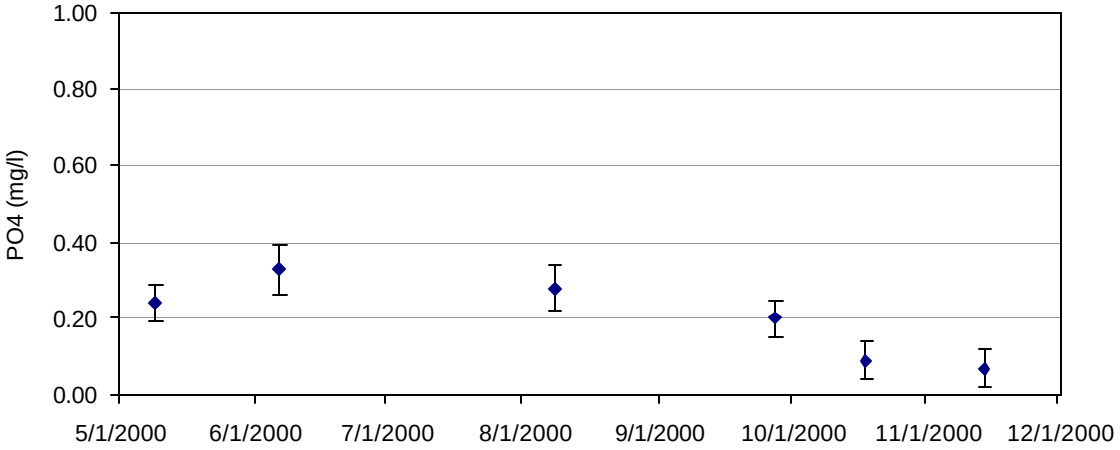


Figure O-5 JC Boyle Reservoir epilimnion, orthophosphate concentration, May – November 2000

[All values at or below the reporting limit of 3.0 mg/l]

Figure O-6 JC Boyle Reservoir epilimnion, BOD concentration, May – November 2000

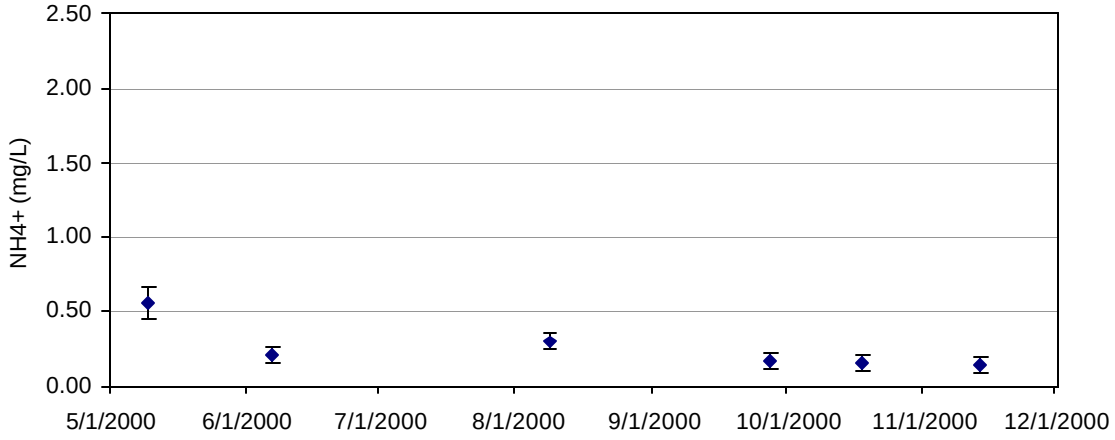


Figure O-7 JC Boyle Reservoir hypolimnion, ammonia concentration, May – November 2000

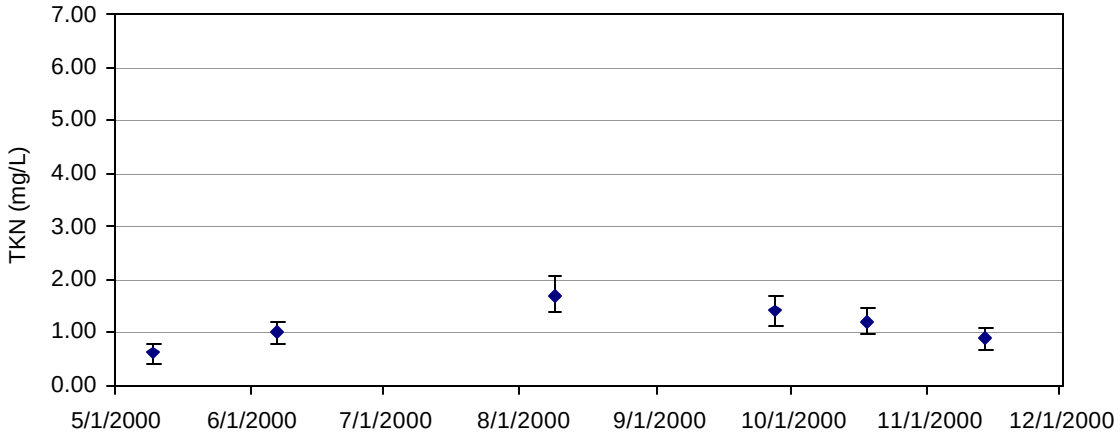


Figure O-8 JC Boyle Reservoir hypolimnion, total Kjeldahl nitrogen concentration, May – November 2000

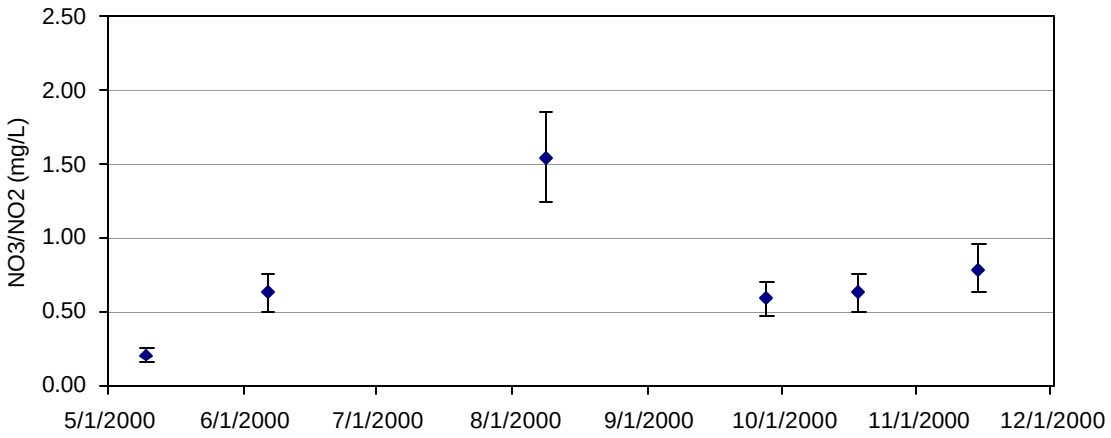


Figure O-9 JC Boyle Reservoir hypolimnion, nitrite plus nitrate concentration, May – November 2000

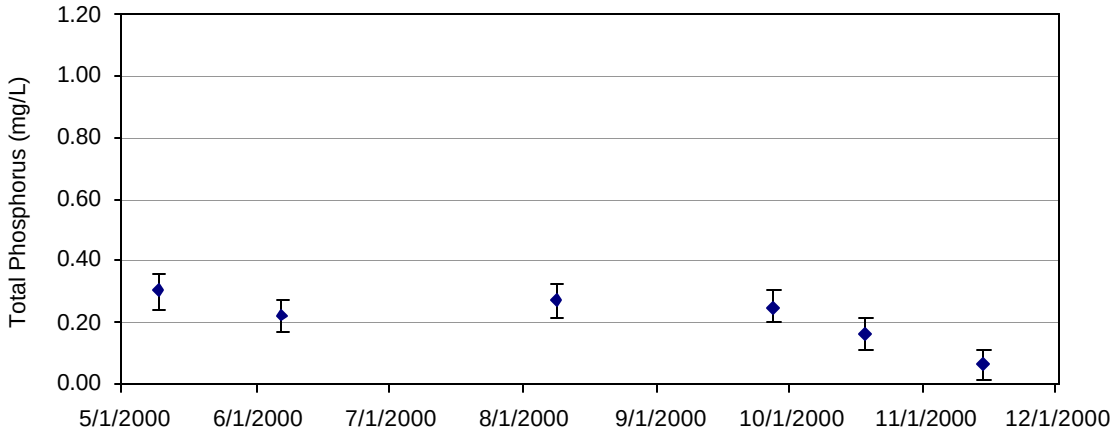


Figure O-10 JC Boyle Reservoir hypolimnion, total phosphorous concentration, May – November 2000

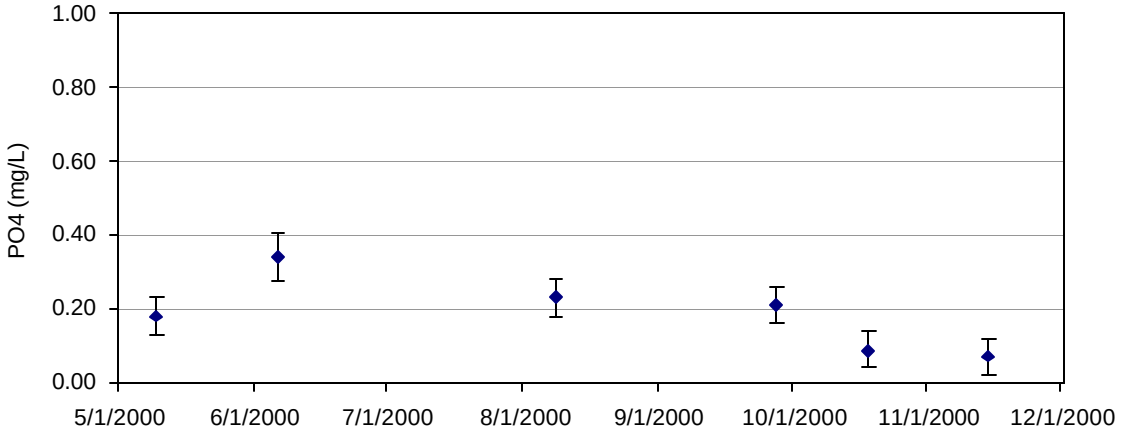


Figure O-11 JC Boyle Reservoir hypolimnion, orthophosphate concentration, May – November 2000

[All values at or below the reporting limit of 3.0 mg/l]

Figure O-12 JC Boyle Reservoir hypolimnion, BOD concentration, May – November 2000

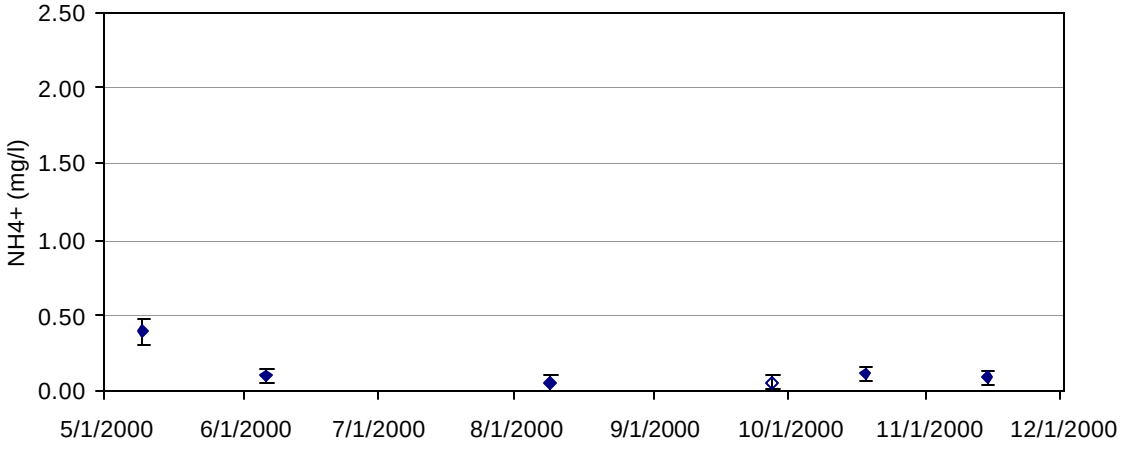


Figure O-13 Copco No. 1 Reservoir epilimnion, ammonia concentration, May – November 2000

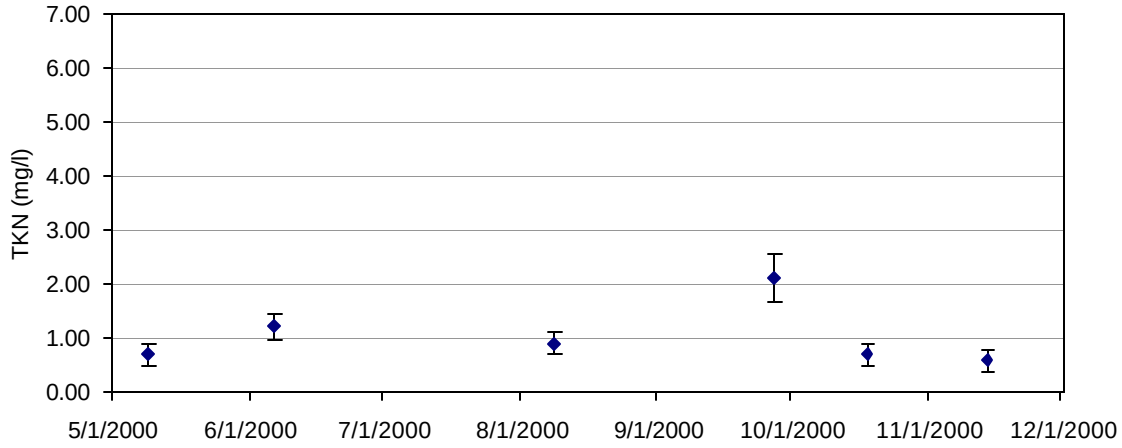


Figure O-14 Copco No. 1 Reservoir epilimnion, total Kjeldahl nitrogen concentration, May – November 2000

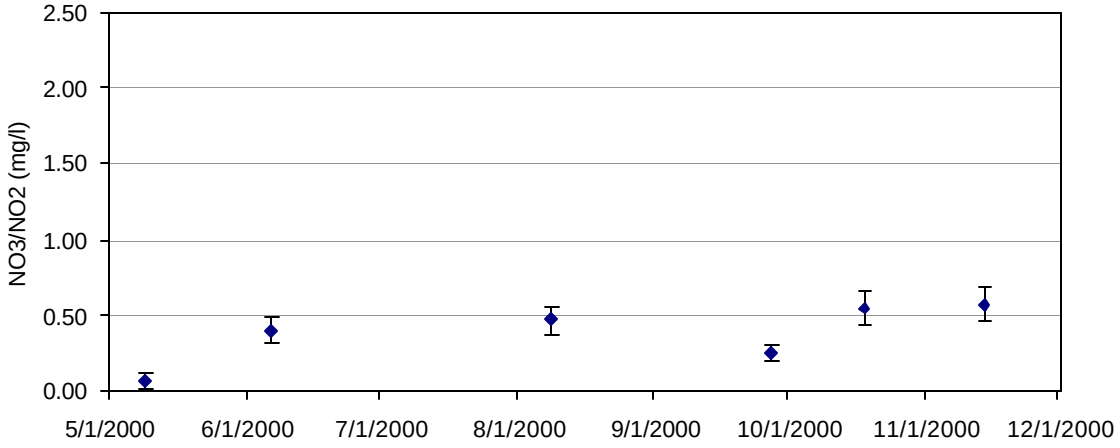


Figure O-15 Copco No. 1 Reservoir epilimnion, nitrite plus nitrate concentration, May – November 2000

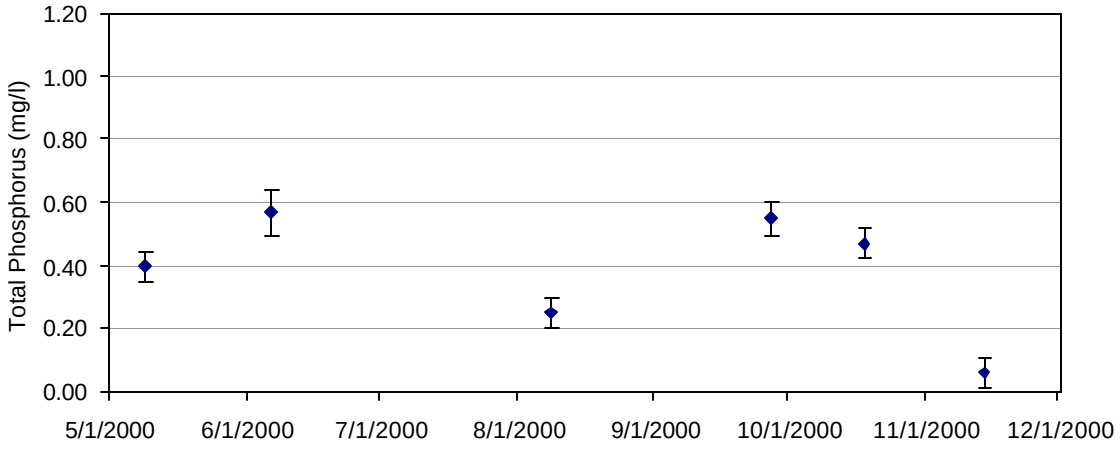


Figure O-16 Copco No. 1 Reservoir epilimnion, total phosphorous concentration, May – November 2000

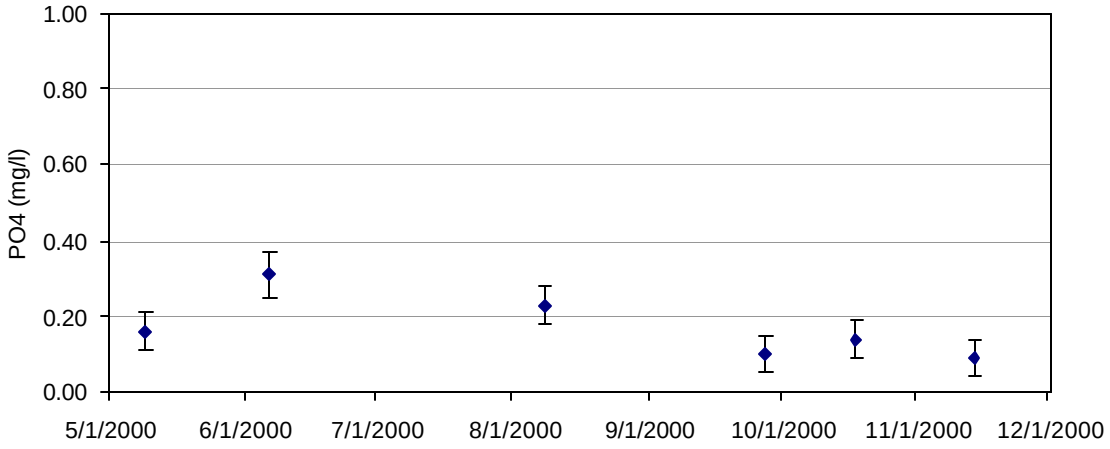


Figure O-17 Copco No. 1 Reservoir epilimnion, orthophosphate concentration, May – November 2000

[All values at or below the reporting limit of 3.0 mg/l]

Figure O-18 Copco No. 1 Reservoir epilimnion, BOD concentration, May – November 2000

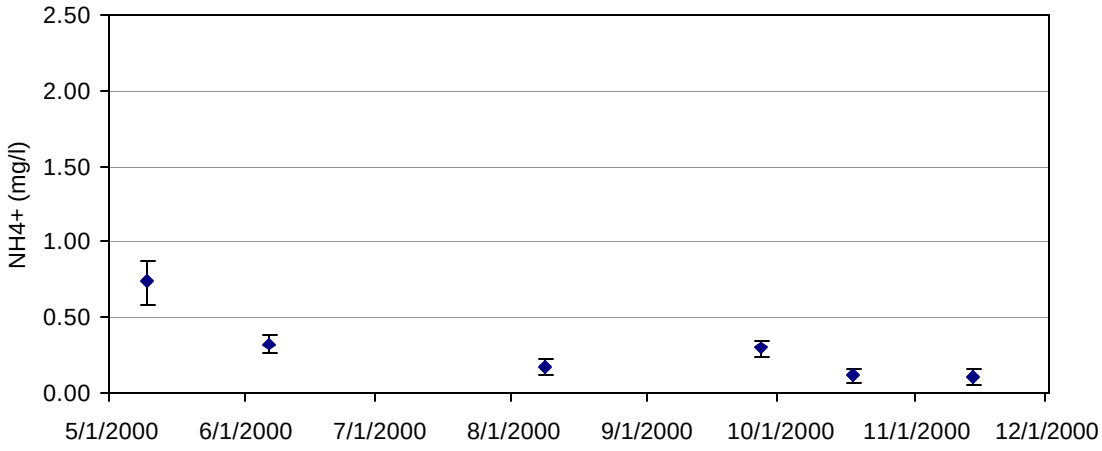


Figure O-19 Copco No. 1 Reservoir metalimnion, ammonia concentration, May – November 2000

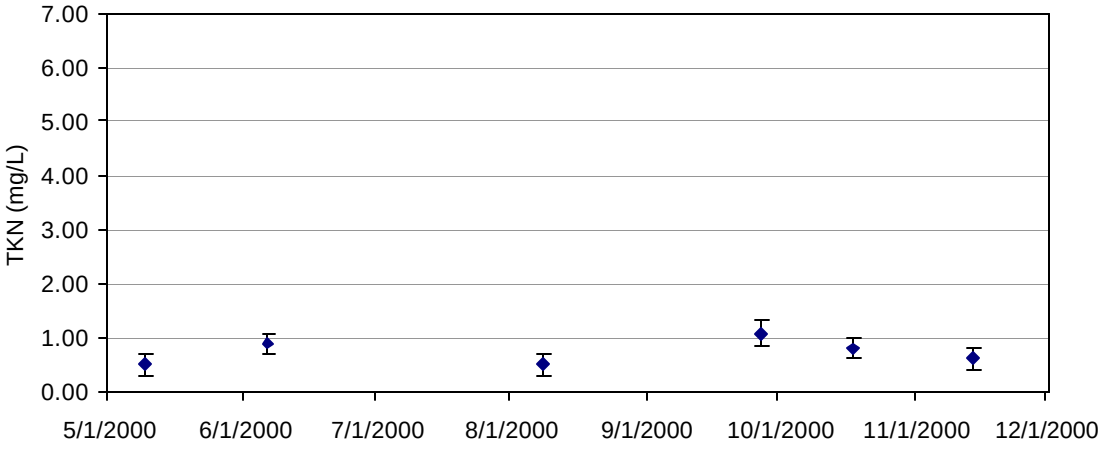


Figure O-20 Copco No. 1 Reservoir metalimnion, total Kjeldahl nitrogen concentration, May – November 2000

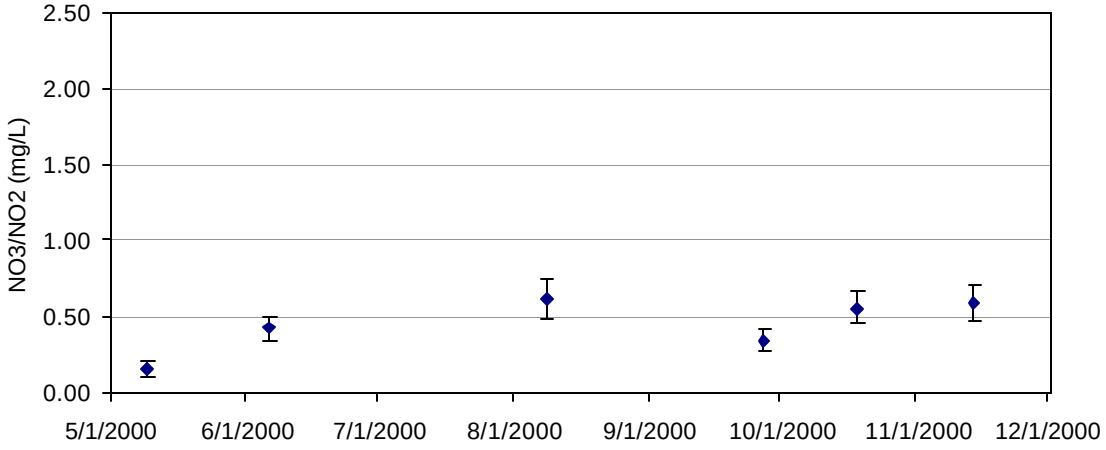


Figure O-21 Copco No. 1 Reservoir metalimnion, nitrite plus nitrate concentration, May – November 2000

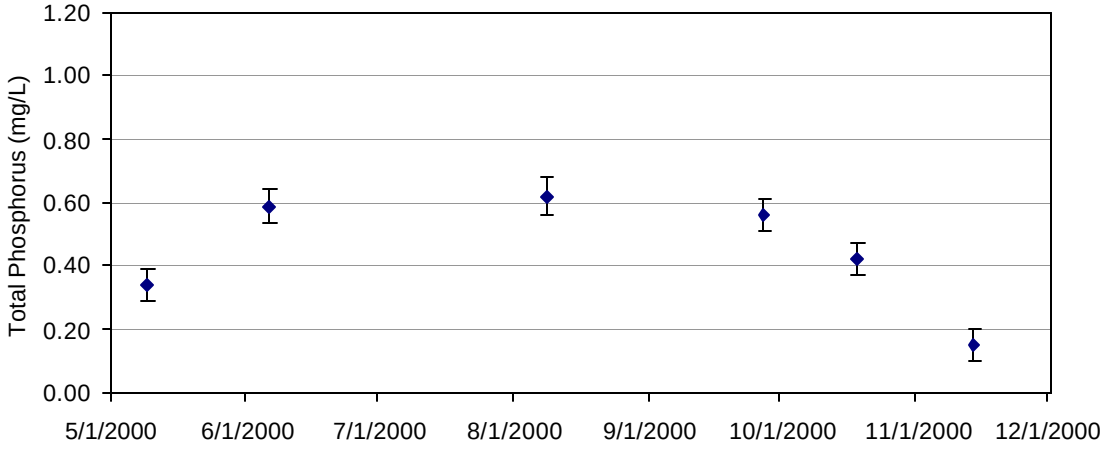


Figure O-22 Copco No. 1 Reservoir metalimnion, total phosphorous concentration, May – November 2000

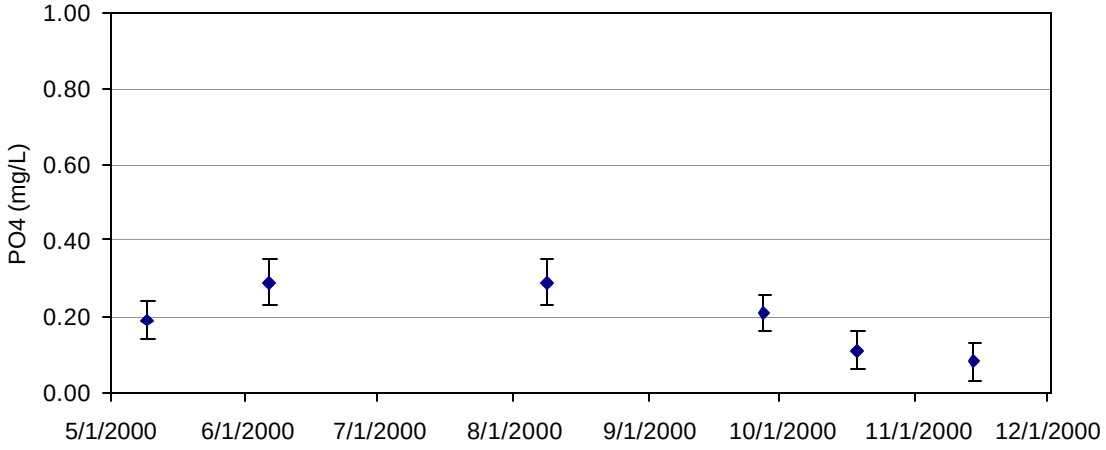


Figure O-23 Copco No. 1 Reservoir metalimnion, orthophosphate concentration, May – November 2000

[All values at or below the reporting limit of 3.0 mg/l]

Figure O-24 Copco No. 1 Reservoir metalimnion, BOD concentration, May – November 2000

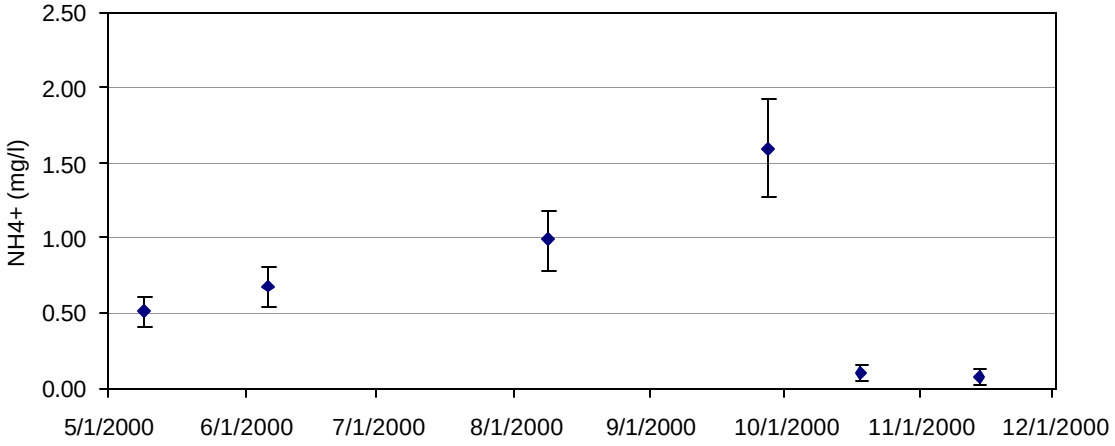


Figure O-25 Copco No. 1 Reservoir hypolimnion, ammonia concentration, May – November 2000

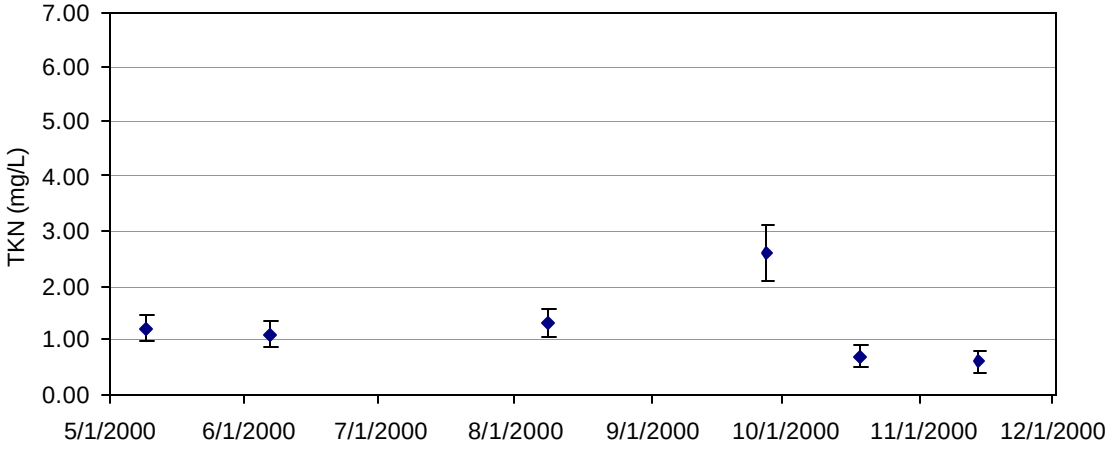


Figure O-26 Copco No. 1 Reservoir hypolimnion, total Kjeldahl nitrogen concentration, May – November 2000

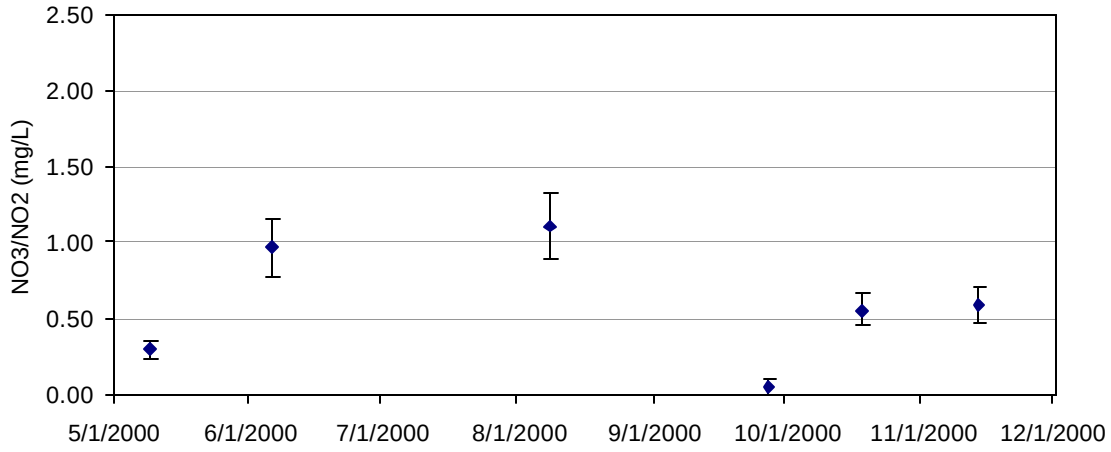


Figure O-27 Copco No. 1 Reservoir hypolimnion, nitrite plus nitrate concentration, May – November 2000

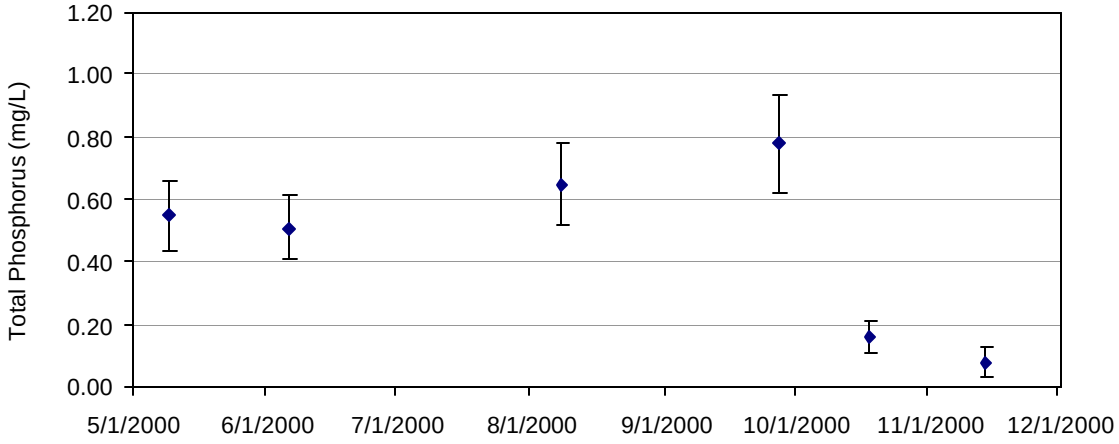


Figure O-28 Copco No. 1 Reservoir hypolimnion, total phosphorous concentration, May – November 2000

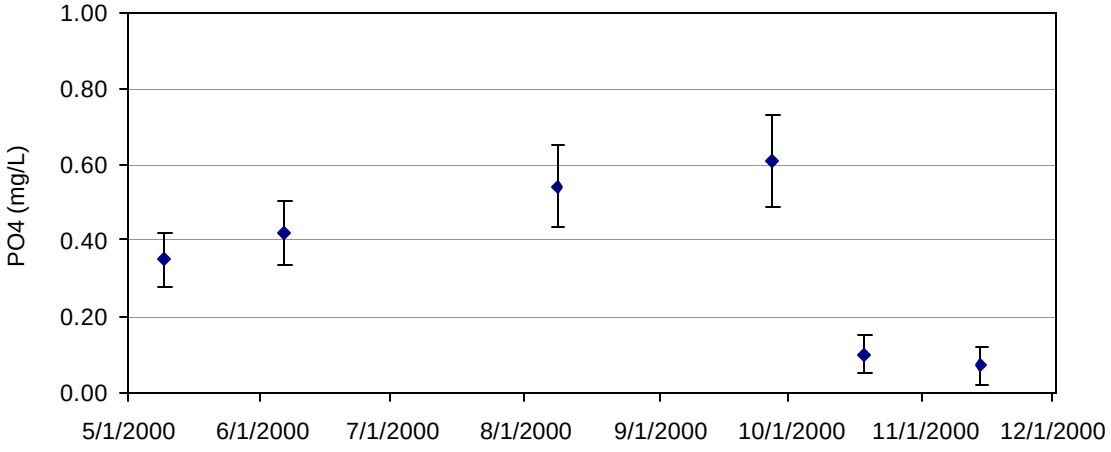


Figure O-29 Copco No. 1 Reservoir hypolimnion, orthophosphate concentration, May – November 2000

[All values at or below the reporting limit of 3.0 mg/l]

Figure O-30 Copco No. 1 Reservoir hypolimnion, BOD concentration, May – November 2000

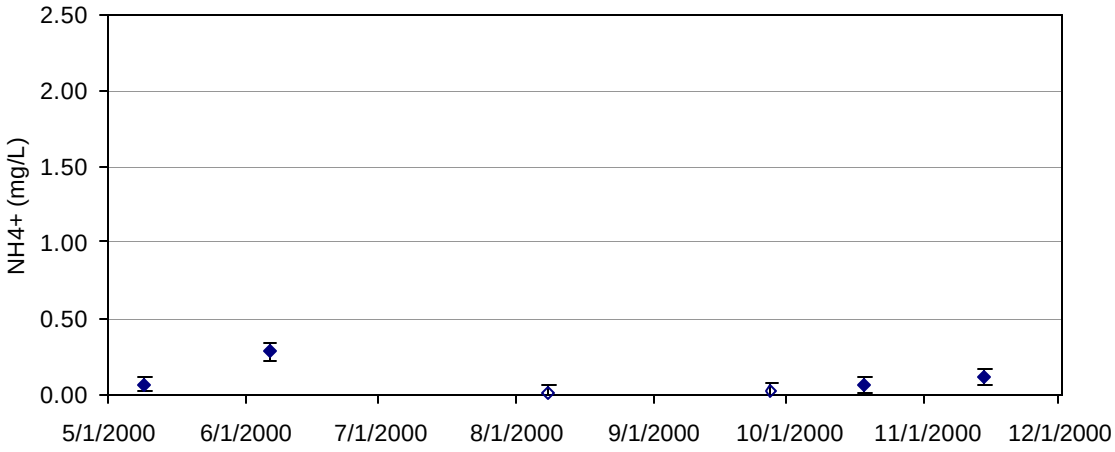


Figure O-31 Iron Gate Reservoir epilimnion, ammonia concentration, May – November 2000

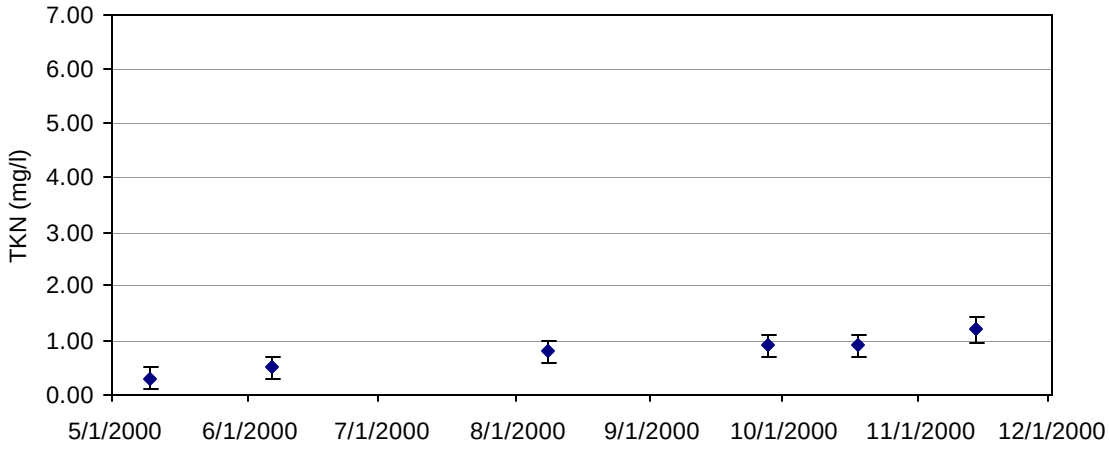


Figure O-32 Iron Gate Reservoir epilimnion, total Kjeldahl nitrogen concentration, May – November 2000

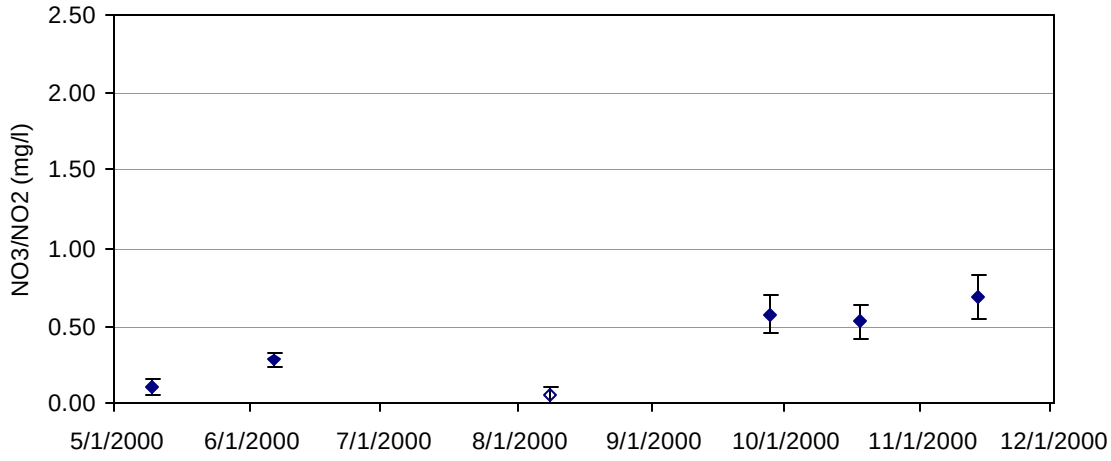


Figure O-33 Iron Gate Reservoir epilimnion, nitrite plus nitrate concentration, May – November 2000

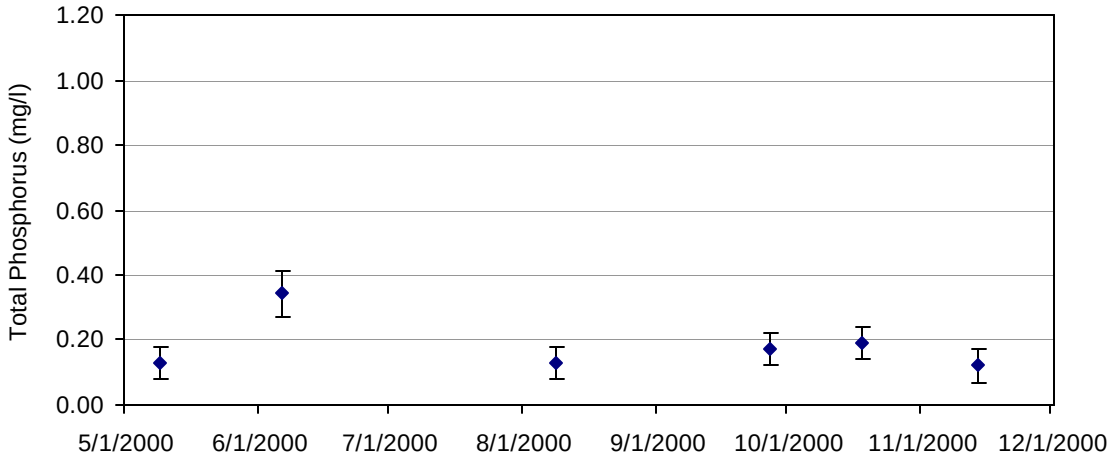


Figure O-34 Iron Gate Reservoir epilimnion, total phosphorous concentration, May – November 2000

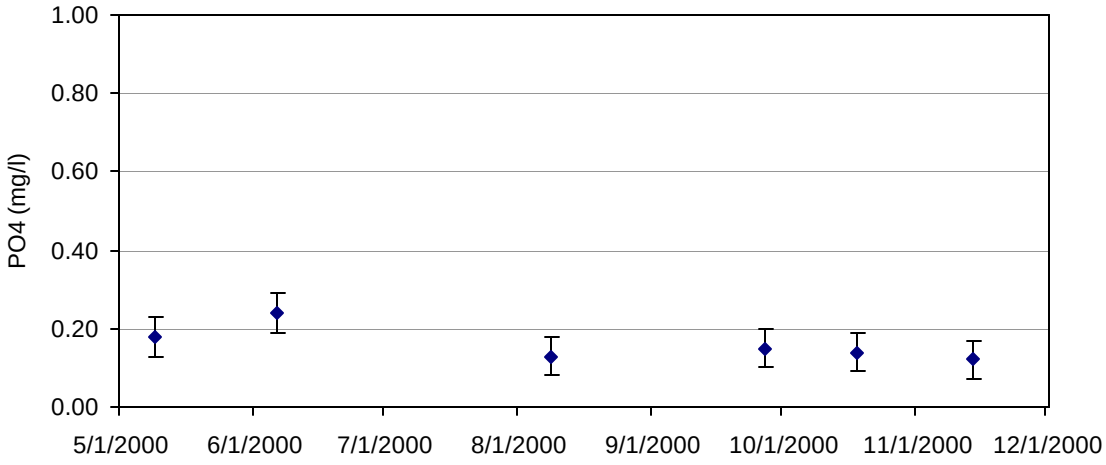


Figure O-35 Iron Gate Reservoir epilimnion, orthophosphate concentration, May – November 2000

[All values at or below the reporting limit of 3.0 mg/l. Exception is 5 mg/l on 8/8/00]

Figure O-36 Iron Gate Reservoir epilimnion, BOD concentration, May – November 2000

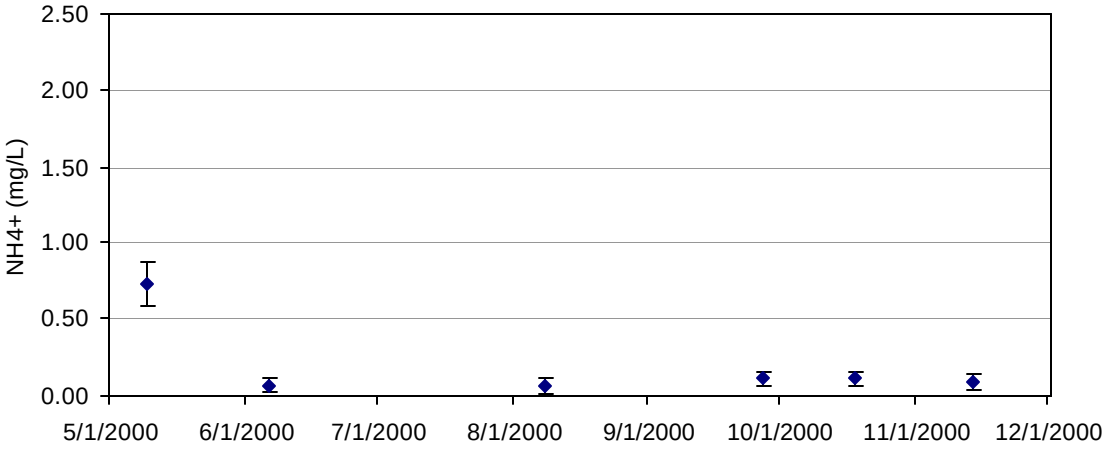


Figure O-37 Iron Gate Reservoir metalimnion, ammonia concentration, May – November 2000

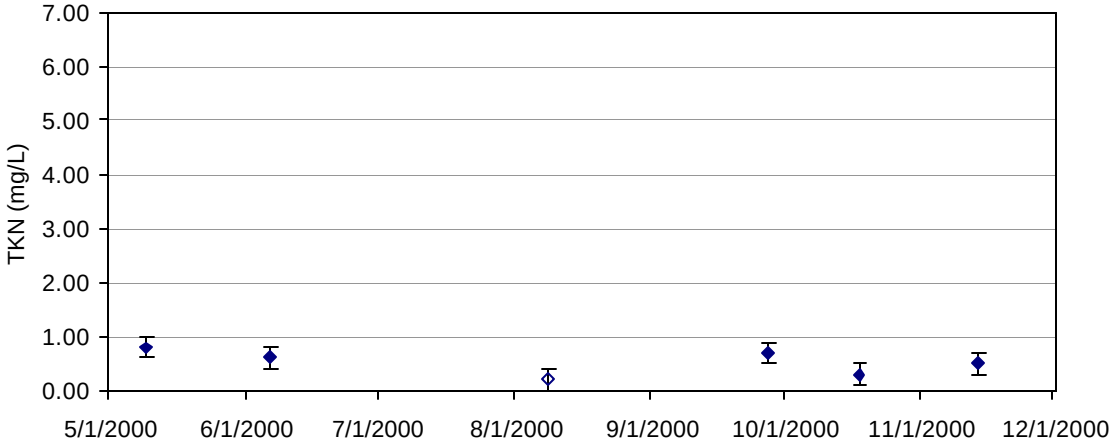


Figure O-38 Iron Gate Reservoir metalimnion, total Kjeldahl nitrogen concentration, May – November 2000

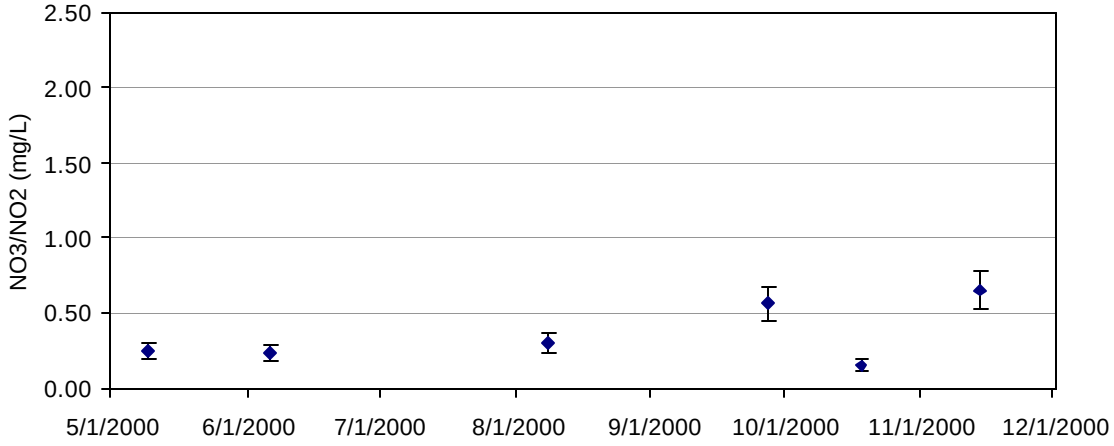


Figure O-39 Iron Gate Reservoir metalimnion, nitrite plus nitrate concentration, May – November 2000

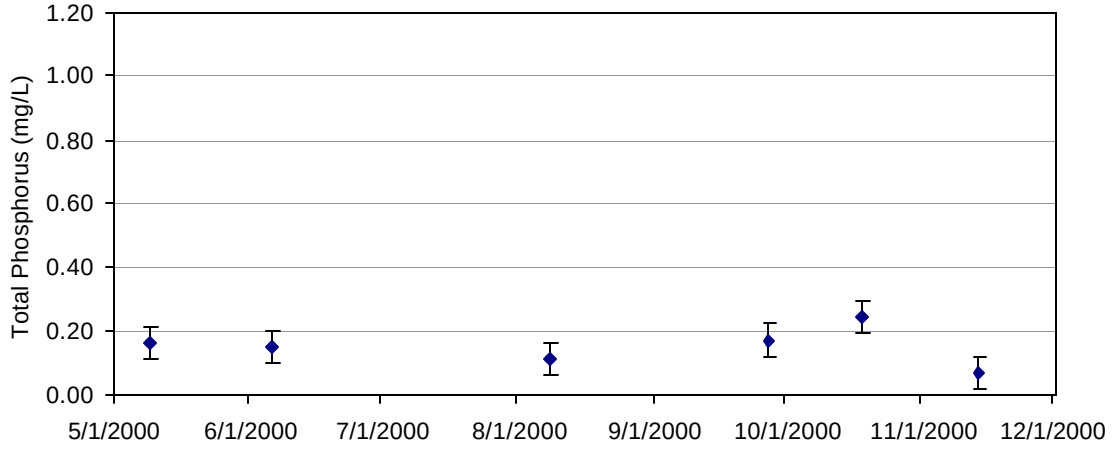


Figure O-40 Iron Gate Reservoir metalimnion, total phosphorous concentration, May – November 2000

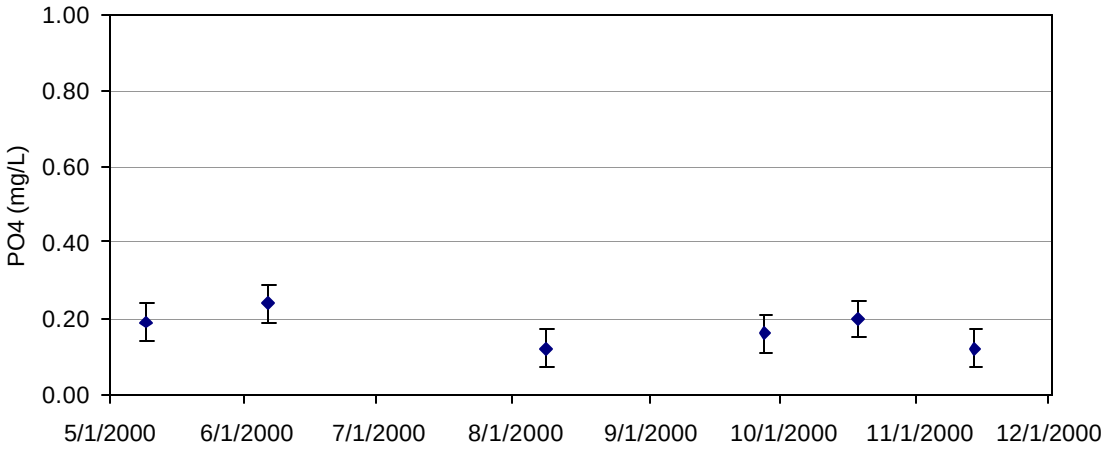


Figure O-41 Iron Gate Reservoir metalimnion, orthophosphate concentration, May – November 2000

[All values at or below the reporting limit of 3.0 mg/l.]

Figure O-42 Iron Gate Reservoir metalimnion, BOD concentration, May – November 2000

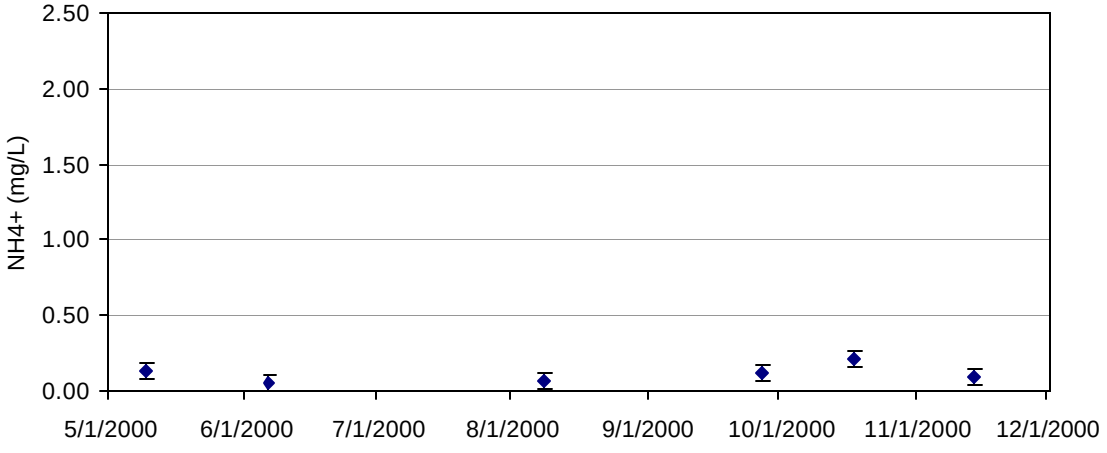


Figure O-43 Iron Gate Reservoir hypolimnion, ammonia concentration, May – November 2000

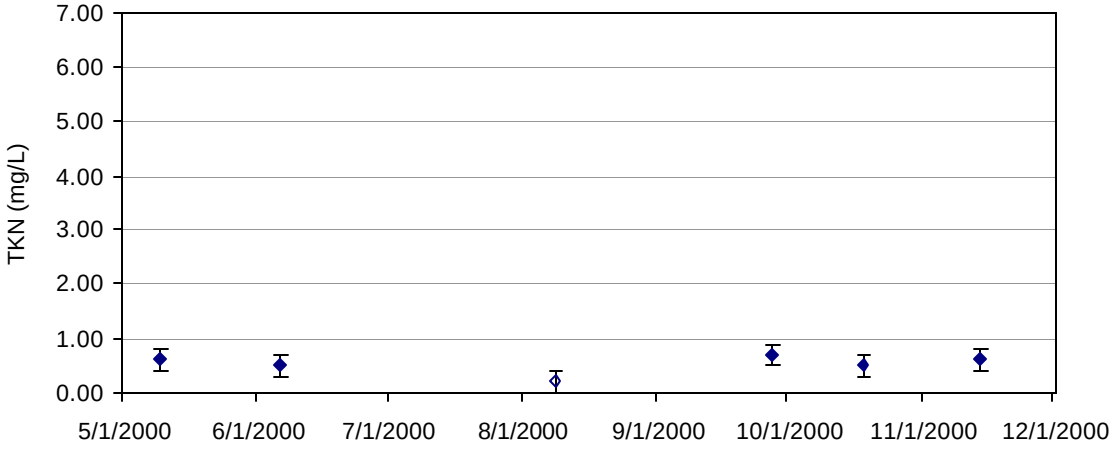


Figure O-44 Iron Gate Reservoir hypolimnion, total Kjeldahl nitrogen concentration, May – November 2000

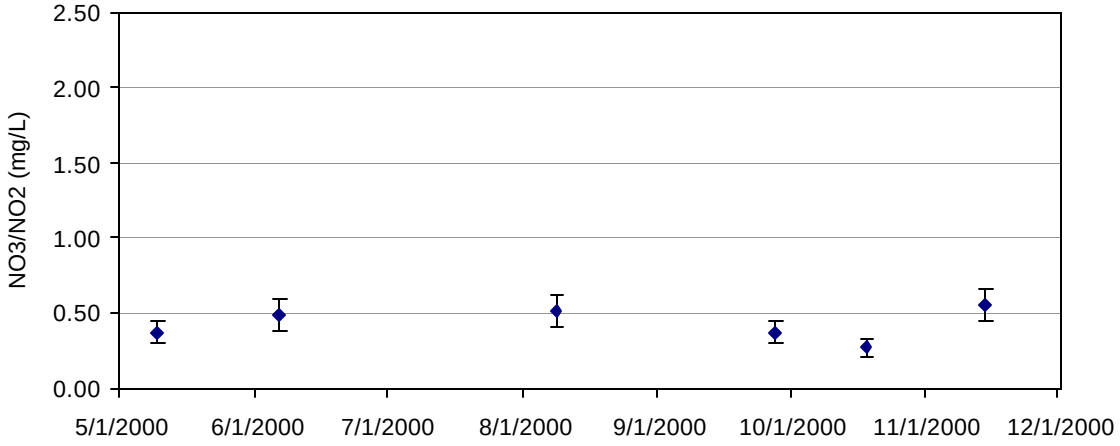


Figure O-45 Iron Gate Reservoir hypolimnion, nitrite plus nitrate concentration, May – November 2000

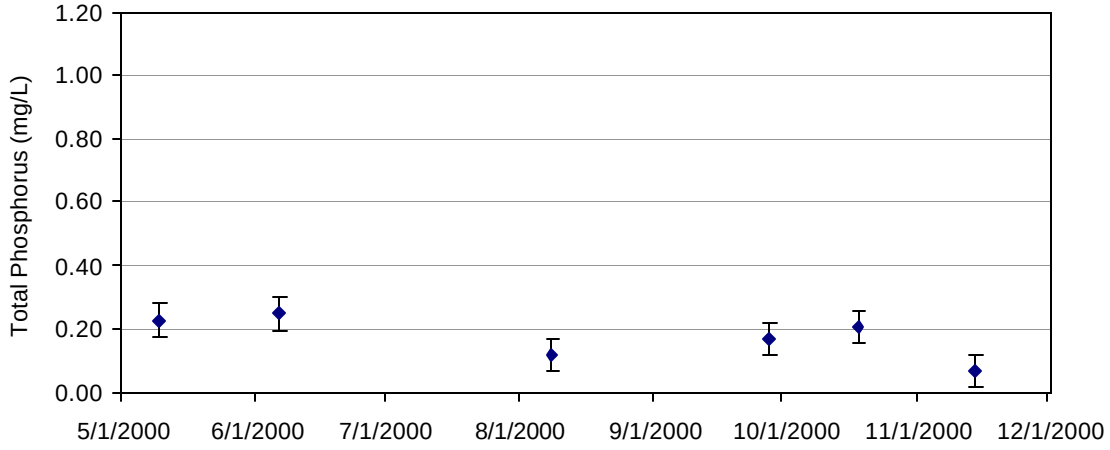


Figure O-46 Iron Gate Reservoir hypolimnion, total phosphorous concentration, May – November 2000

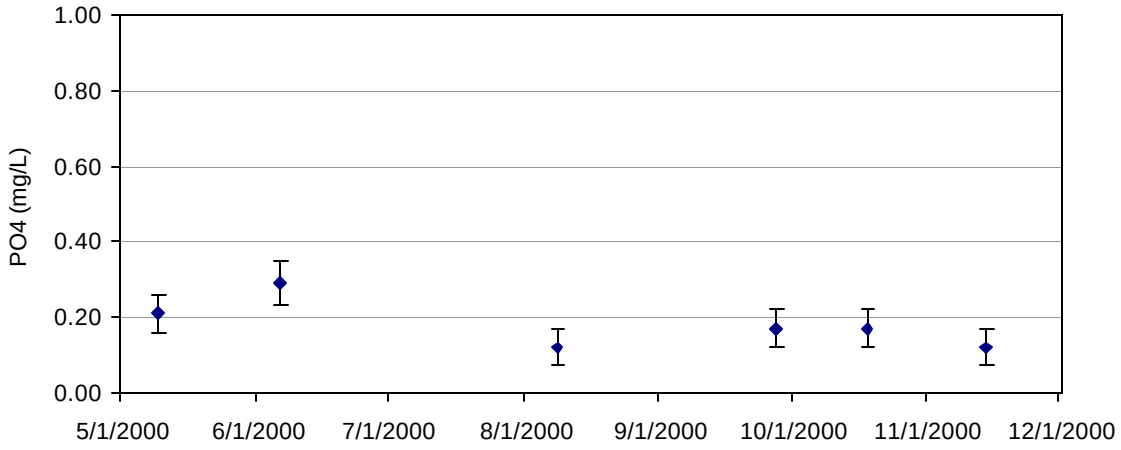


Figure O-47 Iron Gate Reservoir hypolimnion, orthophosphate concentration, May – November 2000

[All values at or below the reporting limit of 3.0 mg/l.]

Figure O-48 Iron Gate Reservoir hypolimnion, BOD concentration, May – November 2000

P RESERVOIR PROFILE DATA

Reservoir profile data were collected at approximately monthly intervals on mainstem reservoirs. Profile data consist of physical parameters measured with a water quality probe. The parameters include: water temperature, dissolved oxygen, electrical conductivity, and pH. Dissolved oxygen values presented are corrected for elevation differences among the various reservoirs. Secchi depth is also measured and is included in Table P-1. All data were supplied by PacifiCorp.

Table P-1 Secchi Depth for JC Boyle, Copco, and Iron Gate Reservoirs, May-November 2000

Date	JC Boyle	Copco	Iron Gate
		Secchi Depth (ft)	
5/9/00	3.25	5.50	6.00
6/6/00	3.50	5.50	6.00
8/8/00	5.00	6.50	5.50
9/27/00	2.70	4.00	14.00
10/18/00	3.50	4.50	6.50
11/14/00	4.00	-	-

Table P-2 Profile data for physical parameters at JC Boyle Reservoir: April - November

Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)	Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)
4/12/00	3.3	3788.9	14.4	146	7.3	8.5	8/8/00	1.6	3789.4	24.4	154	7.7	7.1
	6.6	3785.7	14.3	147	7.3	8.4		3.3	3787.7	24.4	154	7.7	7.0
	9.8	3782.4	14.3	147	7.3	8.4		6.6	3784.4	24.3	155	7.6	6.8
	13.1	3779.1	14.3	149	7.3	8.4		9.8	3781.2	23.7	155	7.4	4.6
	16.4	3775.8	14.3	149	7.3	8.5		13.1	3777.9	23.4	151	7.1	3.6
	19.7	3772.5	14.2	147	7.3	8.5		19.7	3771.3	23.0	154	7.0	3.2
	23.0	3769.3	14.2	156	7.3	8.6		26.2	3764.8	22.8	154	7.0	2.0
	26.2	3766.0	14.1	158	7.3	8.6		31.5	3759.5	22.8	166	6.9	1.9
5/9/00	0.7	3791.7	13.6	152	7.9	8.5	9/27/00	3.3	3788.8	15.5	261	8.5	7.6
	3.3	3789.1	13.6	151	7.9	8.4		6.6	3785.6	15.6	261	8.4	7.7
	6.6	3785.8	13.6	151	8.0	8.4		13.1	3779.0	15.6	261	8.4	7.1
	9.8	3782.5	13.7	150	8.0	8.4		19.7	3772.4	15.6	262	8.4	7.0
	13.1	3779.3	13.6	151	8.0	8.4		26.2	3765.9	15.6	262	8.4	6.8
	19.7	3772.7	13.4	145	7.9	8.1		29.5	3762.6	15.5	257	8.4	6.7
	26.2	3766.1	13.2	150	7.9	8.0	10/18/00	3.3	3789.8	10.6	157	7.5	10.6
6/6/00	3.3	3788.9	19.3	251	8.8	8.6		6.6	3786.5	10.7	160	7.6	9.4
	6.6	3785.6	19.3	249	8.7	8.3		9.8	3783.2	10.7	156	7.6	9.5
	9.8	3782.3	19.3	249	8.7	8.1		13.1	3780.0	10.7	164	7.6	9.7
	13.1	3779.0	19.2	257	8.6	7.5		16.4	3776.7	10.7	159	7.6	9.9
	16.4	3775.7	19.2	251	8.6	7.4		19.7	3773.4	10.7	159	7.6	10.6
	19.7	3772.5	19.2	255	8.6	7.4		23.0	3770.1	10.7	160	7.6	10.0
	23.0	3769.2	19.2	259	8.5	7.2		26.2	3766.8	10.7	160	7.6	10.2
	26.2	3765.9	19.0	258	8.4	6.9		29.5	3763.6	10.7	155	7.6	10.5
	29.5	3762.6	18.8	252	8.3	6.7	11/14/00	3.3	3788.7	3.9	156	7.7	9.3
7/11/00	1.6	3790.0	21.8	136	7.8	7.1		6.6	3785.4	3.9	161	7.7	9.2
	3.3	3788.4	21.0	134	7.7	6.9		9.8	3782.2	3.9	157	7.7	9.1
	6.6	3785.1	20.7	129	7.8	7.0		13.1	3778.9	3.9	155	7.6	9.0
	9.8	3781.8	20.1	126	7.6	6.7		16.4	3775.6	3.9	159	7.6	8.9
	13.1	3778.5	20.0	129	7.5	6.1		19.7	3772.3	3.9	159	7.6	8.9
	16.4	3775.2	19.0	135	7.3	5.3		26.2	3765.8	4.0	154	7.7	9.6
	19.7	3772.0	18.6	137	7.2	4.7							
	23.0	3768.7	18.3	137	7.2	4.3							

Table P-3 Profile data for physical parameters at Copco Reservoir: May - November

Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)	Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)
4/12/00	1.6	2603.0	15.3	151	8.4	11.6	5/9/00	0.0	2604.9	14.3	148	8.6	10.0
	3.3	2601.4	14.7	152	8.3	10.9		3.3	2601.6	14.3	148	8.6	9.8
	6.6	2598.1	14.3	152	8.1	10.5		6.6	2598.4	14.2	147	8.6	9.6
	9.8	2594.8	14.2	152	8.0	10.2		9.8	2595.1	14.0	151	8.5	9.4
	13.1	2591.5	14.1	151	8.0	10.3		13.1	2591.8	14.0	151	8.5	9.3
	16.4	2588.3	14.1	154	8.0	10.3		16.4	2588.5	13.9	149	8.4	9.1
	19.7	2585.0	14.1	151	8.0	10.4		19.7	2585.2	13.9	155	8.4	9.1
	23.0	2581.7	14.0	151	7.9	10.5		26.2	2578.7	13.7	151	8.2	8.6
	26.2	2578.4	13.4	159	7.8	10.0		32.8	2572.1	13.6	155	8.1	8.4
	29.5	2575.1	13.1	158	7.6	9.8		39.4	2565.6	13.3	147	8.0	7.9
	32.8	2571.9	12.4	162	7.5	9.3		45.9	2559.0	12.8	144	7.8	7.4
	39.4	2565.3	11.8	168	7.3	9.2		52.5	2552.4	12.6	148	7.7	7.1
	45.9	2558.7	11.2	171	7.3	9.1		59.1	2545.9	12.2	147	7.6	6.7
	52.5	2552.2	10.2	173	7.2	8.8		65.6	2539.3	11.6	147	7.5	5.5
	59.1	2545.6	9.9	171	7.1	8.4		72.2	2532.7	10.6	167	7.3	3.1
	65.6	2539.0	9.7	179	7.1	8.2		78.7	2526.2	10.2	162	7.2	2.0
	72.2	2532.5	9.3	179	7.0	7.9		85.3	2519.6	10.0	172	7.2	1.3
	78.7	2525.9	8.8	171	6.9	6.2		91.9	2513.1	9.9	175	7.2	0.9
	85.3	2519.4	8.8	174	6.9	6.0		98.4	2506.5	9.8	178	7.2	0.8
	91.9	2512.8	8.7	182	6.8	5.7							

Table P-3 Profile data for physical parameters at Copco Reservoir: May - November (continued)

Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)	Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)
6/6/00	3.3	2600.5	19.2	245	8.9	10.5	8/8/00	3.3	2602.8	23.4	168	9.1	11.6
	6.6	2597.3	18.9	244	8.8	9.7		6.6	2599.5	23.1	167	9.1	11.9
	9.8	2594.0	18.9	244	8.8	9.6		9.8	2596.2	22.8	169	9.0	11.1
	13.1	2590.7	18.9	240	8.8	9.5		13.1	2592.9	22.7	169	8.9	10.1
	16.4	2587.4	18.8	242	8.7	9.1		19.7	2586.4	22.3	171	8.5	7.3
	19.7	2584.1	18.5	247	8.5	7.8		26.2	2579.8	21.9	169	8.0	5.9
	26.2	2577.6	17.9	245	8.3	7.4		32.8	2573.3	21.5	165	7.6	4.5
	32.8	2571.0	17.0	242	8.1	6.8		39.4	2566.7	20.6	176	7.3	31.2
	39.4	2564.5	15.9	221	7.9	6.3		45.9	2560.1	20.0	172	7.1	1.9
	45.9	2557.9	14.3	197	7.6	5.1		52.5	2553.6	18.5	168	7.0	0.5
	52.5	2551.3	13.2	189	7.5	4.8		59.1	2547.0	16.7	171	7.0	0.4
	59.1	2544.8	12.6	188	7.4	4.1		65.6	2540.4	15.2	196	7.0	0.3
	65.6	2538.2	12.4	176	7.3	3.8		72.2	2533.9	13.7	186	6.9	0.3
	72.2	2531.6	12.2	185	7.3	3.3		78.7	2527.3	13.2	185	6.9	0.3
	78.7	2525.1	11.9	195	7.2	2.0		85.3	2520.8	12.9	186	6.9	0.3
	85.3	2518.5	11.5	195	7.1	0.4		91.9	2514.2	12.8	180	6.8	0.3
	91.9	2512.0	11.5	197	7.1	0.3		98.4	2507.6	12.8	188	6.8	0.3
	98.4	2505.4	11.5	176	7.1	0.2							

Table P-3 Profile data for physical parameters at Copco Reservoir: May - November (Continued)

Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)	Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)
7/11/00	1.6	2602.5	20.9	144	8.5	9.4	10/18/00	3.3	2600.9	13.6	201	7.7	10.5
	3.3	2600.9	20.6	143	8.4	8.8		6.6	2597.6	13.2	203	7.7	8.7
	6.6	2597.6	20.2	142	8.3	8.1		9.8	2594.3	13.2	203	7.7	8.6
	9.8	2594.3	20.1	144	8.2	7.6		13.1	2591.0	13.2	198	7.7	8.6
	13.1	2591.0	20.0	142	8.1	7.3		16.4	2587.7	13.2	198	7.7	8.7
	16.4	2587.8	20.0	143	8.1	7.4		19.7	2584.5	13.2	204	7.7	8.8
	19.7	2584.5	19.9	141	8.1	7.3		26.2	2577.9	13.2	203	7.7	9.0
	26.2	2577.9	19.1	150	7.5	4.6		32.8	2571.3	13.1	207	7.7	9.8
	32.8	2571.4	18.4	137	7.4	4.3		39.4	2564.8	12.7	184	7.7	9.8
	39.4	2564.8	18.2	140	7.4	4.4		45.9	2558.2	12.4	182	7.7	10.2
	45.9	2558.2	17.9	148	7.3	4.1		52.5	2551.6	12.2	179	7.8	11.0
	52.5	2551.7	16.4	166	7.1	0.3		59.1	2545.1	12.1	189	7.8	11.2
	59.1	2545.1	14.3	168	7.0	0.2		65.6	2538.5	12.0	164	7.9	11.6
	65.6	2538.6	13.3	176	7.0	0.2		72.2	2532.0	12.0	186	7.8	12.0
	72.2	2532.0	12.8	156	7.0	0.2		78.7	2525.4	11.9	173	7.9	12.3
	78.7	2525.4	12.6	169	6.9	0.2		85.3	2518.8	11.9	196	7.9	12.5
	85.3	2518.9	12.4	155	6.9	0.1		91.9	2512.3	11.8	165	7.9	12.8
	91.9	2512.3	12.3	148	6.9	0.1		98.4	2505.7	11.8	168	7.9	13.0
9/27/00	1.6	2600.0	18.5	193	9.0	8.8							
	3.3	2598.4	17.5	195	8.8	7.9							
	9.8	2591.8	17.3	196	8.6	7.2							
	16.4	2585.3	17.1	198	8.5	6.7							
	32.8	2568.9	16.7	202	8.3	5.2							
	49.2	2552.5	16.0	217	8.2	3.4							
	65.6	2536.1	15.5	220	8.2	3.9							
	82.0	2519.7	14.7	210	7.8	0.1							
	95.1	2506.5	14.5	211	7.8	0.0							

Table P-3 Profile data for physical parameters at Copco Reservoir: May - November (Continued)

Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)
11/14/00	3.3	2597.9	8.26	140	8.9	8.7
	6.6	2594.6	8.26	141	8.5	8.5
	13.1	2588.1	8.27	140	8.2	0.1
	19.7	2581.5	8.28	140	8.1	0.1
	26.2	2575.0	8.22	141	8.0	0.1
	32.8	2568.4	7.84	143	7.9	0.1
	39.4	2561.8	7.83	143	7.9	0.1
	45.9	2555.3	7.69	144	7.9	0.2
	52.5	2548.7	7.36	145	7.8	0.2
	59.1	2542.2	7.30	145	7.8	0.2
	65.6	2535.6	7.25	146	7.8	0.4
	68.9	2532.3	7.19	146	7.8	0.5
	72.2	2529.0	7.16	146	7.8	0.9
	78.7	2522.5	7.13	146	7.8	2.0
	85.3	2515.9	7.13	146	7.8	4.9
	91.9	2509.3	7.12	146	7.8	6.9
	98.4	2502.8	7.25	189	7.5	4.2

Table P-4 Profile data for physical parameters at Iron Gate Reservoir: May - November

Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)	Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)
4/12/00	0.3	2327.9	14.7	166	8.7	11.8	5/9/00	1.6	2327.3	14.3	146	8.4	9.3
	3.3	2325.0	14.7	165	8.7	12.5		3.3	2325.7	14.3	147	8.4	9.3
	6.6	2321.7	14.4	166	8.7	12.8		6.6	2322.4	13.7	147	8.3	9.1
	9.8	2318.4	13.5	165	8.3	11.8		9.8	2319.1	13.8	150	8.3	9.0
	13.1	2315.1	13.2	165	8.0	11.2		13.1	2315.8	13.3	144	8.1	8.5
	16.4	2311.8	12.8	166	7.8	10.8		16.4	2312.5	13.2	150	8.0	8.4
	19.7	2308.6	12.2	167	7.5	10.2		19.7	2309.3	12.9	147	8.0	8.2
	23.0	2305.3	12.1	165	7.5	10.1		26.2	2302.7	12.4	156	7.9	8.0
	26.2	2302.0	12.1	167	7.5	10.1		32.8	2296.1	12.1	158	7.8	7.9
	29.5	2298.7	11.8	168	7.5	10.0		39.4	2289.6	11.7	151	7.7	7.5
	32.8	2295.4	11.7	166	7.4	10.0		45.9	2283.0	11.3	140	7.6	7.1
	39.4	2288.9	9.7	167	7.3	10.0		52.5	2276.4	10.8	161	7.6	6.8
	45.9	2282.3	9.2	168	7.3	10.0		59.1	2269.9	10.4	170	7.5	6.6
	52.5	2275.7	8.6	172	7.2	10.0		65.6	2263.3	9.1	168	7.5	6.5
	59.1	2269.2	8.0	171	7.2	10.0		72.2	2256.8	7.8	157	7.4	6.4
	65.6	2262.6	7.3	171	7.1	10.0		78.7	2250.2	6.9	170	7.4	6.3
	72.2	2256.1	6.9	170	7.1	10.0		85.3	2243.6	6.6	176	7.4	6.2
	78.7	2249.5	6.7	171	7.1	10.1		91.9	2237.1	6.4	183	7.3	6.0
	85.3	2242.9	6.5	159	7.1	10.1		98.4	2230.5	6.8	171	7.4	6.2
	91.9	2236.4	6.4	165	7.1	10.1		105.0	2224.0	6.2	182	7.3	6.1
	98.4	2229.8	6.4	163	7.1	10.1		111.5	2217.4	6.1	150	7.3	5.9
	105.0	2223.3	6.3	167	7.1	10.0		118.1	2210.8	6.1	164	7.4	5.6
	111.5	2216.7	6.2	161	7.1	10.0		124.7	2204.3	6.0	166	7.2	5.2
	118.1	2210.1	6.2	160	7.1	10.1		131.2	2197.7	6.0	153	7.2	4.9
	124.7	2203.6	6.2	163	7.1	10.0		137.8	2191.1	6.0	163	7.2	3.9
	131.2	2197.0	6.2	165	7.0	9.6		144.4	2184.6	6.0	150	7.2	2.9
	137.8	2190.4	6.2	176	7.0	9.3							
	144.4	2183.9	6.1	173	6.9	8.4							

Table P-4 Profile data for physical parameters at Iron Gate Reservoir: May - November (Continued)

Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)	Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)
6/6/00	3.3	2322.1	19.7	225	8.8	10.5	7/11/00	3.3	2323.0	22.3	157	8.6	8.8
	6.6	2318.8	19.1	223	8.8	10.1		6.6	2319.7	22.2	157	8.6	8.8
	9.8	2315.5	18.9	224	8.7	9.7		9.8	2316.5	22.2	157	8.6	8.7
	13.1	2312.2	18.8	226	8.7	9.5		13.1	2313.2	21.6	155	8.3	7.6
	16.4	2308.9	17.7	216	8.4	8.4		16.4	2309.9	20.0	160	7.5	4.6
	19.7	2305.7	17.2	220	8.2	7.8		19.7	2306.6	19.7	153	7.4	4.6
	26.2	2299.1	16.6	218	8.0	7.2		26.2	2300.1	19.5	156	7.4	4.4
	32.8	2292.5	15.8	205	7.9	6.7		32.8	2293.5	19.1	149	7.4	4.3
	39.4	2286.0	14.1	189	7.8	6.4		39.4	2286.9	18.8	166	7.3	3.5
	45.9	2279.4	12.9	169	7.6	6.5		45.9	2280.4	17.6	186	7.3	3.6
	52.5	2272.8	11.8	172	7.5	6.0		52.5	2273.8	15.9	178	7.3	3.5
	59.1	2266.3	10.9	175	7.4	5.7		59.1	2267.2	14.4	159	7.2	3.6
	65.6	2259.7	8.9	181	7.3	5.4		65.6	2260.7	12.7	140	7.1	4.0
	72.2	2253.2	7.3	173	7.3	5.0		72.2	2254.1	10.7	146	7.1	3.5
	78.7	2246.6	6.8	174	7.2	4.9		78.7	2247.6	8.8	140	6.9	2.6
	85.3	2240.0	6.5	176	7.2	4.9		85.3	2241.0	7.5	139	7.0	2.9
	91.9	2233.5	6.5	179	7.2	4.8		91.9	2234.4	7.0	154	6.9	2.4
	98.4	2226.9	6.4	172	7.1	4.6		98.4	2227.9	6.8	145	6.8	1.5
	105.0	2220.4	6.4	167	7.2	4.3		105.0	2221.3	6.7	156	6.8	1.0
	111.5	2213.8	6.3	163	7.1	4.2		111.5	2214.8	6.7	148	6.8	0.5
	118.1	2207.2	6.2	166	7.1	4.0		118.1	2208.2	6.6	139	6.8	1.1
	124.7	2200.7	6.2	193	7.2	3.4		124.7	2201.6	6.5	146	6.8	0.2
	131.2	2194.1	6.2	162	7.1	2.2		131.2	2195.1	6.5	142	6.7	0.3
	137.8	2187.5	6.1	159	7.0	1.1		137.1	2189.2	6.5	147	6.7	0.2
	144.4	2181.0	6.1	183	6.9	0.3							

Table P-4 Profile data for physical parameters at Iron Gate Reservoir: May - November (Continued)

Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)	Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)
8/8/00	3.3	2323.2	25.3	162	9.5	14.1	9/27/00	3.3	2320.8	18.4	176	7.6	6.4
	6.6	2319.9	24.6	162	9.4	13.1		6.6	2317.5	17.8	171	7.6	6.1
	9.8	2316.6	24.1	164	9.2	10.6		9.8	2314.2	17.4	170	7.5	5.7
	13.1	2313.3	22.0	170	7.9	4.9		13.1	2310.9	17.3	172	7.5	5.4
	19.7	2306.8	21.5	168	7.7	4.2		19.7	2304.4	17.3	171	7.4	5.2
	26.2	2300.2	21.3	164	7.5	3.3		26.2	2297.8	17.2	170	7.4	4.9
	32.8	2293.7	20.6	158	7.3	3.0		32.8	2291.3	17.0	179	7.3	3.5
	39.4	2287.1	20.0	171	7.2	2.7		39.4	2284.7	16.8	179	7.2	3.3
	45.9	2280.5	18.6	187	7.1	1.9		45.9	2278.1	16.7	184	7.3	4.0
	52.5	2274.0	16.4	207	7.1	2.1		52.5	2271.6	16.5	185	7.3	4.1
	59.1	2267.4	13.5	189	7.1	2.8		59.1	2265.0	16.3	191	7.2	3.2
	65.6	2260.8	11.7	156	7.0	2.5		65.6	2258.4	16.1	190	7.1	1.0
	72.2	2254.3	10.1	168	6.9	1.9		72.2	2251.9	14.1	170	7.0	0.3
	78.7	2247.7	8.4	165	6.9	1.4		78.7	2245.3	10.5	173	6.9	0.3
	85.3	2241.2	7.8	174	6.8	1.0		85.3	2238.8	9.5	175	6.9	0.3
	91.9	2234.6	7.3	146	6.8	0.8		91.9	2232.2	8.2	190	6.9	0.3
	98.4	2228.0	7.1	157	6.7	0.4		98.4	2225.6	7.7	192	6.9	0.3
	105.0	2221.5	7.0	156	6.7	0.4		105.0	2219.1	7.5	191	6.9	0.3
	111.5	2214.9	6.9	174	6.7	0.3		121.4	2202.7	7.2	190	7.0	0.3
	118.1	2208.4	6.8	156	6.7	0.3		137.8	2186.3	7.1	190	6.9	0.3
	124.7	2201.8	6.8	159	6.7	0.3							
	131.2	2195.2	6.7	170	6.6	0.3							
	137.8	2188.7	6.7	131	6.7	0.3							
	144.4	2182.1	6.6	178	6.6	0.3							

Table P-4 Profile data for physical parameters at Iron Gate Reservoir: May - November (Continued)

Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)	Date	Depth (ft)	Elevation (ft msl)	Tw (C)	EC (uS/cm)	pH	DO (mg/l)
10/18/00	3.3	2320.8	14.9	210	7.5	6.5	11/14/00	3.3	2322.8	9.84	155	7.7	6.6
	6.6	2317.5	14.8	208	7.5	5.4		6.6	2319.5	9.82	155	7.7	6.5
	9.8	2314.3	14.7	209	7.5	5.4		13.1	2312.9	9.82	155	7.7	6.5
	13.1	2311.0	14.7	210	7.5	5.4		19.7	2306.4	9.82	155	7.6	5.7
	16.4	2307.7	14.6	203	7.5	5.4		26.2	2299.8	9.82	154	7.6	1.9
	19.7	2304.4	14.6	207	7.5	5.4		32.8	2293.2	9.81	155	7.6	1.0
	26.2	2297.9	14.6	211	7.5	5.4		39.4	2286.7	9.80	156	7.6	0.9
	32.8	2291.3	14.5	208	7.5	5.3		45.9	2280.1	9.77	154	7.6	1.1
	39.4	2284.7	14.3	207	7.5	5.3		52.5	2273.5	9.65	152	7.6	1.5
	45.9	2278.2	14.2	212	7.5	4.9		59.1	2267.0	9.46	150	7.6	2.3
	52.5	2271.6	14.0	210	7.5	5.2		65.6	2260.4	9.42	150	7.6	4.7
	59.1	2265.0	13.9	203	7.6	5.4		72.2	2253.9	9.32	151	7.5	4.8
	65.6	2258.5	13.9	215	7.6	5.4		78.7	2247.3	9.31	149	7.6	6.7
	72.2	2251.9	13.8	198	7.6	5.2		85.3	2240.7	9.26	151	7.6	6.9
	78.7	2245.4	13.5	200	7.5	3.8		91.9	2234.2	9.23	150	7.6	6.8
	85.3	2238.8	9.9	191	7.3	2.6		98.4	2227.6	9.16	150	7.6	6.8
	91.9	2232.2	8.6	168	7.1	2.2		105.0	2221.1	9.10	151	7.5	6.1
	98.4	2225.7	8.0	194	7.1	1.7		111.5	2214.5	9.00	153	7.5	5.6
	105.0	2219.1	7.6	186	7.1	1.7		118.1	2207.9	8.07	163	7.4	1.0
	111.5	2212.6	7.4	212	7.1	1.5							
	118.1	2206.0	7.3	195	7.1	1.0							
	124.7	2199.4	7.3	184	7.1	0.5							
	131.2	2192.9	7.2	175	7.0	0.4							

Q RESERVOIR THERMISTOR STRINGS

Temperature logging thermistors were deployed at multiple depths in JC Boyle, Copco and Iron Gate Reservoir. The devices were attached at fixed intervals to a cable and suspended from the cable or log boom in each reservoir. For JC Boyle, the thermistor spacing was 5 feet, for Copco and Iron Gate Reservoirs the spacing was 10 feet. Temperature was monitored at one-hour intervals. The data are too numerous to reproduce in complete tabular or graphical form, but selected time series at selected depths are plotted and briefly discussed below. It is notable that the long term deployments, collecting sub-daily data, provided significantly more insight into system dynamics than the monthly temperature profiles. All data are included in the electronic files.

Q.1 Iron Gate Reservoir

Remote logging thermistors (Onset Computer Corporation model TBI32-05+37) were deployed on May 10, 2000 and removed April 10, 2001. Devices were suspended on a braided wire cable from the log boom at the surface, 5 feet deep, and at 10 foot intervals from 10 feet to 120 feet of depth. Plotted in Figure Q.1 are the time series from selected depths (surface, 20, 40, 60, 80, and 100 feet). Several processes and conditions are readily apparent from these detailed data sets, and are outlined in the table below corresponding to figure labels. Thorough investigation of reservoir profiles based on these thermal records has not been completed. This presentation is intended to provide only a cursory description of potential field processes.

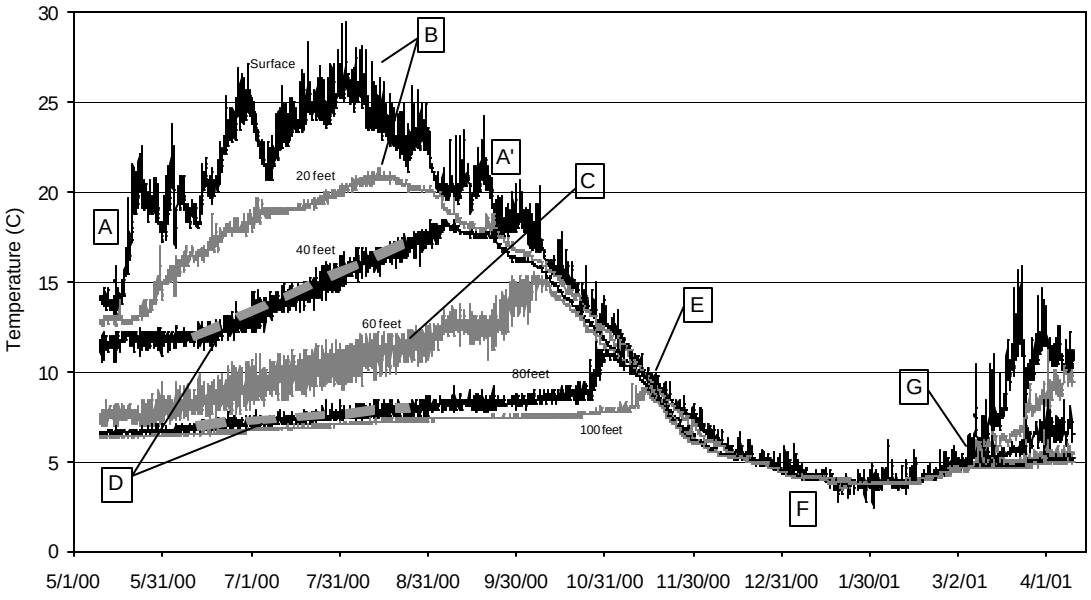


Figure Q-1 Iron Gate Reservoir measured hourly water temperature at the surface and 20, 40, 60, 80, and 100 foot depths, May 2000 - April 2001

Table Q-1 Iron Gate Reservoir summary of short term (sub-daily) to long-term (seasonal) thermal response

Label	Description
A, A'	Surface waters are prone to appreciable rates of heating (A) and cooling (A'), responding quickly to atmospheric conditions. Maximum surface water temperatures approach 30°C.
B	Surface waters are generally prone to larger diurnal variations in response to atmospheric conditions than deeper reservoir waters, but exceptions occur (see "C" below).
C	Significant diurnal variation occurs in the temperature trace at the 60 foot depth, especially when compared with the signal at the 20 foot depth. Deas and Orlob (1999) identified that this phenomenon is probably associated with daily peaking power production releases from Copco Reservoir. A close inspection of the data illustrate that these data typically have more than one maxima and minima per day.
D	Heating rates at various depths are readily discernable from the data series in response to mixing processes and thermal stratification within the reservoir. For example temperatures at the 40 foot depth increase at a rate of roughly 2°C per month, while those at the 100 foot depth increase at a rate of roughly 0.5°C per month (as approximated by grey dashed lines). The data further indicate that at the deepest depths the reservoir is heating well into November, prior to turnover.
E	Fall cooling through the process of convective cooling and a deepening of the thermocline is apparent as the temperature traces of the deeper time series intersect the descending limb of the surface and near-surface water temperature traces. Fall turnover is complete (isothermal conditions) around the third week of November.
F	During the middle of winter, the entire reservoir experiences cold water temperatures – in the neighborhood of 4°C. This water is the source of water for the upcoming summer cold water supply. It is interesting to note that the coldest temperatures at this time of year (about 3°C) occur in the surface waters as the point of maximum density occurs at just under 4°C.
G	The onset of thermal stratification occurs in the first week of March 2000 when surface and near surface temperatures deviate markedly from bottom waters.

Q.2 Copco Reservoir

Remote logging thermistors (Onset Computer Corporation model TBI32-05+37) were deployed on May 10, 2000 and removed April 10, 2001. Devices were suspended on a braided wire cable from the log boom at the surface, 5 feet deep, and at 10 foot intervals from 10 feet to 120 feet of depth. Plotted in Figure Q.2 are the time series from selected depths (surface, 20, 40, 60, and 80 feet). Several processes and conditions are readily apparent from these detailed data sets, and are outlined below corresponding to labels on the figure

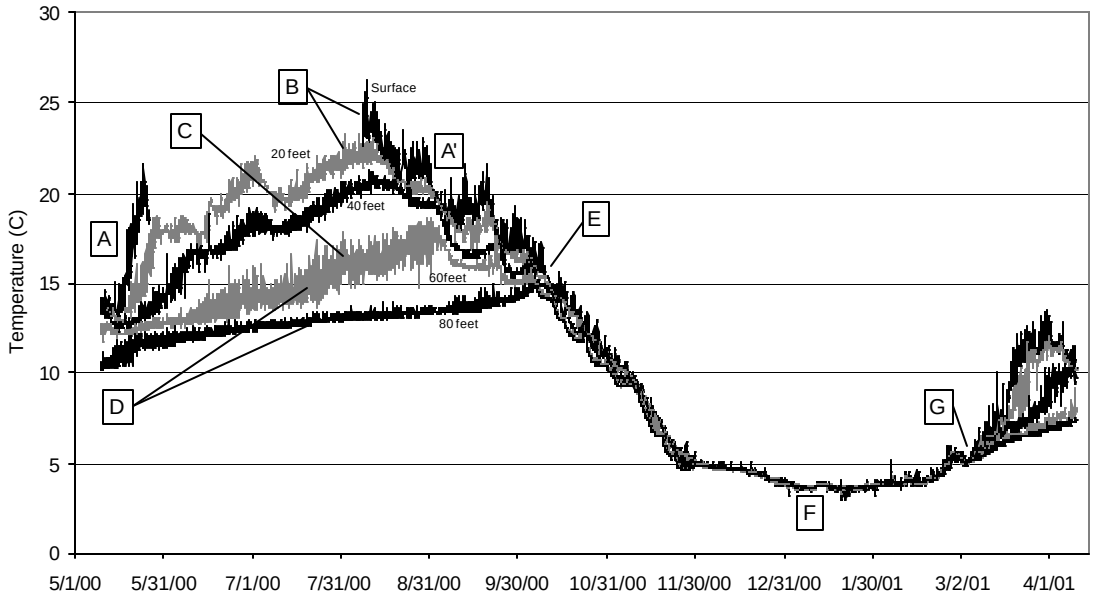


Figure Q-2 Copco Reservoir measured hourly water temperature at the surface and 20, 40, 60, and 80 foot depths in, May 2000 - April 2001

Table Q-2 Copco Reservoir summary of short term (sub-daily) to long-term (seasonal) thermal response

Label	Description
A, A'	Surface waters are prone to appreciable rates of heating (A) and cooling (A'), responding quickly to atmospheric conditions. Because a portion of the Copco surface temperature record is missing, it is unclear if Copco or Iron Gate Reservoir experiences higher surface water temperatures.
B	Surface waters are generally prone to larger diurnal variations in response to atmospheric conditions than deeper reservoir waters, but exceptions occur (see "C" below).
C	Significant diurnal variation occurs in the temperature trace at the 60 foot depth, especially when compared with the signal at the 20 foot depth. This phenomenon is probably associated with daily peaking power production releases from JC Boyle Reservoir.
D	As with Iron Gate Reservoir, heating rates at various depths within Copco Reservoir are readily discernable from the data series in response to mixing processes and thermal stratification within the reservoir, with deeper waters heating at a slower rate than shallower waters The data further indicate that at the deepest depths the reservoir is heating through September, prior to turnover.
E	Fall cooling through the process of convective cooling and a deepening of the thermocline is apparent as the temperature traces of the deeper time series intersect the descending limb of the surface and near-surface water temperature traces. Fall turnover is complete (isothermal conditions) around the first week of October – some six to seven weeks prior to Iron Gate Reservoir. Review of temperature data from the Klamath River upstream of Copco Reservoir illustrate that the river cools much quicker than the reservoir in the fall period. Cooler influent waters (both long term and diurnally) coupled with mixing energy of waters of lower density probably lead to the early turnover of Copco Reservoir when compared with Iron Gate Reservoir. Iron Gate Reservoir does not experience such cool water inputs because the thermal mass of Copco takes appreciable time to cool – when fall turnover occurs in Copco the reservoir reaches an isothermal condition at about 15°C, well above the cooler bottom waters of Iron Gate Reservoir. Compared to Iron Gate Reservoir, the smaller and less complex morphology, and shallower conditions at Copco may further lend itself to early turnover.

F	During the middle of winter, the entire reservoir experiences cold water temperatures – in the neighborhood of 4°C. This water is the source of water for the upcoming summer cold water supply.
G	The onset of thermal stratification occurs in the first week of March 2000 when surface and near surface temperatures deviate markedly from bottom waters. Iron Gate Reservoir onset of stratification occurs at the same time, indicating that meteorological conditions are superseding flow conditions. This may not be the case in all years.

Q.3 JC Boyle Reservoir

Remote logging thermistors (Onset Computer Corporation model TBI32-05+37) were deployed on May 10, 2000 and removed November 14, 2000. Devices were suspended on a braided wire cable from the log boom at the surface and at 5 foot intervals from the surface to 25 feet of depth. Plotted in Figure Q.3 are the time series from selected depths (surface, 10, and 20feet). Several processes and conditions are readily apparent from these detailed data sets, and are outlined below corresponding to labels on the figure

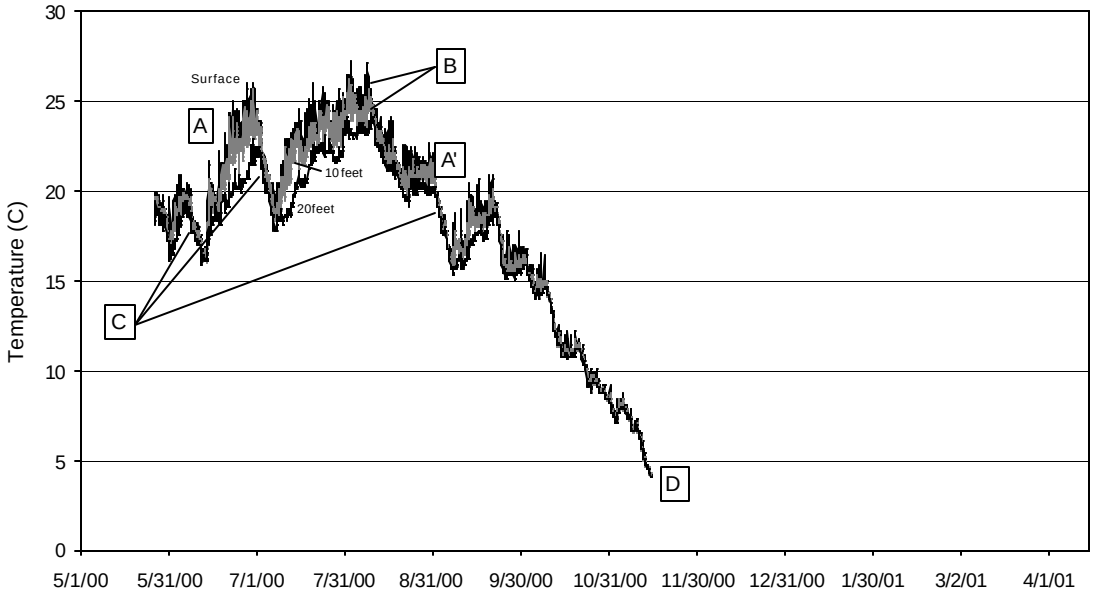


Figure Q-3 JC Boyle Reservoir measured hourly water temperature at the surface, 10 and 20foot depths, May 2000 - November 2000

Table Q-3 JC Boyle Reservoir summary of short term (sub-daily) to long-term (seasonal) thermal response

Label	Description
A, A'	Surface waters are prone to appreciable rates of heating (A) and cooling (A'), responding quickly to atmospheric conditions. Maximum surface water temperatures are in excess of 27°C.
B	Surface waters are generally prone to larger diurnal variations in response to atmospheric conditions than deeper reservoir waters.
C	Intermittent destratification in systems that is typically weakly stratified.
D	JC Boyle Reservoir, with a small volume and short residence time response more akin to a river than a reservoir when thermal loading is small in the late fall months. Note that JC Boyle Reservoir is isothermal at close to 4°C by 11/14/00 (as compared to Copco and Iron Gate Reservoirs which are both nearly isothermal by mid-November at about 8-9°C).

R RIVER AND RESERVOIR FLOW DATA

All sampling dates shown as vertical dashed lines. Flow data below the Iron Gate Dam station was unavailable after 9/30/00.

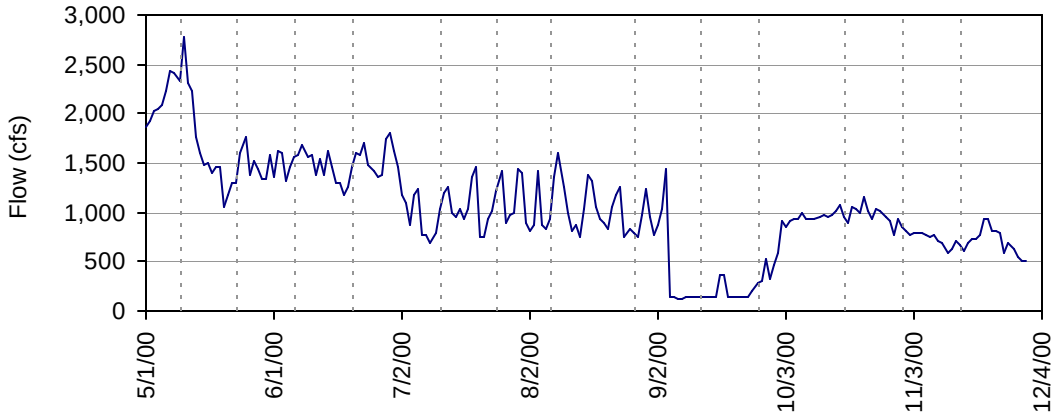


Figure R-1 Klamath River below Link Dam, daily

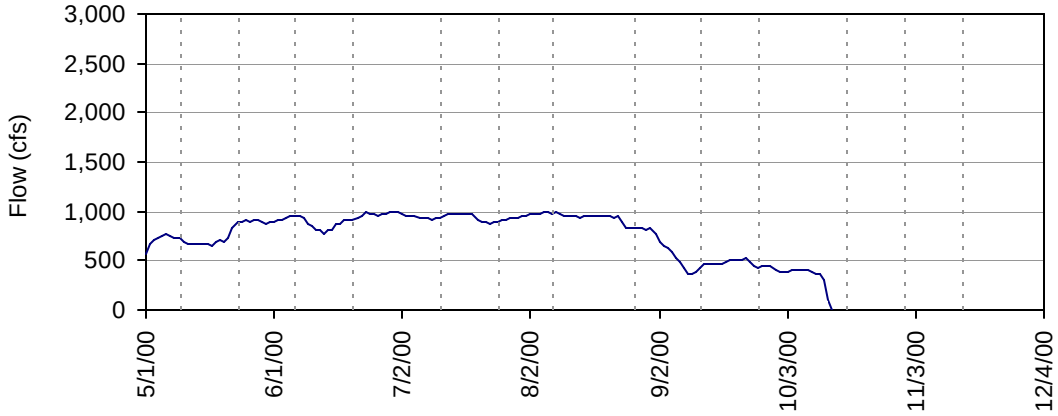


Figure R-2 A-Canal, daily

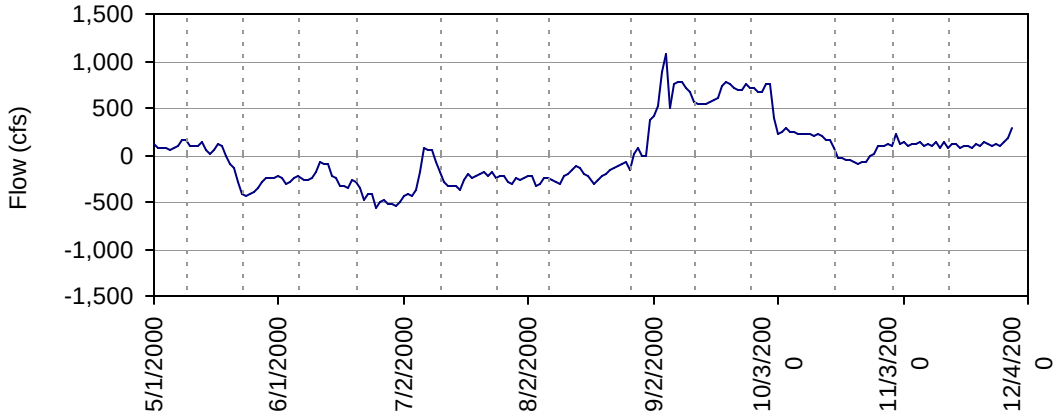


Figure R-3 Lost River Diversion Canal to Klamath River, daily

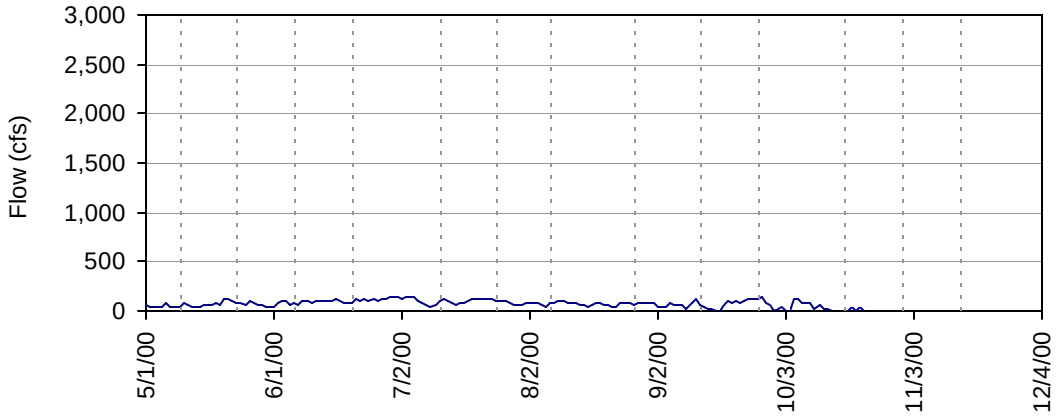


Figure R-4 North Canal, daily

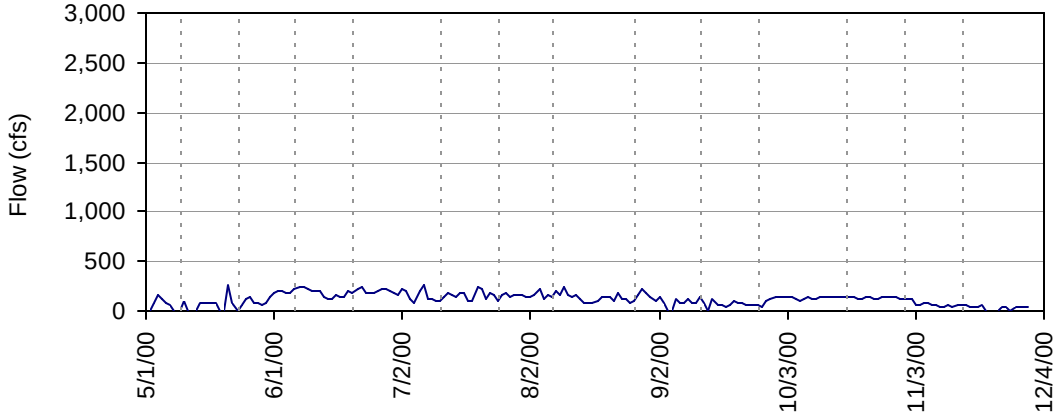


Figure R-5 ADY Canal, daily

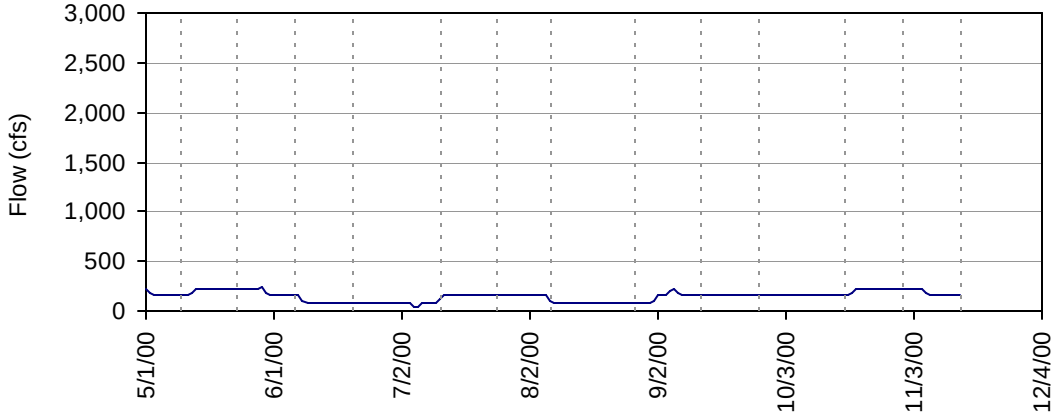


Figure R-6 Klamath Straits Drain – P Canal, daily

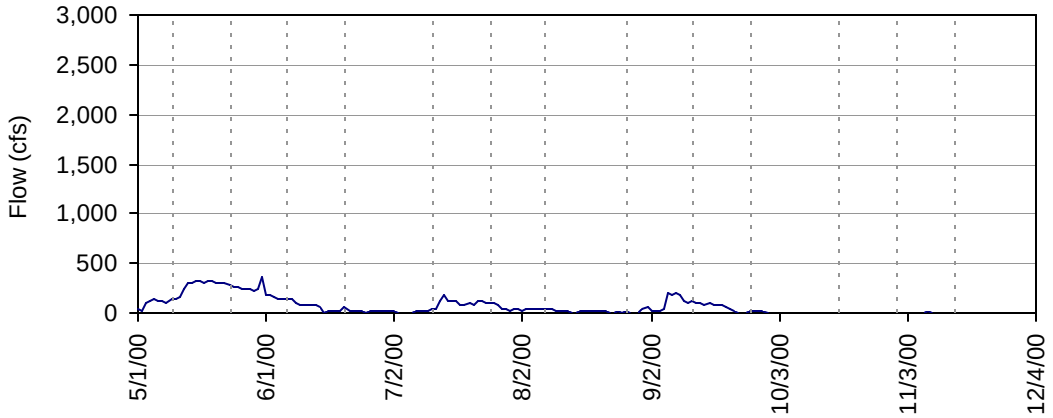


Figure R-7 Klamath Straits Drain at State Line, daily

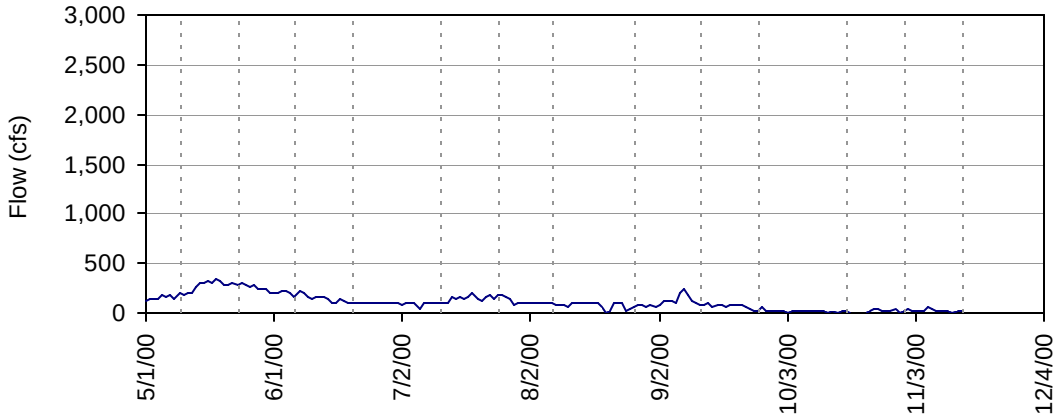


Figure R-8 Klamath Straits Drain at Highway 97, daily

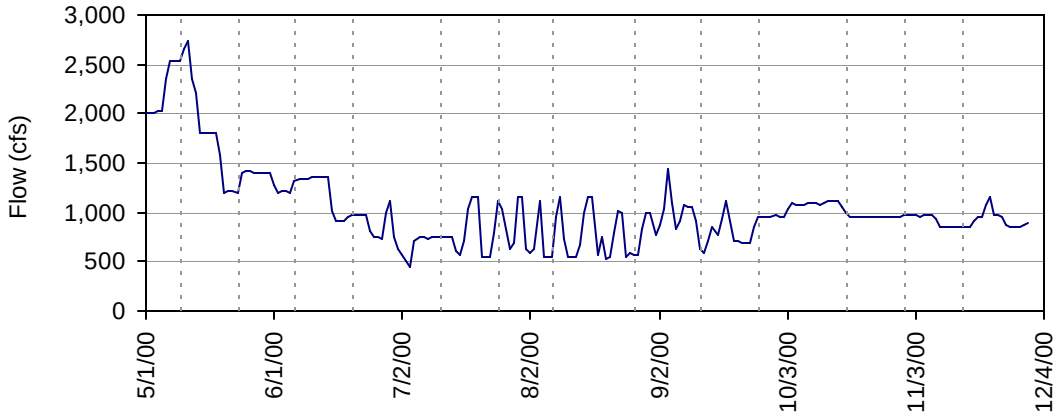


Figure R-9 Klamath River at Keno, daily

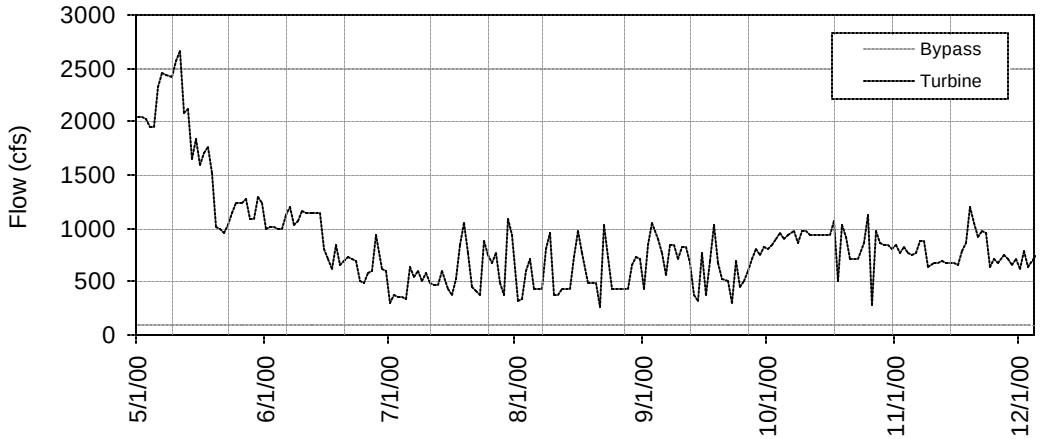


Figure R-10 JC Boyle Reservoir release, daily

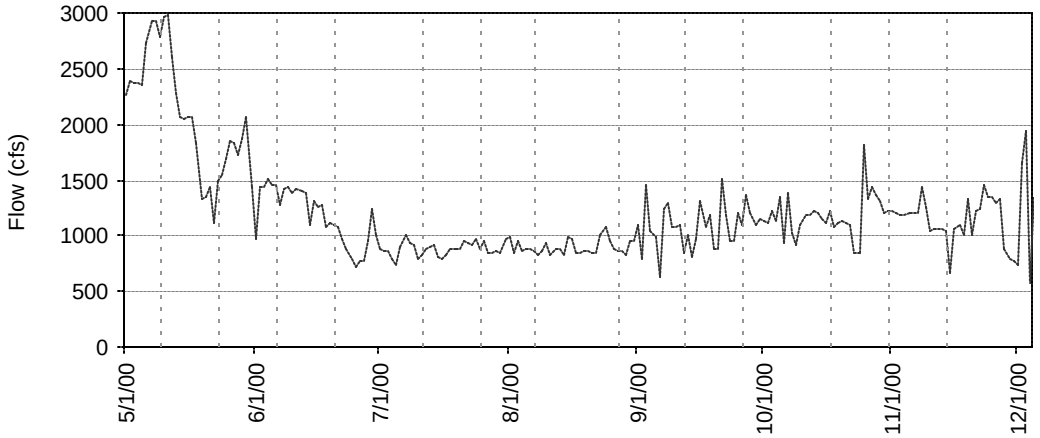


Figure R-11 Copco No. 1 Reservoir releas e, daily

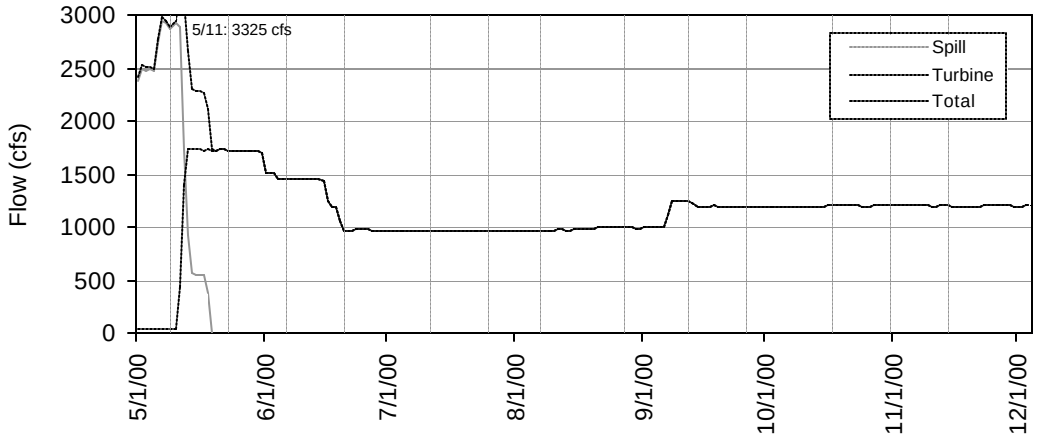


Figure R-12 Klamath River below Iron Gate Dam, daily

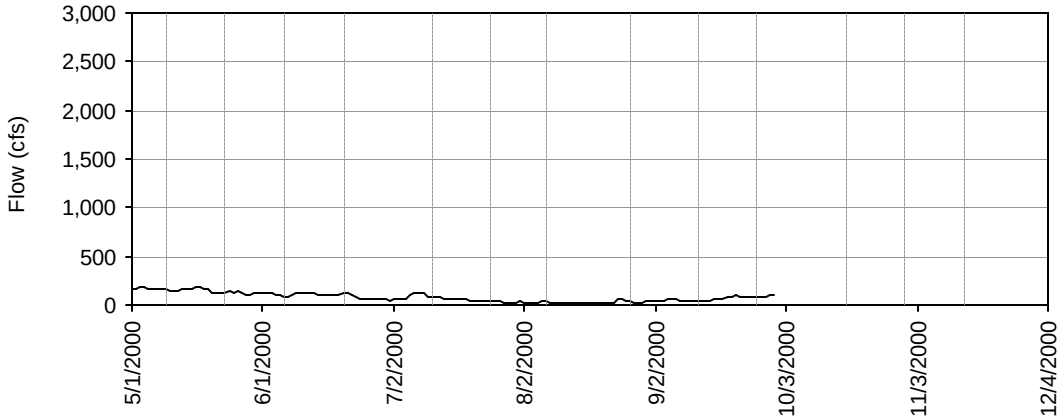


Figure R-13 Shasta River near Yreka, daily

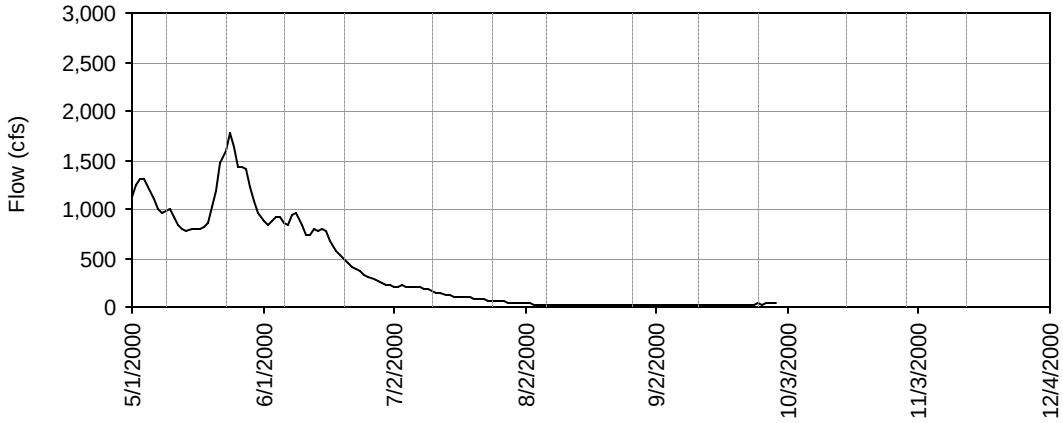


Figure R-14 Scott River near Ft. Jones, daily

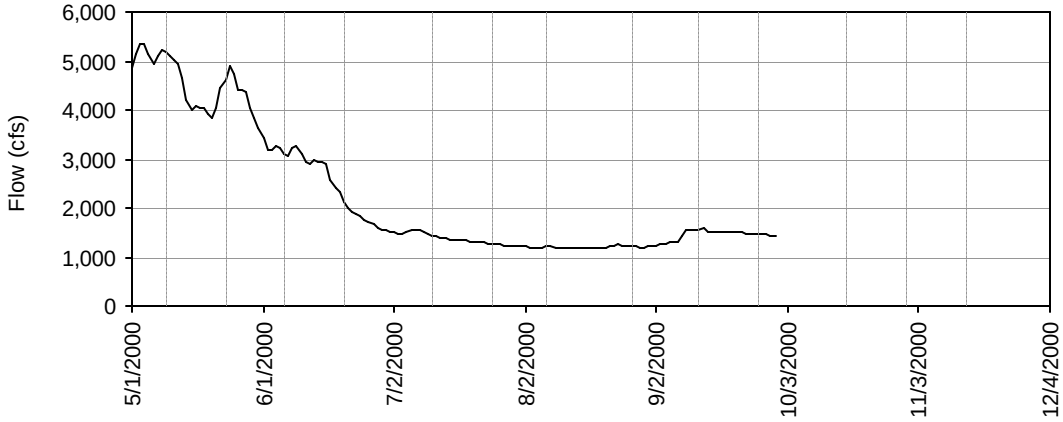


Figure R-15 Klamath River near Seiad Valley, daily

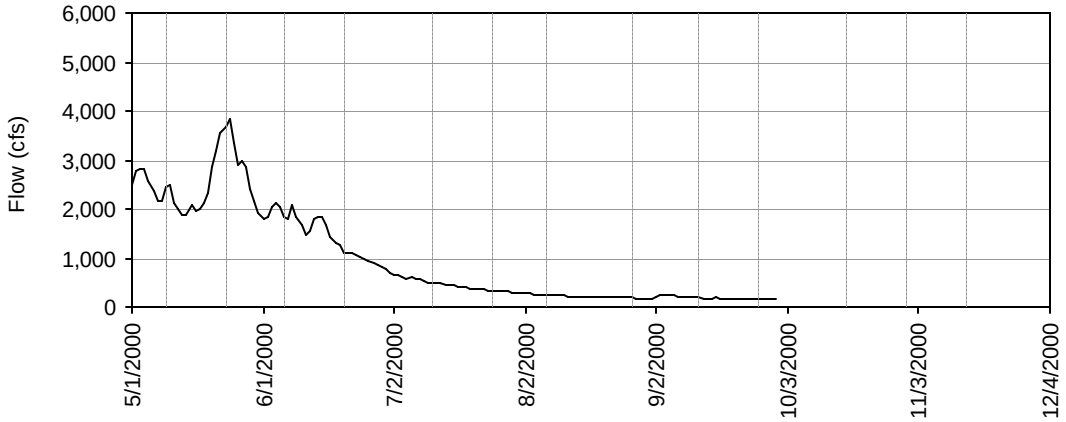


Figure R-16 Salmon River at Somes Bar, daily

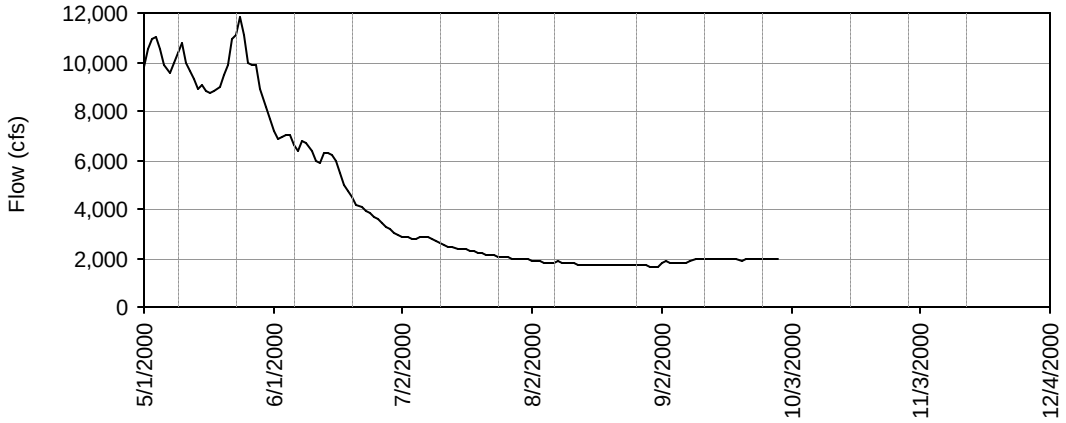


Figure R-17 Klamath River at Orleans, daily

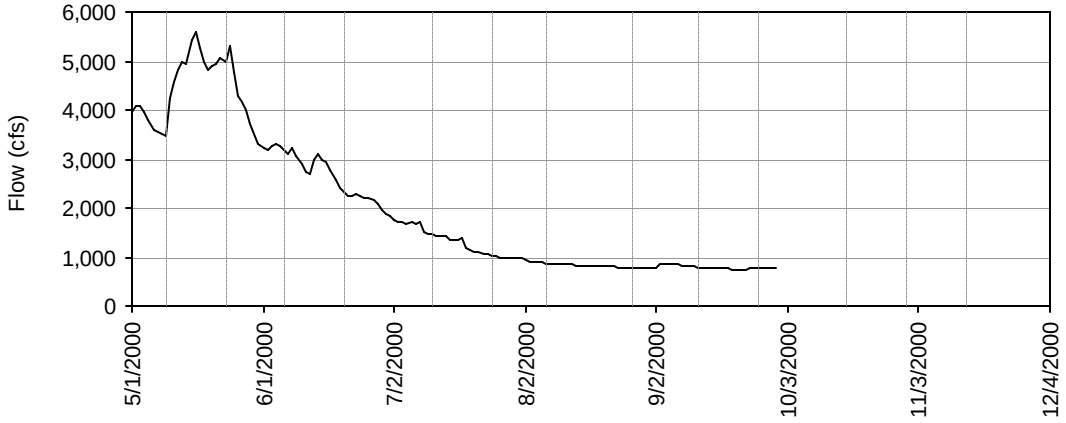


Figure R-18 Trinity River at Hoopa, daily

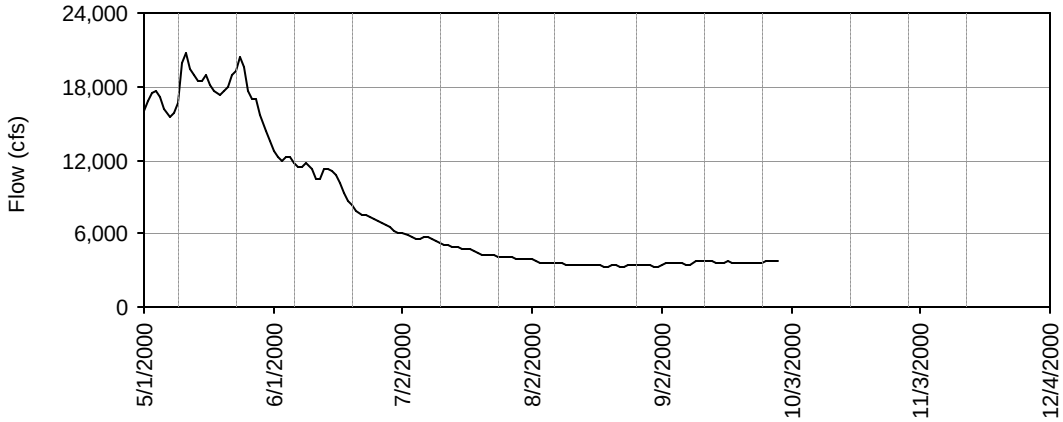


Figure R-19 Klamath River near Turwar Creek, daily

S RESERVOIR STAGE AND VOLUME DATA

Reservoir storage is "total" versus "active." Total storage is the entire volume of the reservoir, while active storage refers the storage that is actively managed for day-to-day operations. Total maximum storage at JC Boyle is 3495 acre-feet, at Copco No. 1 is 45,500 acre-feet, and at Iron Gate Reservoir is 58,794 acre-feet. Active maximum storage at JC Boyle is 1724 acre-feet, at Copco No. 1 is 6235 acre-feet, and at Iron Gate Reservoir is 3790 acre-feet.

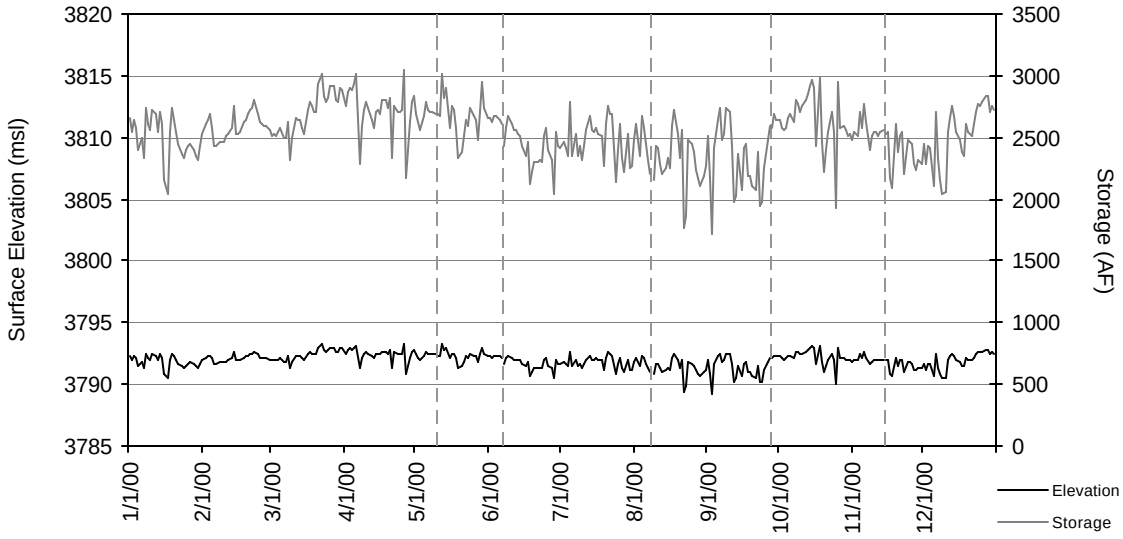


Figure S-1 JC Boyle Reservoir daily stage and volume

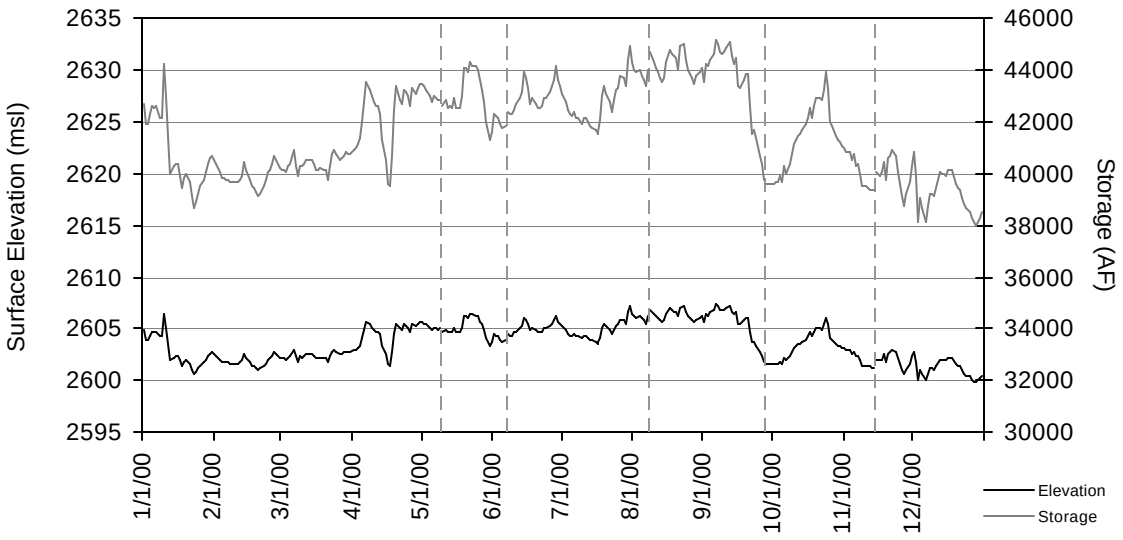


Figure S-2 Copco No. 1 Reservoir daily stage and volume

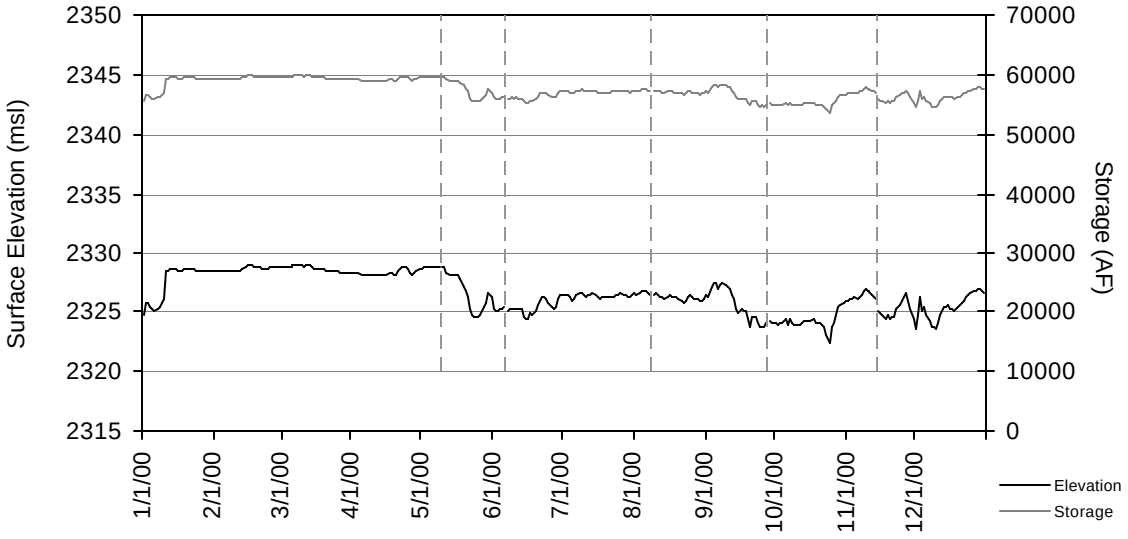


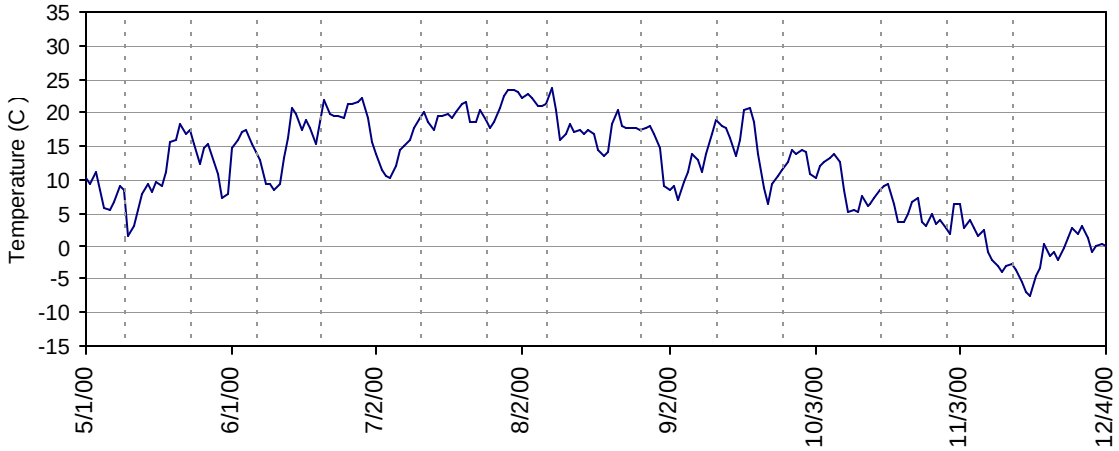
Figure S-3 Iron Gate Reservoir daily stage and volume

T METEOROLOGICAL DATA

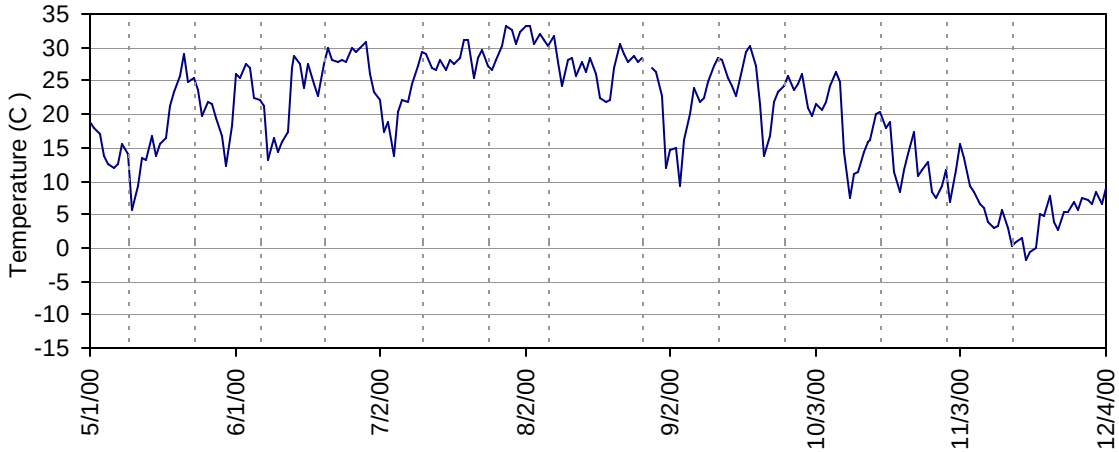
Because conditions change spatially throughout the basin due to elevation, orographic features, and other local effects, meteorological data for two locations are presented: Klamath Falls, Oregon, and Brazie Ranch, California, which is near Yreka. These two stations are used to represent two portions of the project study area. The Klamath Falls station is assumed to represent conditions in the USBR project study area as well as Lake Ewauna and the Klamath River down to JC Boyle Reservoir. The Brazie Ranch station is presumed to approximately represent conditions in the middle Klamath River from Iron Gate Reservoir to Seiad Valley. No complete meteorological stations were available in the lower Klamath River. There are obvious limitations to the extrapolation of data from one location to another, and certain locations are not well represented by either of these two locations. Nonetheless, the meteorological conditions provide useful information for interpreting water quality data.

The Klamath Falls station is maintained by the U.S. Bureau of reclamation and is part of a satellite-based network (The Pacific Northwest Cooperative Agricultural Weather Network) of automated agricultural weather stations. The stations are located in irrigated agricultural areas throughout the Pacific Northwest and are dedicated to regional crop water use management and research. The data listed below are from the Klamath Falls, Oregon Station (KFLO), elevation 4100 feet, latitude 42° 09' 53" and longitude 42° 09' 53". The May-December 2000 mean, maximum, and minimum air temperature, and relative humidity, dew point temperature, wind speed, and solar radiation are presented in Figure T-1 to Figure T-5, respectively.

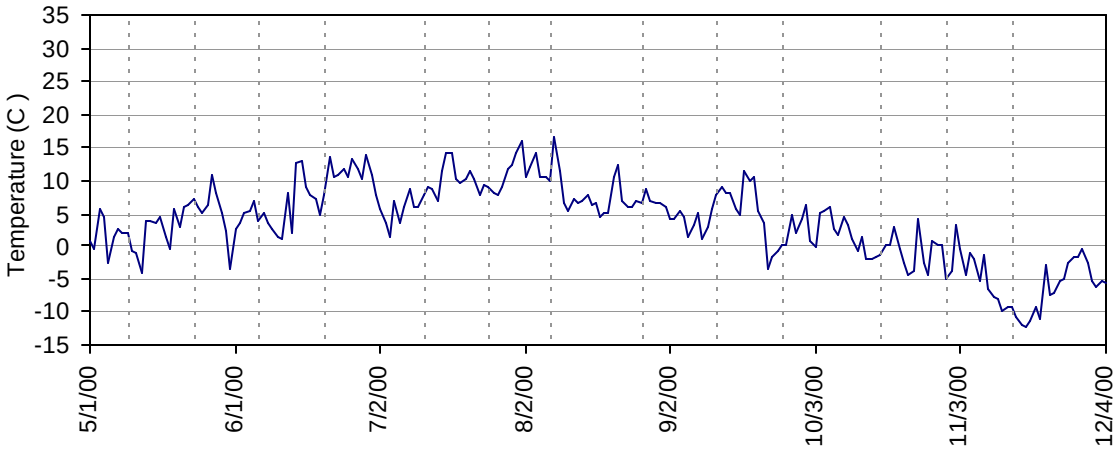
The Brazie Ranch station is maintained by the California Department of Forestry as part of their RAWS (remote automatic weather station) program. The station (BZR) is located at elevation 3020 feet, latitude 41.6870° and longitude 122.6000°. The May-December 2000 mean, maximum, and minimum air temperature, wind speed, and relative humidity are presented in Figure T-6 to Figure T-8, respectively. The meteorological station at Brazie Ranch experienced several periods where data were not collected. Dew point is not reported at Brazie Ranch, and solar radiation was not collected previous to September 2000 and is not presented. Data at Brazie Ranch are not corrected for daylight savings time. All sampling days are depicted by a vertical dashed line in each figure.



(a)



(b)



(c)

Figure T-1 Daily air temperature at Klamath Falls Oregon (KFLO), (a) mean, (b) maximum, (c) minimum (sampling dates shown with dashed lines)

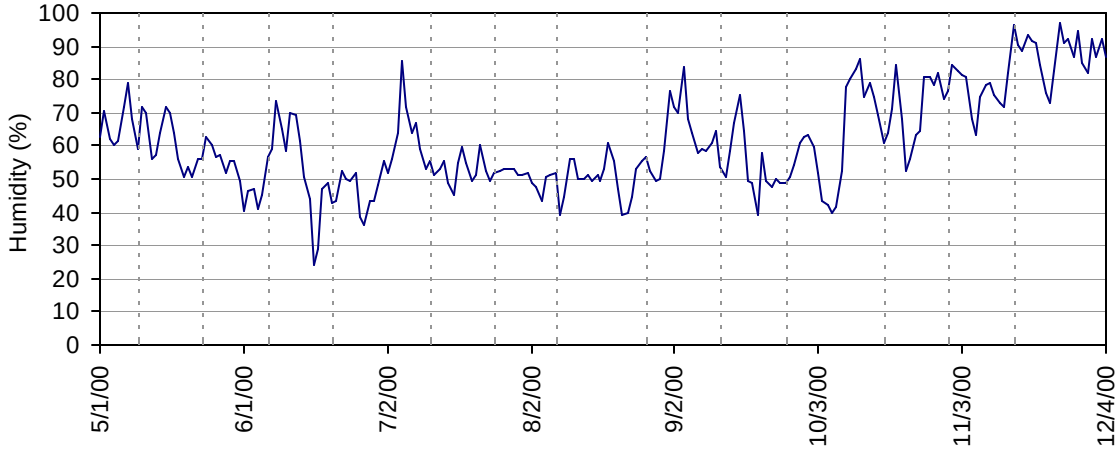


Figure T-2 Daily relative humidity at Klamath Falls Oregon (KFLO)

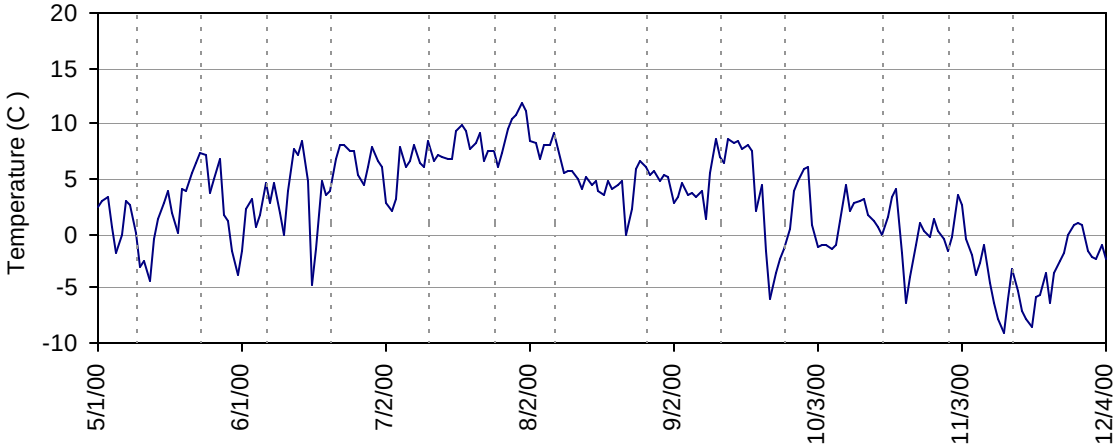


Figure T-3 Daily dew point temperature at Klamath Falls Oregon (KFLO)

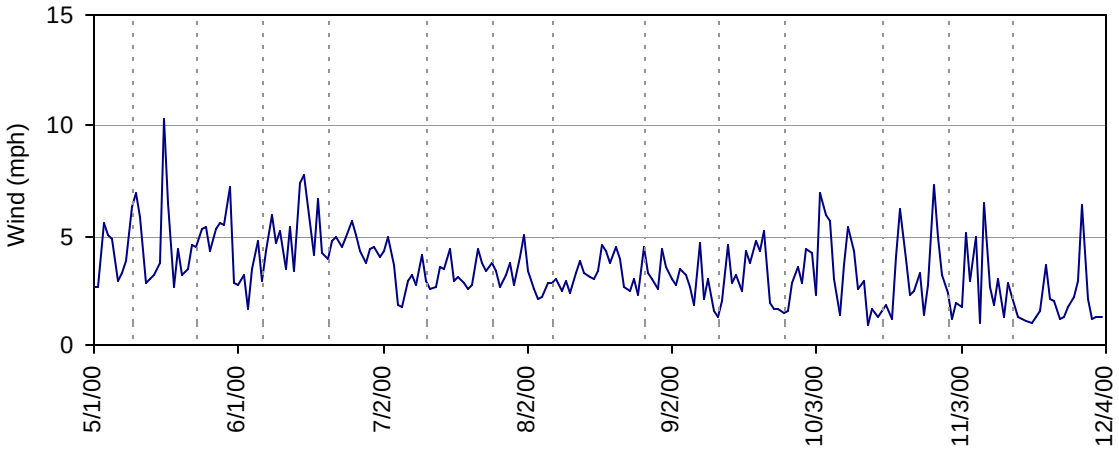


Figure T-4 Daily wind speed at Klamath Falls Oregon (KFLO)

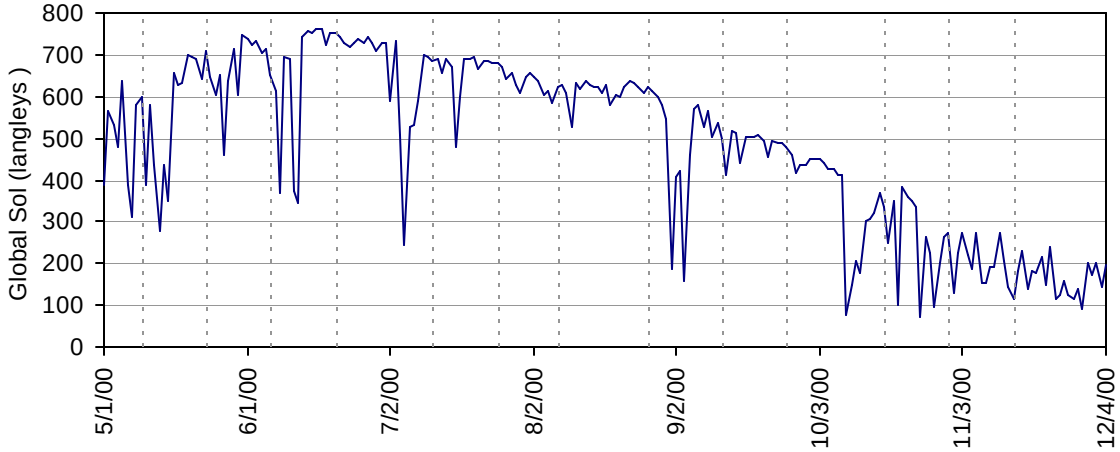
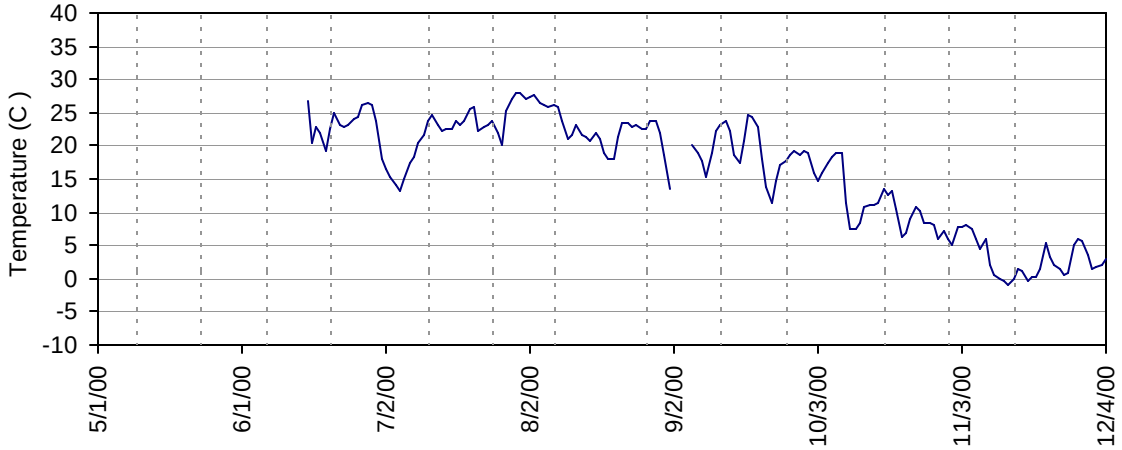
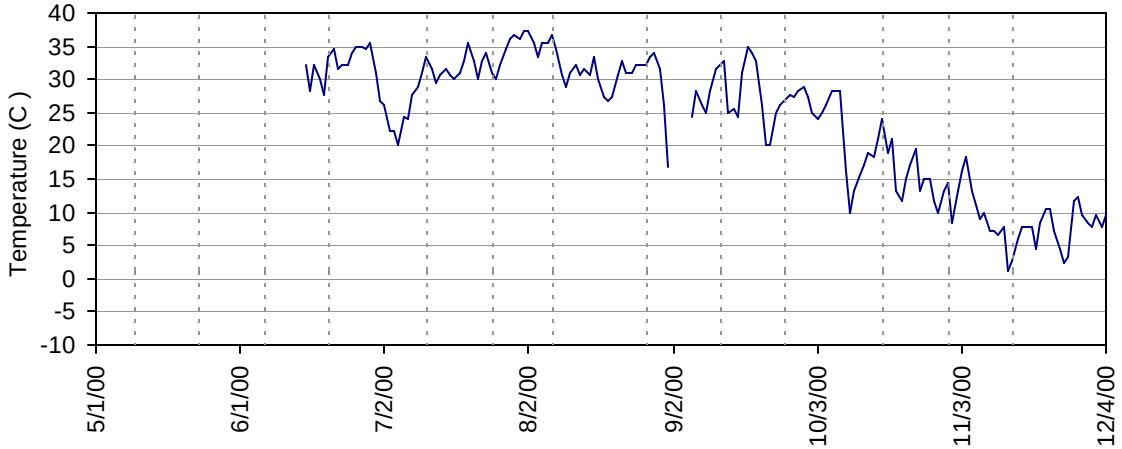


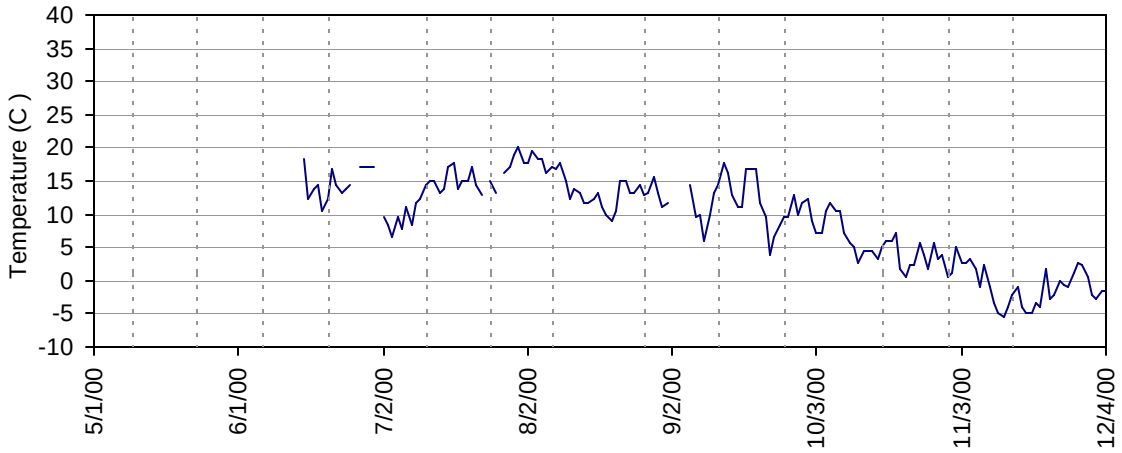
Figure T-5 Daily solar radiation at Klamath Falls Oregon (KFLO)



(a)



(b)



(c)

Figure T-6 Daily air temperature at Brazie Ranch (BRZ), (a) mean, (b) maximum, and (c) minimum

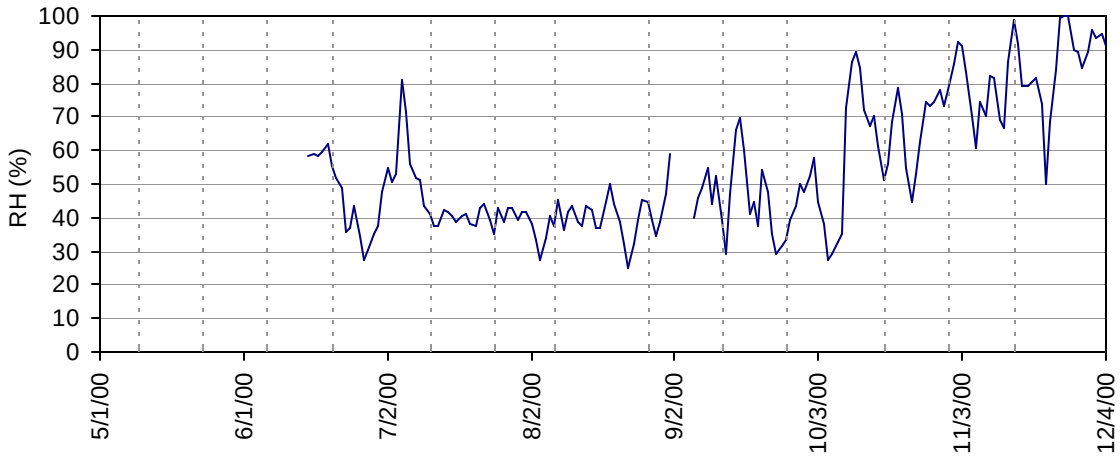


Figure T-7 Daily mean relative humidity at Brazie Ranch (BRZ)

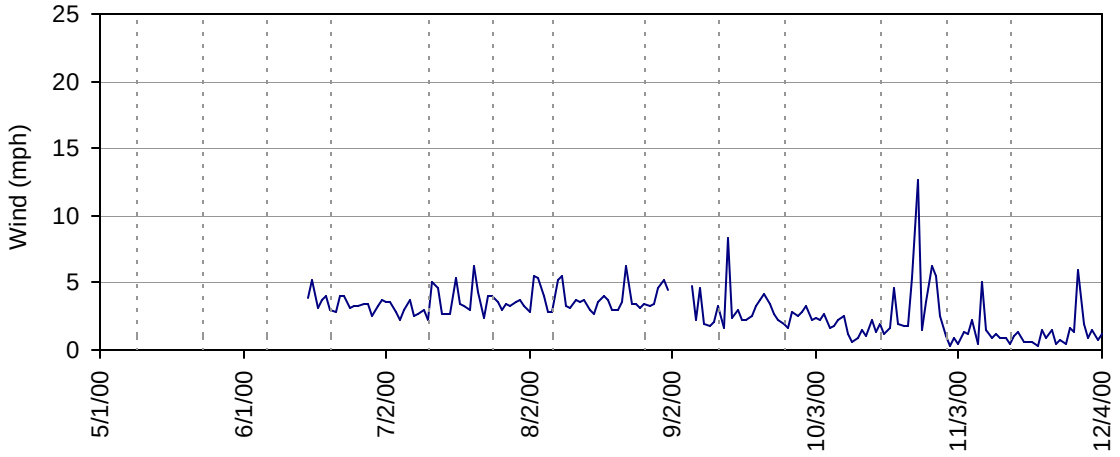


Figure T-8 Daily mean wind speed at Brazie Ranch (BRZ)

U DATASONDE POPULATION TESTING

"After I purchased my first watch I knew exactly what time it was; since I received a second one as a gift, I haven't a clue." Anonymous

The water quality probes used in this project included Hydrolab Datasonde III as well as the H-20 models. The Datasondes were used for remote deployment in the study area, while the H-20 units were used to collect physical parameter information during grab sampling. Scientists, field technicians, resource managers, and others who have used multiple water quality probes in field studies have noted that, although the units theoretically should produce coincident results, it is not uncommon to find two or more probes that record different parameter values when sampling the same water - differences that are in excess of factory specification. Most likely, the differences occur due to improper calibration, probe drift, probe malfunction, instrument mishandling, improper membrane, not letting a membrane mature, hardware, and/or age. Regardless of the cause, the fact that when immersed in a common body of water observations among probes can differ in excess of factory specifications.

Building on past experience, the protocol for probe deployment in the Klamath basin was changed in two fundamental ways. First, each sampling site was assigned two probes. These probes would be exchanged on a weekly basis and would only be used at that site. Second, all probes would be tested in a common body of water to ascertain differences, providing information, to the degree possible, for post correction of the data. Other minor changes in protocol included cleaning the probes more completely and formulating a deployment protocol

The impetus behind the simulataneous testing of Datasondes was not only to compare units directly, but to ascertain a "population" accuracy for the entire assemblage of units (Datasondes and H-20 units). Because no known standard was available to test each unit, the mean value for the entire population was assumed representative of actual water quality conditions.

U.1.1 Experimental Method

Hydrolab Calibration

The "Hydrolab Datasonde 3 and H20 calibration protocol" was followed for the calibration of the units. The units were calibrated at the Bureau of Reclamation Klamath Basin Area Office. Similar setup was used for both the Spring and Fall testing.

Specific conductance was calibrated with a 300 µs/cm standard and a specific conductance linearity check was completed with a 147 µs/cm standard. The pH was calibrated using pH 7 and pH 10 standards. The dissolved oxygen sensors with standard dissolved oxygen membranes were calibrated using the method outlined in the "Hydrolab Datasonde 3 and H20 calibration protocol". The dissolved oxygen sensors with Lo-Flow dissolved oxygen membranes were calibrated using the method outlined in the Hydrolab Datasonde 3 operating manual. Units placed in the tub with Lo-Flow membranes are units that were deployed with Lo-Flow membranes in the field.

Set-up
The tub utilized for the December 20, 2000 measures 30”x 30”x 24” and is made of high-density polyethylene. The bottom of the tub was insulated from the floor with two “Rubbermaid Rough-Tote” container lids. The “Rubbermaid Rough-Tote” container lids are ~2” thick and are constructed of two layers of plastic with air between.

A 20-slot aluminum map rack supported the Hydrolab units in a vertical position. The aluminum map rack measures 21”x 16”x 25” (LxWxH). Hydrolab units not supported directly by the rack were attached to the rack with loops of wire (see photos). Units that were supported by wire loops were spaced the same distance apart as the units directly supported by the map rack.

Two 12-volt 500 GPH bilge pumps were used to circulate the water in the tub. One pump was placed in the northwest corner and the other was placed in the southeast corner of the tub. A one foot curved hose was attached to the output of each pump, which created a swirling flow within the tub.

All Hydrolab Datasonde 3 and Hydrolab Recorder units were fitted with weighted sensor guards immediately prior to placement in the tub. Stirrer/sensor guards were used for the Hydrolab H20 units. The stirrers on the H20 units were operated during the course of the tub test.

The tub was filled and both pumps were allowed to run for at least 30 minutes prior to the submersion of any units. The first unit was submerged at ~10:41 am. The addition of Hydrolab units continued until the last unit was submerged at ~11:15 am.

Once all of the units were in the tub, photos were taken and the lid was put in place. The lid to the tub didn’t fit snug. There was a 3” gap at the northwest corner because the cables on the H20 units extended beyond the top of the tub. Two 5’x 8’ insulating blankets (hazardous materials absorbent sheets) were folded in half and placed on the lid of the tub with the excess of the blanket draped over the sides of the tub.

Problems/Difficulties
One of the problems encountered while conducting the tub test was the loose fit of the lid on the tub. The cables to the H20 units extended beyond the top of the tub and prevented a snug fit of the lid. There was a gap ~3” at the northwest corner of the tub. The southeast corner of the lid fit snug on the top of the tub. Another problem encountered was one of the H20 units experienced an internal battery failure which caused the unit to shut down. An external battery was connected and the operation of the unit was restored.

U.1.2 Data Processing

The probes were tested in the spring prior to initial deployment and in the fall upon completion of the monitoring season. The method of processing the data was the same for each test. Differences between the spring and fall test are noted.

It was assumed that constant water temperature represented steady-state conditions. Review of the data for the other examined constituents (dissolved oxygen, pH, and specific conductance) supported this assumption. For the spring test, probes recorded information every 30 seconds and a fifteen-minute steady-state period was identified for analysis. For the fall test, probes recorded information at one-minute intervals and a thirty-minute period steady-state period was identified for analysis. In each case there were 30 samples. Twenty-seven probes (with two failures) were tested in the spring and twenty-four in the fall testing.

The average and standard deviation for each parameter for each probe were calculated using data from the identified steady state period. Subsequently, the population means, maximums, minimums, and standard deviations of all the probes for each parameter were calculated using the individual probe averages. Tables 1 and 2 summarize the average values for temperature, dissolved oxygen, pH, and specific conductance time series during the steady-state period for the spring and fall test, respectively. The statistics at the bottom of each table represent the population mean, maximum, minimum, and standard deviation. These data were plotted as well (see below).

U.1.3 Findings

A comparison of the spring and fall tests was done by comparing the population standard deviations for each parameter for the two tests. Table 3 illustrates that the standard deviations are comparable. Presuming the data are normally distributed, 95 percent of the data should fall within plus or minus two standard deviations from the mean. Using the average of the spring and fall test, 95% of the recorded probe temperatures fall within ±0.23°C of the mean (assumed "true" value), pH falls within ±0.32 of the mean, specific conductance falls within ±11.77 mS/cm, and dissolved oxygen falls within ±0.72 mg/l of the mean. These ranges are not to be confused with confidence intervals, but rather illustrate the variance among the samples (probes). Note, in the fall test, one temperature probe malfunctioned and was dropped from the statistical analysis (unit number 12)

Figure U-1 through Figure U-8 present the findings of the test for both the spring and fall tests. Error bars associated with the mean value for each probe value represent ± two standard deviations (±2SD). The bold solid line is the population mean, and the dashed lines represent uncertainty associated with the individual data points (depicted by error bars) ± two standard deviations from the population mean. The error bars on the individual data points represent plus or minus two standard deviations based on the time series data (i.e., during the selected steady state period).

The temperature and specific conductance probes perform well and are generally within factory specifications. However, dissolved oxygen and pH did no fair as well. While the factory specifications on DO are ± 0.1 mg/l, the population varies (as defined by ±2SD) on the order of 0.7 mg/l. Factory specifications for pH are ± 0.1 unit and probes regularly reported values which deviated from the mean by greater than this value. These results are consistent with the findings of fled deployment of Datasonde probes. Namely, temperature and specific conductance perform well, while dissolved oxygen and pH

present data that is often inconsistent among probes – even those deployed at the same location.

U.1.4 Summary

Water quality probes are valuable instruments used in collection of certain water quality parameters. However, individual probes, for one or more of several reasons including

- human error (reading, calibration, post calibration corrections)
- calibration standards (incorrect, aged)
- deployment conditions (including testing apparatus)
- probe failure (age, malfunction, factory calibration)

As a result, the probes do not consistently report constituent concentrations when sampling a common water body. To overcome some of the limitations encountered when monitoring with multiple instruments a test of all probes simultaneously was conducted. The population means for temperature and specific conductance were consistent with factory specifications for all instruments; however dissolved oxygen and pH vary from factory specifications.

These results provide increased confidence in the use of data collected using this set of water quality probes. The tests also indicated that probes report values outside the range of their factory specified values, even when well maintained and properly operated. This variability should be incorporated into interpretation and application of all Datasonde data collected with these probes.

U.1.5 Future Work/Recommendations

The population test proved to be valuable in identifying probes that were not functioning properly, as well as the variability among the various probes. Further, although extensive measures were undertaken to ensure the probe test was carried carefully and under "steady state" conditions, there were difficulties encountered. Some of the key issues to consider in future tests include:

- Hydrolab (Datasonde) units should be calibrated using the same containers of calibration standards to avoid introducing error due to inconsistencies in different batches of calibration standards.
- individuals performing calibrations should use the same batch of de-ionized water. Different batches of DI water may have different concentrations of impurities. To avoid any discrepancies in calibrations due to differing quality of rinse water, all calibrations should be completed using the same rinse water.
- Hydrolab calibrations should be performed in similar environmental (office) conditions. All locations where calibrations are conducted should have similar wind current, air temperatures, etc.
- Hydrolab units should be calibrated the same day of the tub test. Units were calibrated over a two-day period for the fall test.
- longer "steady-state" periods (e.g. hour) leading to a larger sample for analysis may be desirable.
- improved control of environmental conditions (e.g., insulation, minimal disturbance, sufficient in tank mixing, etc.)

- specific tests over a range of conditions (e.g., multiple water temperatures, pH values, specific conductance)
- more complete statistical analysis

The tests are time and resource intensive, as are the data analyses. The tests carried out under this project were deemed sufficient to fulfill the objectives identified above in an economical manner.

Table U-1 Datasonde water quality probe test summary – spring 2000

Probe Information		Temp	pH	SC	DO (mg/L)
Probe #	Serial #	(^oC)		(µS/cm)	(mg/l)
1	tt36818	11.93	8.27	303.17	5.51
2	tt10797	12.14	8.14	315.70	4.67
3	tt12018	failed			
4	tt12084	12.23	8.27	311.60	5.18
5	tt12086	12.18	8.14	317.97	4.77
6	tt14352	12.02	8.15	306.07	5.66
7	tt14353	12.05	7.90	311.03	5.25
8	tt14507	11.92	8.03	296.00	4.58
11	tt14667	12.05	8.67	315.03	5.48
12	tt14825	failed			
13	tt14886	12.11	8.23	308.23	5.27
16	tt14889	12.06	7.97	319.17	4.54
17	tt14909	12.16	7.71	311.00	5.39
19	tt14911	12.05	8.35	307.63	4.93
20	tt14912	12.10	8.24	315.47	5.20
21	tt14913	12.06	8.22	305.37	5.07
22	tt14914	12.08	8.00	317.67	4.86
23	tt14915	11.95	8.22	312.80	4.96
24	tt14916	12.10	8.20	314.00	5.17
25	tt15809	11.90	8.15	301.00	5.00
26	tt15817	12.04	8.27	308.00	5.09
28	tt18396	11.91	8.14	311.03	4.69
29	tt18397	11.89	7.90	310.60	5.17
30	tt18398	11.85	7.78	320.00	4.79
31	tt23363	11.89	8.14	320.00	4.80
34	tt36817	11.91	8.15	320.80	5.06
35	tt36818	11.93	8.27	303.17	5.51
	Mean	**12.02**	**8.14**	**311.30**	**5.06**
	max	12.23	8.67	320.80	5.66
	min	11.85	7.71	296.00	4.54
	stdev	0.10	0.19	6.51	0.31

Table U-2 Datasonde water quality probe test summary – spring 2000

Probe Information		Temp	Temp	pH	SC	DO
Probe #	Serial #	(^oC)	(^oC)		(µS/cm)	(mg/l)
1	TT12018	20.58	20.58	7.68	140.12	6.48
2	TT12084	20.52	20.52	7.57	146.90	6.57
3	TT12086	20.85	20.85	7.62	149.51	6.59
4	TT14352	20.46	20.46	7.58	150.00	6.90
5	TT14353	20.71	20.71	7.52	139.31	6.51
6	TT14508	20.80	20.80	7.77	148.97	6.37
7	TT14666	20.80	20.80	7.66	148.94	6.78
8	TT14667	20.55	20.55	7.63	146.94	6.51
9	TT14887	20.47	20.47	7.62	150.00	6.54
10	TT14888	20.82	20.82	7.71	151.65	6.30
11	TT14889	20.69	20.69	7.61	150.35	6.11
12	TT14910	*17.74*		7.59	137.68	7.14
13	TT14911	20.70	20.70	7.55	152.00	7.21
14	TT14912	20.51	20.51	7.71	158.74	6.50
15	TT14913	20.75	20.75	7.61	148.00	6.12
16	TT15809	20.61	20.61	7.46	152.26	6.46
17	TT15818	20.44	20.44	7.65	150.00	6.46
18	TT23363	20.59	20.59	7.59	148.53	6.41
19	TT23365	20.65	20.65	7.41	150.97	7.34
20	TT14665	20.76	20.76	7.54	150.97	5.75
21	TT23120	20.62	20.62	7.56	149.00	6.21
22	TT23364	20.65	20.65	7.69	149.55	7.27
23	TT12080	20.83	20.83	7.41	156.06	7.14
24	TT37519	20.73	20.73	7.10	150.97	7.06
	Mean	**20.53**	**20.66**	**7.59**	**149.06**	**6.61**
	max	20.85	20.85	7.77	158.74	7.34
	min	17.74	20.44	7.10	137.68	5.75
	stdev	0.61	0.13	0.13	4.66	0.41

Table U-3 Comparison of standard deviation for the spring and fall population test

		Temp	pH	SC	DO
		(^oC)		(µS/cm)	(mg/l)
Spring Test	**+/- 1 stdev**	0.13	0.13	4.66	0.41
Fall Test	**+/- 1 stdev**	0.10	0.19	6.51	0.31
Spring Test	**+/- 2 stdev**	0.26	0.26	9.32	0.82
Fall Test	**+/- 2 stdev**	0.20	0.38	13.02	0.62
	Avg. of +/- 2 stdev	*0.23*	*0.32*	*11.17*	*0.72*

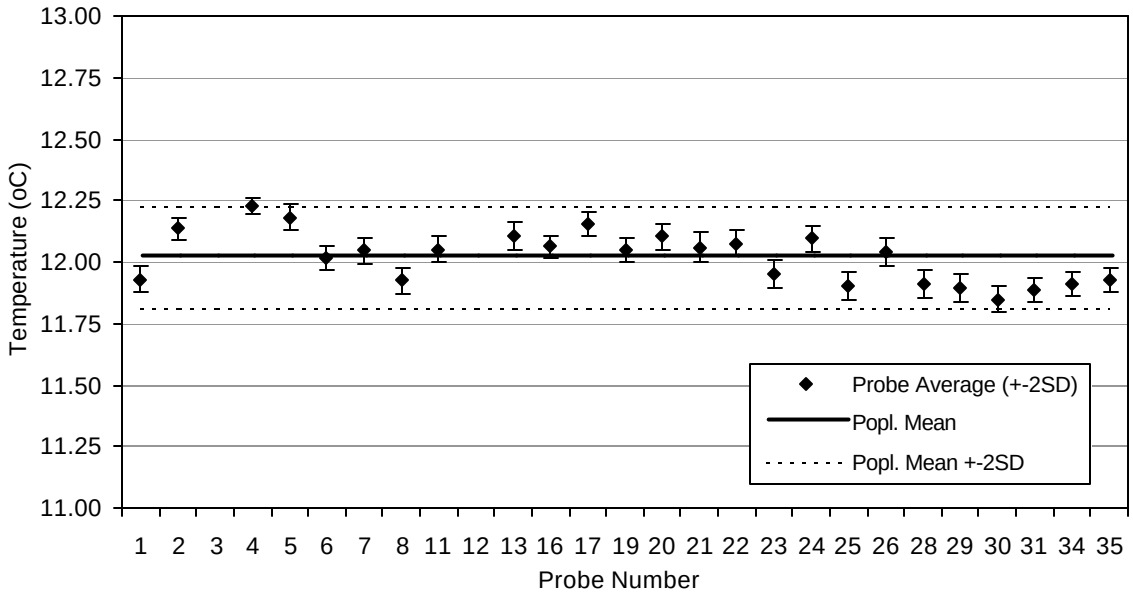


Figure U-1 Datasonde temperature probe population test results – Spring 2000

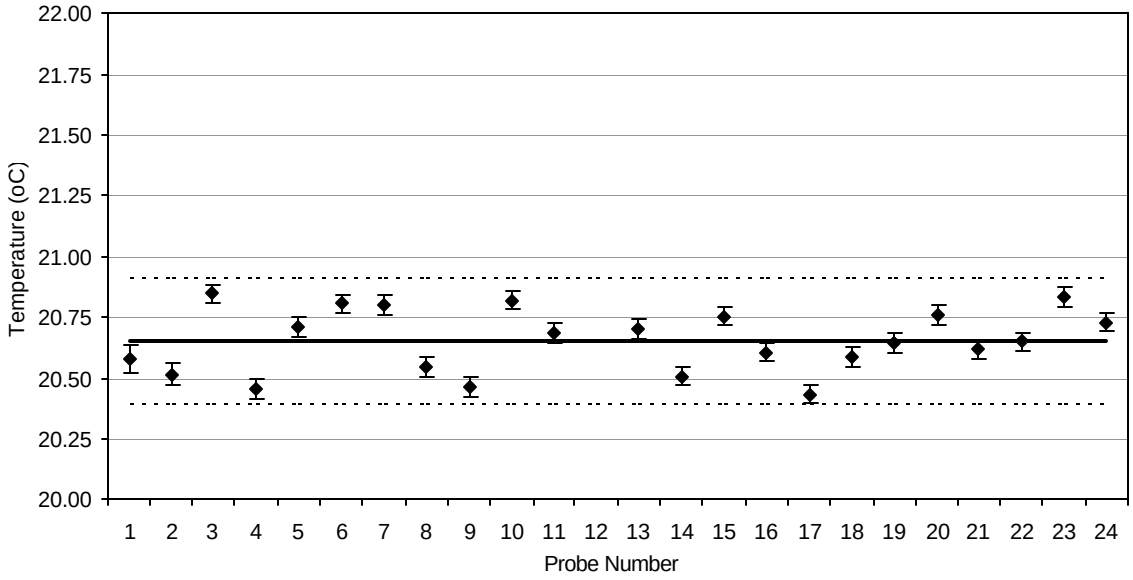


Figure U-2 Datasonde temperature probe population test results – Fall 2000

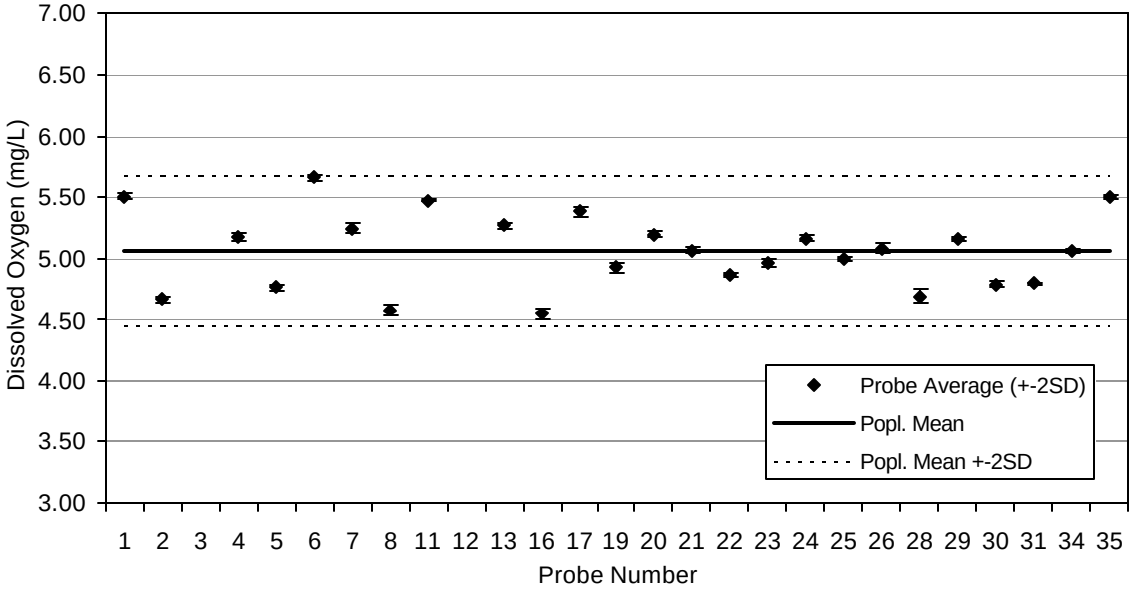


Figure U-3 Datasonde dissolved oxygen probe population test results – Spring 2000

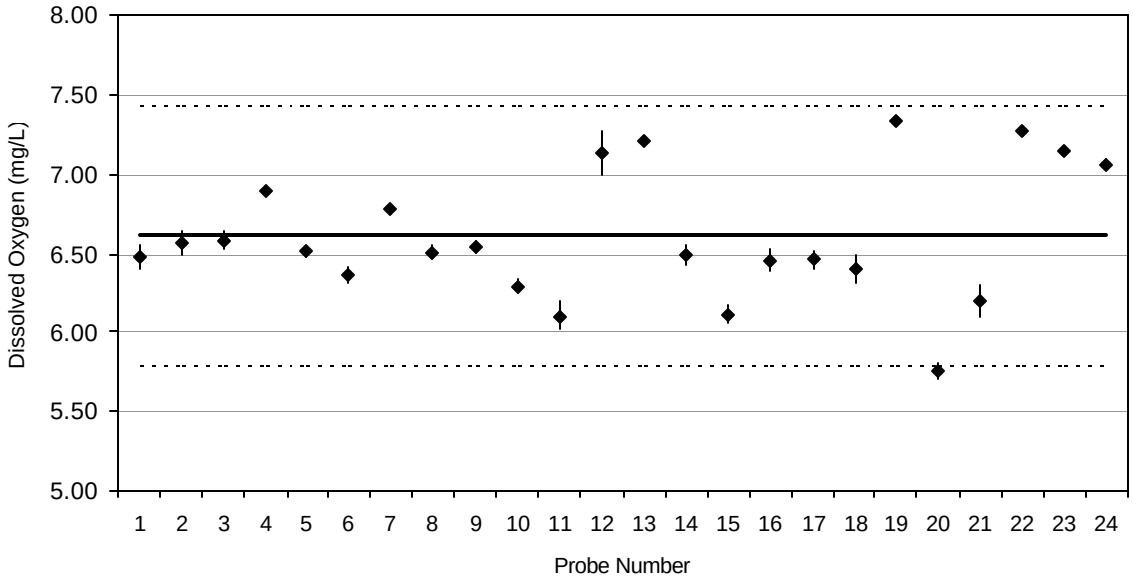


Figure U-4 Datasonde dissolved oxygen probe population test results – Fall 2000

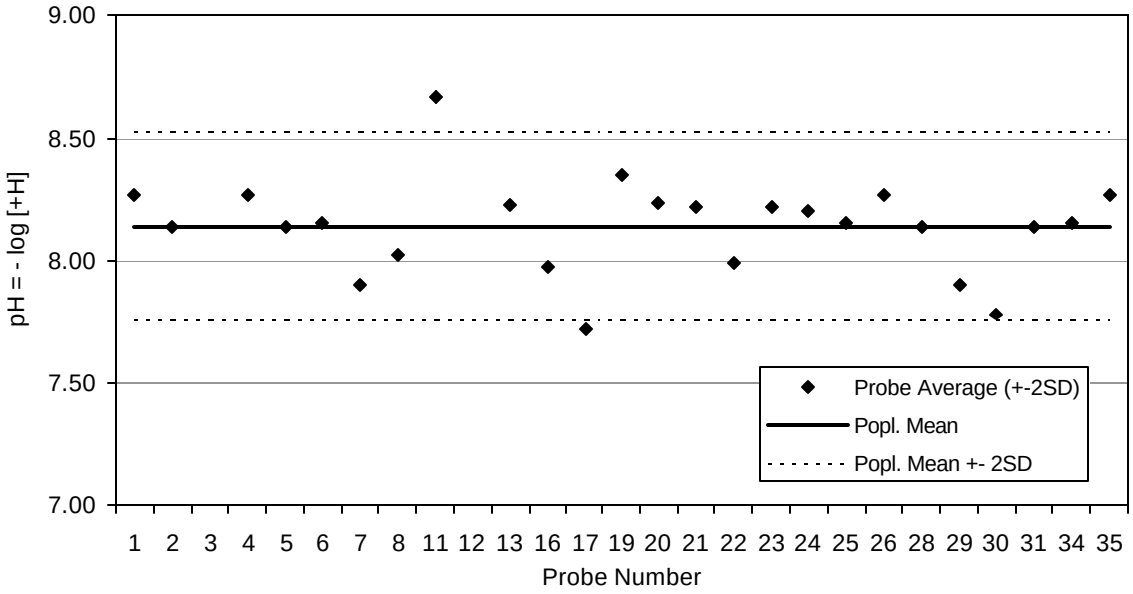


Figure U-5 Datasonde pH probe population test results – Spring 2000

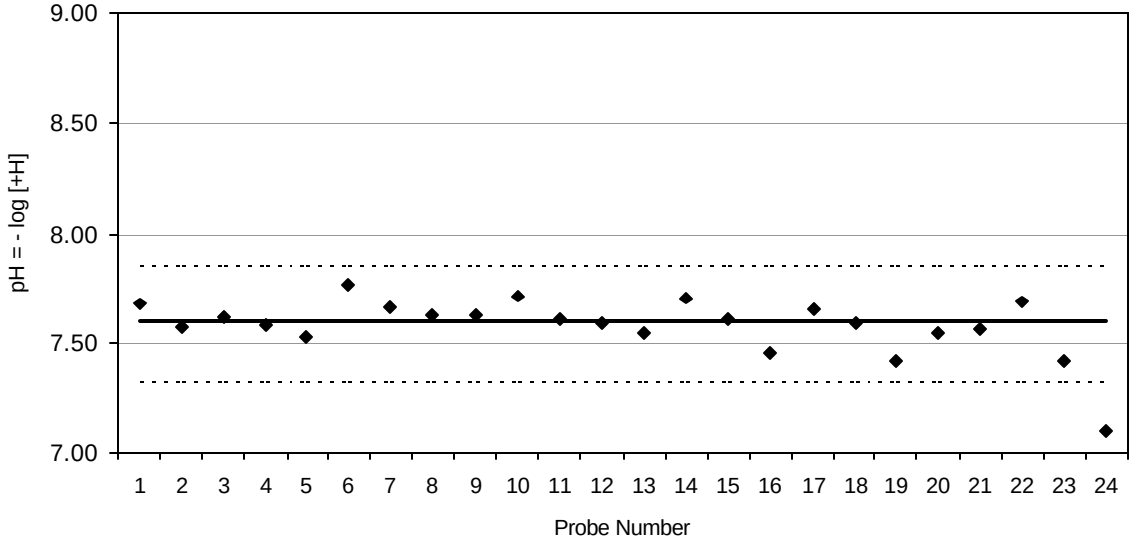


Figure U-6 Datasonde pH probe population test results – Fall 2000

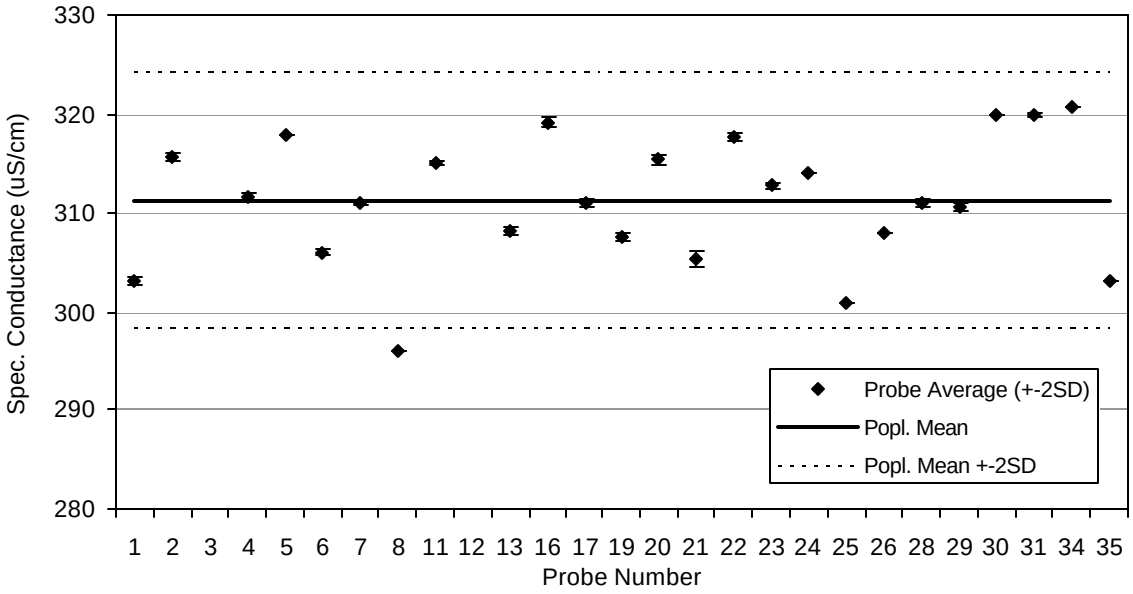


Figure U-7 Datasonde specific conductance probe population test results – Spring 2000

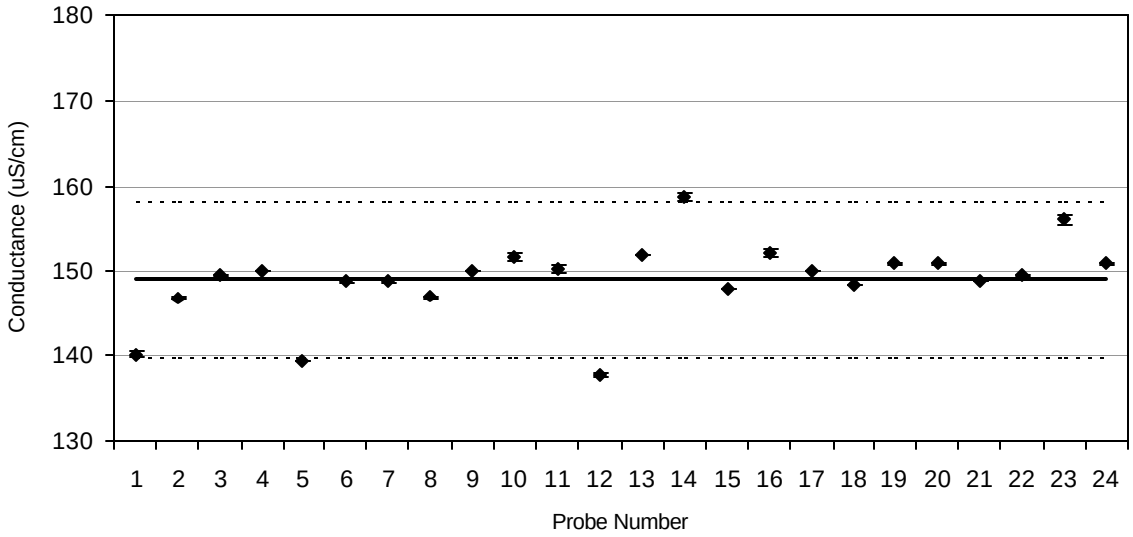


Figure U-8 Datasonde specific conductance probe population test results – Fall 2000

KLAMATH RIVER WATER QUALITY 2000 MONITORING PROGRAM
- PROJECT REPORT -

Sponsored by the

U.S. Bureau of Reclamation
Klamath Falls Area Office

with support from

PacifiCorp

Watercourse Engineering, Inc.
Napa, CA 95449

January 25, 2003

The U.S. Bureau of Reclamation contracted with Watercourse Engineering, Inc. (formerly Michael L. Deas, P.E.) to complete various studies in the Klamath River basin with respect to water quality conditions (requisition 00250000022, order number 00pg250021). The studies were intended to support long-term project operations planning as well as environmental and biological studies to determine the impacts of altering Klamath River flows from project operations on Tribal trust resources and listed, proposed, and candidate anadromous fish species under the Endangered Species Act.

Project goals included primarily gathering necessary information to improve characterization of water quality in the Klamath River basin to support existing modeling capability in the mainstem Klamath River between Iron Gate Dam and Seiad Valley. Response to diel changes in key water quality constituents, such as temperature, dissolved oxygen, and nutrient levels were deemed critical to assessing environmental and biological conditions. The project area extended from Link Dam at Upper Klamath Lake to Youngs Bar below the Trinity River, a distance of over 230 river miles. Major tributaries encompassed in the study area included the Shasta, Scott, Salmon, and Trinity Rivers. In cooperation with the U.S. Bureau of Reclamation (USBR), PacifiCorp funded water quality sampling on the mainstem reservoirs (JC Boyle, Copco, and Iron Gate Reservoirs).

The project was designed around several related tasks aimed at further characterizing water quality in the Klamath River while supporting ongoing model development. The tasks included:

- The design, implementation and oversight of water quality monitoring for the 2000 field season
- An update, as necessary, of the existing water quality model for the Klamath River mainstem between Iron Gate Reservoir and Seiad Valley, including calibration and validation of the existing model with new information. Application of the model to identified studies/analyses
- Reporting

These tasks, with the exception of "reporting," are addressed below. The individual programs and their associated subtasks were designed to answer an identified question or to provide information to gain insight into a process or processes in the Klamath River. The nature of such explorations generally spawns additional questions. During the project several issues were brought to light. Examples include identifying the potential value of including censored data (those data points that fall below the laboratory reporting limit) in the final data sets, quantifying the variability among the nearly three dozen water quality probes, relating benthic algae field data to model simulations, etc. In several cases, a decision was made to pursue these questions. The result is that in addition to the monitoring and modeling work, there are a handful of other issues documented and included in the report or in the report appendices. The desire was to broaden the scope of the project and (hopefully) not detract from it.

Design, Implementation, and Management of Water Quality Field Program

The water quality field program was the primary task in the Klamath River Water Quality Studies. The field program consisted of seven inter-related monitoring programs:

- Semi-monthly grab sampling
- Continuous water quality probe (Hydrolab Datasonde) deployment
- Water temperature monitoring
- Benthic algae monitoring
- Three-day synoptic surveys
- Trace elements screening
- Reservoir water quality sampling

As noted above, in addition to these elements PacifiCorp monitored mainstem reservoirs in coordination with USBR. All grab sample work was covered under a single QAPP, SOP, and field sampling schedule. Each program is briefly described below.

Semi-Monthly Grab Samples

The objective of the semimonthly program was to build a data set providing insight to background levels of physical and chemical constituents. Principal constituents included inorganic and organic nitrogen and phosphorous species, biochemical oxygen demand, total dissolved solids (TDS), calcium, magnesium, carbonate and bicarbonate, and chlorophyll a. Grab samples were collected twice per month from May through November at the following locations:
Klamath Reclamation Project area:

- Klamath Straits Drain at Tule Lake Outlet
- Klamath Straits Drain at Stateline
- Klamath Straits Drain at Hwy 97,

Mainstem Klamath River locations:

- Klamath River at Miller Island
- Klamath River near Keno
- Klamath River above Copco Reservoir
- Klamath River below Iron Gate Dam
- Klamath River at Seiad Valley,

Klamath River tributaries:

- Shasta River near mouth
- Scott Rivers near Ft. Jones.

USBR MP-157 assisted in identifying the need and scope of quality assurance for 2000. A quality assurance program plan (QAPP) and standard operating procedures were developed for the grab sampling program.

To accommodate the increased cost of developing and implementing the QAPP, the scope of the sampling program was modified. Certain physical parameters were dropped (e.g., sodium, chloride, manganese), while nutrients were retained and biochemical oxygen demand and chlorophyll a were added. Sampling was shifted from a frequency of every two weeks to twice per month to further reduce costs. Finally, grab sampling at three locations was eliminated: Salmon River near Somes Bar, Trinity River at Hoopa, and Klamath River Youngs Bar. The impetus for dropping these sites was based on limited existing data and the fact that only one mainstem Klamath River site was included between Seiad Valley (river mile 129) and the Pacific Ocean. It was decided to focus above Seiad Valley and seek funding for a more comprehensive/intensive monitoring program for the lower river in subsequent years.

USBR funded USFWS to provide field support for the lower river sites (from Klamath River above Copco Reservoir to Seiad Valley. All field crews were trained by MP-157 and support for

field personnel was available throughout the season. External QA samples consisting of a blank, spike, duplicate, and rinseate blank were incorporated into the grab sample program. Overall, sampling and lab results were good for all parameters except chlorophyll a. The processing lab was unable to produce results with a reporting limit less than 40 ug/l (desired reporting limit was <5 ug/l), although they worked throughout much of the field season to improve their methods.

All data have undergone validation by MP-157 and season summary reports for all data and the associated laboratories are included herein. The data was further processed to

- Estimate values below the reporting limit,
- Provide summary statistics (e.g., maximum, minimum, mean, standard deviation),
- Formulate exceedance probabilities (figures) for each site,
- Graphically depict the data on a site by site and date with error bars representing the range of variation consistent with the QAPP.

Field and processed data are included in a separate data appendix

Datasonde Deployment

Hydrolab Datasonde (Datasonde) water quality probes were used to record physical parameters at 1-hour intervals at 13 sites in the basin. Parameters included temperature, dissolved oxygen, pH, specific conductance and redox potential (not all probes). Probes were deployed at all grab sample sites, as well the Klamath River at Youngs Bar and in the Salmon River near Somes Bar and Trinity River at Hoopa. USBR provided funding to the Hoopa and Yurok tribes to assist in deployment, retrieval of Datasondes at Youngs Bar and for the Trinity River near Hoopa. The Datasonde in the Salmon River was serviced by the USFWS.

Previous water quality deployment efforts led to several changes in 2000. Probes were exchanged weekly and were shipped to and from Klamath Falls. All calibration and downloading took place in Klamath Falls. Biolfouling of the dissolved oxygen membrane was a problem at nearly all monitoring locations, sometimes occurring within 48 hours of deployment. Certain measures were taken in an attempt to minimize the biofouling including cleaning the probes thoroughly after each download. A shorter deployment time was discussed (3 and 4 day exchange frequency), but the shipping costs as well as increased field and in-house staff time were prohibitive. Field deployment and in-house calibration and maintenance protocols were formalized (attached herein) to ensure the best possible results from the probes. Still, variation among instruments was common. To quantify the variation among instruments (and individual probes) a "probe population" test was conceived wherein all probes were subject to equivalent environmental conditions and the results compared. The results of this test identified probes that consistently reported high or low values as well as quantify the variation or range of reported values. The average value of the parameter (T_w, DO, pH, specific conductance) based on all instruments was assumed to represent "actual" environmental conditions. Standard deviation was used to illustrate variance among instruments. The test was carried out prior to field season and upon completion of the field season. Most probes performed well, i.e., were within factory specifications, but dissolved oxygen and pH for many instruments ranged beyond factory specifications. All results are presented in the appendices.

To ease interpretation of the data given the variability identified in the aforementioned probe population test, efforts were made to keep the same probes at each sampling location. Due to the extensive amount of data, each location is only presented in graphical form in the data appendix. The tabular (numerical) data is included on the data CD. These data are raw data. The only processing that took place was to remove those periods of time when the probes were not in the

water. Using this data requires a review of the probe population test data, as well as consideration of in-field conditions (i.e., biofouling).

Water Temperature

There was a desire to collect additional physical parameters in the river reach between Iron Gate Dam and Seiad Valley, but resource limitations precluded the acquisition and deployment of additional probes. However, a cost effective method of collecting water temperature data was implemented wherein remote logging thermistors (Onset Corporation Stowaway®) were deployed at Cottonwood Creek, above the Shasta River; at Walker Road Bridge, above the Scott River; and Scott River at mouth. Site locations were determined based on previous studies and field monitoring efforts completed by various agencies and organizations. Because grab sampling and a Datasonde deployment occurred in the Scott River at the USGS gage near Ft. Jones (over 20 miles upstream from the confluence with the Klamath River), a temperature logger was deployed at the mouth to determine if temperature varied between the gage and the mouth. Comparison of the records did indicate that differences occurred, especially in the spring.

These remote logging devices record temperatures to ±0.2°C (0.38°F), and were downloaded at approximately 2 month intervals. All loggers were tested prior to deployment to ensure proper operation. Loggers were deployed in metal canisters (3-inch pipe) attached to shore with stainless steel cables.

Benthic Algae Monitoring

The impetus to monitoring benthic algae in the Klamath River was a direct result of previous water quality modeling efforts on the Klamath River, wherein limited algae data were available. The initial investigation was to monitor growth of algae with artificial substrate. Unglazed ceramic tiles were deployed in the river in March for a test period at three locations: below Iron Gate Dam, above Cottonwood Creek, and near the Shasta River. The site below the Shasta River was not used in the field study because of topographic and riparian shading that was inconsistent with the other two sites.

The principal finding of the test period was that grazing is an important issue. At the Cottonwood Creek site snails grazed the tiles clean. Although no grazing was apparent at Iron Gate Dam, it was decided to deploy floating periphyton samplers to minimize the impact of grazing. Three periphyton samplers (8 microscope slides each) were deployed at each site and monitored for two 4-week periods in June and August. The unglazed ceramic tiles were maintained to qualitatively address grazing and other benthic impacts. Microscope slides from the floating periphyton samplers were randomly sampled at intervals that ranged from 3 to 8 days. Detached, drifting filamentous algae (e.g., macrophytes) often fouled the samplers. This problem was overcome to a large extent by placing a t-post upstream of the samplers, effectively capturing much of the debris.

Three slides were processed individually for dry weight and ash free weight, and one slide was processed for chlorophyll a. Additionally, a sample from one collection effort was submitted for algal speciation/identification. Twelve species of diatoms were present (typical of periphyton). The dominant species tended to favor conditions with a fairly high nutrient content. Algal growth rates varied among the two sampling sites and periods. Results of these data as they pertain to model simulations are discussed below.

The floating periphyton samplers only reflect a portion of the algal assemblage in the Klamath River below Iron Gate Dam. Though periphyton is readily seen on the river bed, several other

types of algae are apparent. Most visible are the large filamentous forms dominated by *Cladophora* and *Potamogeton*. Further work is required to more completely characterize this complex fraction of the aquatic system.

Synoptic Survey

Previous studies suggested that during certain times of the day and certain seasons nitrogen species (ammonia and nitrate) might be limiting to algal growth. To ascertain sub-daily water quality conditions several synoptic water quality surveys were designed and implemented to augment the semimonthly grab sampling program and Datasonde deployment. Three synoptic surveys were completed between Iron Gate Dam and Seiad Valley during the months of June, August, and September. Two of the three synoptic surveys (June 5-7 and August 7-9) included grab sampling three-times per day for three days and the deployment of additional Datasondes. The sampling locations were:

- Klamath River below Iron Gate Dam
- Klamath River above Shasta River
- Shasta River near mouth
- Klamath River above Scott River
- Scott Rivers near mouth
- Klamath River at Seiad Valley,

The grab sample parameters included ammonia, total Kjeldahl, nitrate plus nitrite, total phosphorous, orthophosphate. In addition, two filtered samples at each site were collected: organic phosphorous and organic nitrogen. The purpose of the latter samples was to identify how much of the total organic nitrogen and phosphorous fractions were in dissolved form and presumably immediately bio-available for primary production. Data suggest that under most circumstances the majority of the organic nitrogen and phosphorous was in dissolved (versus particulate) form. Datasondes were deployed at the same locations specified for grab samples and hourly water temperature, dissolved oxygen, pH, specific conductance, and redox.

The September 26-29, 2000 synoptic survey was completed using only Datasondes. A third grab sampling effort was not deemed economical. Preliminary lab results illustrated that the there were modest variations in nutrient concentrations throughout the course of a day, but significant variations were not clearly apparent. One notable finding was the variation in nutrient concentrations between the June and August synoptic surveys. During the June survey, the data suggest that nitrogen was in short supply; while in August this was not the case. Phosphorous (as orthophosphate) levels in August were roughly half of the levels found in June.

The synoptic sampling programs were designed to coincide with the semimonthly sampling program to allow a broader (spatial) representation of water quality conditions, as well as use limited resources more economically.

Trace Elements

The 1998 and 1999 program sampled for selected metals that are deemed important to aquatic life: lead, cadmium, zinc, and copper. However, there are many additional metals and other trace elements that have potentially deleterious effects on aquatic systems. Although this component of the sampling program was not directly related to modeling, it was retained due to its potential importance in water quality conditions in the basin. After conferring with several entities, including USGS (Portland) and the North Coast Regional Water Quality Control Board, it was decided to expand the sampling from 4 metals to 15 trace elements. To accommodate the

increased number of constituents and associated costs, the sampling frequency was reduced to four times during the field season (based roughly on project operations). Monitoring occurred at the following sites:

- Link Dam
- Klamath Straits Drain at Hwy 97
- Klamath River near Keno
- Klamath River below Iron Gate Dam

Sampling was completed on May 23, June 20, July 25, and September 26, 2000. The dates were selected based on discussions with USBR staff and are intended to reflect conditions prior to, during, and near the end of irrigation season. Trace elements that were monitored included:

Aluminum	Antimony	Arsenic
Cadmium	Chromium	Copper
Iron	Lead	Magnesium
Mercury	Nickel	Selenium
Silver	Thallium	Zinc

Hardness data, as represented by calcium and magnesium, were collected coincident with these samples because several freshwater aquatic life (FAL) criteria are functions of hardness. Mercury and aluminum were above FAL criteria on multiple occasions at nearly all sites. Silver and lead exceeded FAL criteria on a few occasions. The QAPP required a different grade of bottle be employed after minor contamination was discovered.

Mainstem Reservoirs

The work completed by PacifiCorp in JC Boyle, Copco, and Iron Gate Reservoirs provided a critical link between the river reaches. The impoundment of water in and operations of these reservoirs can affect downstream river reaches.

PacifiCorp completed grab sampling and profiles of physical parameters on approximately a monthly basis for JC Boyle, Copco, and Iron Gate Reservoirs. Physical parameters included water temperature, dissolved oxygen, pH, and specific conductance. Secchi depth was also measured during field visits. Principal grab sample constituents included inorganic and organic nitrogen and phosphorous species, biochemical oxygen demand, and chlorophyll a. External QA samples consisting of a blank, spike, duplicate, and rinseate blank were incorporated into the grab sample program. Overall, sampling and lab results were good for all parameters except chlorophyll a (as noted above, the lab was unable to reproduce the desired reporting limit).

In addition to grab samples and physical profiles, PacifiCorp also placed remote logging thermistors suspended from cables attached to the booms in the aforementioned reservoirs, as well as Keno Reservoir. These temperature loggers recorded on hourly intervals and provide a much more comprehensive picture of the reservoirs when compared with the monthly profile data.

Some of the concerns that existed in the field monitoring program were not an issue in the reservoir work. Biofouling of the water quality probes did not occur because deployment was not continuous and regular maintenance kept probes in good condition. Likewise shipping probes to and from Klamath Falls was not a factor, as PacifiCorp was responsible for their own probes.

Grab sampling was done in concert with USBR, with USBR providing support for external QA spikes, as well as miscellaneous field materials as necessary.

Model Assessment and Application

Model Assessment

One component of the project was updating, as necessary, the existing water quality model for the Klamath River mainstem between Iron Gate Reservoir and Seiad Valley. This included an investigation for improving representation of benthic algae in the model as well as incorporating year 2000 data in model calibration and validation. During the benthic algae monitoring study it became readily apparent that the Klamath River benthic community was not only extremely complex, but also poorly understood. The sampling effort provided the first concrete values on growth rates, and the dynamic processes that were observed in the system. Most notable were grazing by mollusks and invertebrates and the apparent shift of algal species below Iron Gate Dam as the river temperature changed. Further, respiration rate, another model parameter was not measured.

To further evaluate the options for representing benthic algae in simulation models a literature review was completed (see attached appendix). The findings identify important parameters in modeling benthic algae, associated biomass, dissolved oxygen and nutrient effects, and the overall importance of benthic communities. Fundamentally, rivers are different environments than lakes, wherein phytoplankton (free floating) algae typically dominate. The relatively fast moving water of river systems with short residence times prove a challenge to modelers aiming to represent these processes. Selected water quality models currently available include logic to represent benthic algae; however, they are all limited in their ability to characterize the diversity of benthic communities and their complexity and dynamics.

The current model, RMA-11, presumes that algae grow in accordance with a growth rate, respiration (and mortality) rate, and are limited by light and nutrients. Nutrient limitation is based on inorganic nitrogen and phosphorous forms (the role of silica with respect to diatom growth in the Klamath River system is unknown). This fairly simple formulation incorporates only a single "bulk" community (represented by one set of parameters, i.e., it does not look at individual species) and does not directly account for losses by grazing, scour, senescence and sloughing, etc. Further, the selected initial conditions can affect simulated algal biomass at future time steps. Nonetheless, the model has provided considerable insight into the potential dynamics of primary production on water quality conditions in the Klamath River between Iron Gate Dam and Seiad Valley.

There are models available that provide a wider range of input parameters to represent the benthic community and its response on water quality. However, these models often require a large amount of data, or include simplifications of other processes that make them infeasible for most practical applications. Gathering information on the benthic community at a sufficient number of locations over a long period (e.g., spring through fall) would be required.

One available methodology may provide improved results with modest data collection costs, and at a minimum would provide additional data to the existing formulation. The general model representations follow a similar vein to that presented in RMA-11, that is the representation of a bulk community, but in this methodology algal biomass is calibrated to dissolved oxygen concentrations under steady-state conditions. Using a simulation model algal biomass is estimated consistent with dissolved oxygen observations and algal photosynthesis. Respiration

rates are calculated based on the estimated algal mass accounting for stream re-aeration. Some models accommodate grazing and sloughing as well. By calibrating to dissolved oxygen the model aggregates all benthic processes into a "bulk" community. The limitation of the methodology is that it is most readily adaptable to steady-state conditions, while the conditions of interest in many cases are highly dynamic. Nonetheless, with systematic data collection over a broad reach of river, it is plausible that sufficient data could be gathered to represent a dynamic system response in space and time. Any such water quality study should include a corresponding ecological component to characterize the flora and fauna of the benthic community.

Model Application

The models and model output were used for various studies during the project period. The principal studies included examining the temperature impact of flow changes in the Klamath River below Iron Gate Dam during summer months. Three studies were completed; the first examined a specific flow change during the late summer and early fall months (August and September), the second looked at a broader range of flows and cumulative effects over the June through September period, and the third revisited benthic algae dynamics in the river system below Iron Gate Dam. Because the first two model applications were predominately limited to water temperature response and the third application was exploratory, water quality calibration was not revisited at this time (the model is already calibrated for temperature).

Late Summer and Early Fall Flow Change: Iron Gate Dam to Seiad Valley

Temperature dynamics in the Klamath River below Iron Gate Dam are affected by quantity of release from upstream reservoirs, regulation of releases to the Klamath River, and tributary contributions. Thus, varying the flow releases to the River at Iron Gate Dam can directly influence water temperature through increased transit time, varied depth and width, and altering the impact of tributary contributions. Model simulations illustrate that daily maximum temperatures are greater at a flow rate of 1030 cfs than at 1330 cfs for all days of the month – up to 1°C (1.8°F) greater at Seiad Valley. Daily minimum temperatures at Seiad Valley are lower at a flow rate of 1030 cfs than at 1330 cfs for all days of the month – up to 0.8°C (1.4°F) lower. The lower flow rate has a longer transit time – on the order of 6 to 8 hours longer between Iron Gate Dam and Seiad Valley. With shorter days and longer nights, the smaller thermal mass and depth associated with the 1030 cfs flow rate allows the river to heat and cool at a more rapid rate, leading to greater diurnal temperature swings in the river (~1.3°C / 2.3°F). Daily mean data tend to mask these conditions, thus hourly simulations were implemented. Flow changes (i.e., withdrawal rate) have the potential to affect the thermal structure of Iron Gate Reservoir as well.

It is apparent that reduced flows can lead to increases in mean daily water temperatures. However, short-term meteorological conditions play a significant role. Clear sky conditions can result in increased daily mean temperatures on the order of a few tenths of a degree Celsius between Iron Gate Dam and Seiad Valley for a flow change from 1330 cfs to 1030 cfs. However, when conditions cool (e.g., cold front), such as can occur during September, the lower flow scenario exhibits cooler water temperatures. The lower flow rate leads to extended exposure to cool conditions, and the smaller thermal mass cools more quickly.

Impact of Normal, Dry, and Critically Dry Hydrological conditions on Water Temperature: June – September: Iron Gate Dam to Seiad Valley

Temperature dynamics in the Klamath River below Iron Gate Dam are affected by upstream reservoirs, local meteorological conditions, regulation and quantity of release at Iron Gate Dam, and tributary contributions. Some principal findings include:

- Under drought conditions tributary contributions are typically small.
- Under typical summer time flows, re-regulation produces predictable "nodes" of minimum temperature variation separated by a one-day travel time in the river (at mean velocity). This phenomenon, apparent in sub-daily data and simulations, are critical in interpreting sub-daily water temperature information.
- Seasonal changes are apparent in the system as well as short-term climatic meteorological conditions.
- Iron Gate Reservoir (and possibly Copco Reservoir) affect the thermal regime of the downstream river in three principle ways (under current operating conditions):
    - In mid-to late spring Iron Gate Dam releases are often slightly below equilibrium temperature, maintaining a slight cool water "benefit" for releases to the Klamath River.
    - In summer, there is minimal cool water benefit to the Iron Gate release (with respect to anadromous fishes). The release is only marginally below equilibrium temperature; however, the release does moderate the daily maximum and minimum temperature.
    - In fall, for short periods, the Iron Gate release can be warmer than equilibrium temperature. Under such conditions, the release is a heat source to the river. This condition is probably short lived.

Dissolved oxygen (DO) dynamics in the Klamath River below Iron Gate Dam were also simulated. The response of DO in the river downstream of Iron Gate Dam is a complex function of flow, release water quality, and primary production. A few notable findings suggest that:

- Simulated mean daily dissolved oxygen (as depicted in longitudinal profiles) is fairly constant throughout most of the summer throughout the river reach. However, in the fall, DO releases from Iron Gate dam begin to decrease to levels well below saturation.
- Further examination of the daily mean DO profiles illustrates that there is potentially appreciable primary production immediately below Iron Gate Dam, shown by a slightly increased daily mean DO.
- Examination of the simulated time series suggests that seasonally (and spatially) primary production directly and appreciably impacts sub-daily dissolved oxygen levels.
- The various flow regimes had a modest impact on daily mean DO concentration. The lower flows did produce a slightly higher mean daily DO, possibly due to increased aeration at shallower depths. Sub-daily data were more highly variable between alternatives, but these data have not been critically assessed at this time to provide an explanation for this response.

Simulated dissolved oxygen results have not been used in any quantitative manner. However, several of the above results are supported by field data.

Benthic Algae Simulations

The flow and water quality models RMA-2 and RMA-11, respectively, were applied under various conditions with the benthic algae logic described by Deas and Orlob (1999). The findings illustrate a system that is highly dynamic in space and time – results that are consistent with information from the field program. Based on these simulations and the results from the field monitoring program, additional logic to incorporate grazing, sloughing, and other processes that potentially affect benthic algae biomass were not incorporated into the model at this time. Although dissolved oxygen probes were in place during the 2000 field season, there are insufficient data to address the highly spatial variability of algal growth in the system. Further, additional fieldwork is necessary to further quantify photosynthesis and respiration (e.g.,

completion of light and dark bottle tests in tandem with water quality probes), sloughing studies, and grazing impacts. Upon completion of this data a complete update of the model, including calibration and validation should be undertaken. Recommendations for these studies are included in the report.

Additional work under the modeling task included review of various documents submitted to or prepared by USBR.

2001 Work

The implementation of quality assurance measures (including lab oversight, quality assurance program plan, and standard operating procedures) in 2000 led to a basin wide awareness of the importance of and methods for collecting high quality water quality data in the basin. In March 2001 a meeting was held among the various stakeholders in the basin in an effort to coordinate resources and sampling schedules, ideally leading to a more integrated and more useful data. The basic goals of the meeting were to introduce quality assurance measures, identify entities that would be monitoring in 2001, and coordinate (to the degree possible) sampling efforts to produce a data set that represented basin-wide conditions versus multiple, unrelated data sets. Those in attendance included representatives from the US Bureau of Reclamation, U.S. Fish and Wildlife, U.S. Forest Service, U.S. Bureau of Land Management, U.S. Environmental Protection Agency, California Department of Fish and Game, Hoopa Valley Tribe, Karuk Tribe, Yurok Tribe, California State Water Resources Control Board, North Coast Regional Water Quality Control Board, Oregon Department of Environmental Quality, PacifiCorp, interests from the Shasta, Scott River, and Salmon watersheds.

The USBR agreed to make available the QAPP, SOP, as well as all other monitoring program materials to interested parties. Sampling locations, parameters, and frequencies on a reach-by-reach basis (including the Shasta, Scott, and Salmon Rivers) were identified. Efforts were made to quantify available resources and/or limitations, common sampling days, and potential available personnel. USFWS agreed to transfer all sampling locations to a GIS and produce a map defining the various locations, parameters, and agencies in charge of sampling, as well as support an email list server for communication among participants. An informal group was formed: the Klamath Monitoring and Assessment Group (KMAG).

The outcome of this single meeting is uncertain – sharing of information and active use of the list service was modest – thus it is difficult to assess any level of success or failure. Nonetheless, there was increased communication among certain entities and there is promise that a more formal framework would provide a more uniform level of quality assurance, better coordination among parties, a more useful/valuable "final" or "basin-wide" data set, and increased efficiency/economy with regard to limited resources. For example, USBR and PacifiCorp both agreed to cooperatively continue monitoring through the winter of 2000-2001. Both entities, as well as USFWS have been continuing their water quality monitoring efforts through 2001.

CONCLUSIONS AND RECOMMENDATIONS

The project objective to implement a basin wide program to collect baseline data was achieved. Through the semimonthly grab sampling program, deployment of water quality probes, and deployment of remote logging thermistors (loggers). Sampling was completed inn river reaches as well as within mainstem reservoirs. Additional information was collected through special studies, including algae studies, trace elements sampling, and intensive synoptic water quality surveys. This report presents the data form these programs, the techniques used to process the data, as well as supporting documentation on sampling protocols, quality assurances procedures,

and appropriate documentation. Although this report by and large focuses primarily on field data, where analysis was completed or information obtained, attempts were made to document the information and findings.

Several findings and recommendation were identified during the project period and subsequent write-up. These are outlined below without regard to order of importance.

- Implementation of a quality assurance project plan and standard operating procedures (SOP) for field sampling provided consistent monitoring methods and allowed multiple agencies to sample in a consistent manner throughout the basin.
  Recommendation: USBR should maintain a QAPP and SOP for field sampling and seek to extend the application of uniform sampling procedures throughout the basin through sharing of the QAPP and SOP developed jointly by MP-157 and the Klamath Area Office staff.

- Implementation of external quality assurance samples (duplicates, spikes, blanks, and rinseate blanks) provided significantly improved confidence in the laboratory data.
  Recommendation: Although there is a cost associated with external quality assurance both in increased field supplies, additional laboratory samples, and in-house staff time to process the results, these quality assurance samples should be continued.

- Monitoring with DataSondes illustrated that long-term collection of physical parameters is possible, albeit with certain limitations. Dissolved oxygen probes suffered from biofouling in a matter of days at many locations within the river. Additionally, ORP probes showed signs of drift during the week long deployments. The frequency of deploying and retrieving the water quality probes is problematic at a basin-wide scale. Limited resources (personnel) and shipping/transportation schedules restrict the deployments period to roughly a week. Finally, it was apparent that there was variation among the individual instruments when measuring pH, and dissolved oxygen.
  Recommendations:
  - Maintain the DataSonde deployment in selected locations.
  - Maintain Datasonde calibration and maintenance procedures to ensure probes are functioning properly and quantify uncertainty associated with individual sensors.
  - Complete pilot studies to determine the time/cost saving associated wherein field staff visit the sites more frequently (e.g., every 3 to 4 days) to clean the dissolved oxygen membrane and reduce download frequency to two weeks. Certain locations require a boat and increasing site visit frequency may be infeasible.
  - Consider a pilot study to determine if completing Winkler titrations may assist in correcting dissolved oxygen data that have been affected by biofouling.
  - Testing the instruments in a single body of water prior to and at the end of each field season can quantify variation among probes. With regard to DataSonde testing, it is recommended that a more rigorous statistical analysis be completed on the results.

- Coordination among multiple agencies can greatly improve the understanding of water quality conditions and response in large basins such as the Klamath River. Reclamation worked with PacifiCorp, the United States Forest Service, and the Yurok Tribe during the 2000 sampling season. In early 2001, and attempt was made to coordinate monitoring within the basin between Link Dam and the Pacific Ocean, including all major tributaries (Shasta, Scott, and Salmon Rivers). The objective of coordination was to identify consistent sampling locations and times, reduce redundant monitoring, identify available

resources, introduce a minimum level of quality assurance and standard operating procedures, and share information. Attendance during the April 2001 coordination meeting held at US Fish and Wildlife Service was attended by over 40 people representing nearly every federal, state, tribal, and watershed group in the basin. Nonetheless, without funding the volunteer effort failed to successfully meet the objectives outlined above. Recommendation: Reclamation should seek to pursue coordination when opportunities arise. To some degree this has been done: Reclamation has shared the QAPP and SOP developed during the 2000 monitoring effort with any interested party in the basin. To the extent feasible, the Reclamation should work with other agencies to identify the potential for a basin-wide water quality coordinator position (not within the US Bureau of Reclamation) to encourage basin-wide coordination of monitoring efforts. Such a position, funded by all participants in the basin, would provide a critical role in ensuring that spatial and temporal water quality sampling be completed in a logical and appropriate fashion, that data quality assurance and sampling procedures be standardized, and that well defined methods for data dissemination are adopted. The result would lead to basin-wide water quality data that would be readily comparable across space and time versus the current efforts that are typically redundant, sample different parameters, include variable sampling times and locations, and utilize different analytical or measurement methods.

- All attempts were made to identify sites that were representative of mainstem conditions for the 2000 field sampling program. However, conditions at sampling sites may vary through time and under different hydrologic, meteorological, and water quality conditions.
  Recommendation: Continue to observe conditions at sampling sites and to carry out small-scale studies, as resources allow, characterizing spatial (e.g., lateral and vertical) and temporal variations (e.g., seasonal and/or operational) at existing and proposed sampling sites. Document findings to support sampling methods and to assist in data interpretation.

- The benthic algae survey provided appreciable new information about the benthic flora and fauna. This information was not formally discussed herein primarily because it was much more complex than could be accommodated by the study plan. A brief review of the narrative descriptions of the conditions of the periphyton samplers and the unglazed ceramic tiles suggests that more detailed studies be completed to characterize these important processes.
  Recommendation: Because the primary impetus behind the 2000 field sampling program was to address anadromous fisheries downstream of Iron Gate Dam, and because the benthic flora and fauna play an integral role in the lifecycle of anadromous fisheries, it is recommended that additional work be completed to characterize the benthic community. The spatial and temporal variability of this community no doubt plays a vital role in water quality throughout the system. A comprehensive study defining algal species present, estimates of biomass (e.g., through direct measurement, light and dark bottle test, or other means), identification of mollusks and invertebrate assemblages that graze on algae, and additional growth rate studies should be carried out over multiple field seasons to define the spatial and temporal variability of algae and its potential role in water quality. Reservoir operations, water quality, as well as the fate of phytoplankton (that is washed out of mainstem reservoirs) on downstream river reaches should be included.

- It is not uncommon for water quality monitoring programs to be funded, designed, and implemented, only to find that the field data is not processed and presented in a formal report.
  Recommendation: Data processing and reporting should be an integral part of any sampling program. Data dissemination procedures should be identified early in the sampling program design such that information can be available to interested parties.

- The model simulations provided insight into potential benthic algae dynamics; however, insufficient data are available to completely characterize the water quality response of the various components potentially affecting water quality (e.g., macroinvertebrate or mollusk grazing on benthic algae).
  Recommendation: continue to explore model formulations and approaches to more effectively characterize water quality response within critical reaches of the Klamath River system. This may include specific field studies designing to acquire critical information necessary to characterize physical, chemical, and biological processes. Temporal and spatial characteristics make this a challenging task.

- Field data indicate that mainstem reservoirs experience oxygen concentrations that deviate from saturation. Keno Reservoir, Copco Reservoir, and Iron Gate Reservoir all experience anoxic persistent conditions, which may lead to sediment nutrient release and thus internal nutrient cycling.
  Recommendation: to determine the potential for reduced conditions, oxidation-reduction potential (ORP) should be collected in all mainstem reservoirs when physical profiles are collected with water quality probes (e.g., DataSonde).

- Metals data were collected and are presented herein; however, as a stand alone data set there usefulness is limited.
  Recommendation: Review year 2000 field data in light of other sources of information concerning metals in the Klamath Basin and Klamath Project area.

- Adaptive management is a critical part of aquatic resource management. Although there are many definitions of adaptive management, a pragmatic approach consists of two steps: 1) conduct experiments to increase the knowledge of the system, and 2) plan to change based on the findings of the first step.
  Recommendation: Identify components of the water quality monitoring program, possibly augmented by data or computer simulation models, to assist in adaptive management of water resources in the Klamath Basin.

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1. KLAMATH BASIN WATER QUALITY MONITORING PROGRAM

The U.S. Bureau of Reclamation contracted with Watercourse Engineering, Inc. (formerly Michael L. Deas, P.E.) to complete various studies in the Klamath River basin with respect to water quality conditions (requisition 00250000022, order number 00pg250021). The studies were intended to support long-term project operations planning as well as environmental and biological studies to determine the impacts of altering Klamath River flows from project operations on Tribal trust resources and listed, proposed, and candidate anadromous fish species under the Endangered Species Act.

Project goals included primarily gathering necessary information to improve characterization of water quality in the Klamath River basin to support existing modeling capability in the mainstem Klamath River between Iron Gate Dam and Seiad Valley. Response to diel changes in key water quality constituents, such as temperature, dissolved oxygen, and nutrient levels were deemed critical to assessing environmental and biological conditions. The project area extended from Link Dam at Upper Klamath Lake to Youngs Bar below the Trinity River, a distance of over 230 river miles. Major tributaries encompassed in the study area included the Shasta, Scott, Salmon, and Trinity Rivers. In cooperation with the U.S. Bureau of Reclamation (USBR), PacifiCorp funded water quality sampling on the mainstem reservoirs (JC Boyle, Copco, and Iron Gate Reservoirs).

The water quality field program was the primary task in the Klamath River Water Quality Studies. The field program consisted of seven inter-related monitoring programs:

- Semi-monthly grab sampling
- Continuous water quality probe (Hydrolab Datasonde) deployment
- Water temperature monitoring
- Benthic algae monitoring
- Three-day synoptic surveys
- Trace elements screening
- Reservoir water quality sampling

As noted above, in addition to these elements PacifiCorp monitored mainstem reservoirs in coordination with USBR. All grab sample work was covered under a single Quality Assurance Project Plan (QAPP), Standard Operating Procedures (SOP), and field sampling schedule. Each element or task is outlined below and includes a "subtask objective." Thus, each task was defined to meet a specific purpose, perceived need, or data gap. However, the task timelines and monitoring efforts were designed to compliment one another. The product is a data set that spans an appreciable section of the Klamath River – from near Klamath Falls to below the Trinity River. Although several efforts were limited to sub-reaches (i.e., Iron Gate Reservoir to Seiad Valley), these efforts provided insight to critical processes that, in certain cases, may be extended to other reaches of the main stem and possibly certain tributaries. Sampling extended from early spring through late fall, including periods when several life stages of anadromous fish are present.

Water quality field monitoring and laboratory protocols were developed for the project to ensure the data set was consistent with the needs of system assessment and anadromous fish restoration objectives. The participating agencies are described below, followed by the description of each program.

1.1 Agency Participation

Several agencies dedicated resources to the water quality monitoring program, including the U.S. Forest Service, Hoopa Tribe, Yurok Tribe, California Department of Fish and Game, and PacifiCorp. The participating agencies, their level of participation, and funding sources are outlined in Table 1-1.

Table 1-1 Participating agencies, contacts, roles and funding source

Agency	Contact	Participation	Funding
US Forest Service: Scott/Salmon River Ranger Districts	Brenda Olson Jim Kilgore	Grab Sample and Datasonde deployment in Middle Klamath Region (Locations: ab. Copco, below Iron Gate Dam, Shasta River, Scott River, and Seiad Valley; Datasonde deployment only at Salmon River	US Bureau of Reclamation
Hoopa Valley Tribe	Tim Hayden Charlie Chamberlein	Datasonde deployment (Location: Trinity River)	US Bureau of Reclamation
Yurok Tribe	James Wroble Clyde Matilton	Datasonde deployment (Location: Young's Bar (Klamath River)	US Bureau of Reclamation
California Department of Fish and Game	Jim Whelan	Benthic algae monitoring, temperature monitoring, local access for Datasonde deployment and grab samples (Locations: Klamath River below Iron Gate Dam and near Cottonwood Creek)	work and supplies: volunteer / laboratory costs: US Bureau of Reclamation
PacifiCorp	Jennifer Kelly	Reservoir monitoring, hydrolab (WQ probe) profiles of physical parameters and WQ grab samples (Location: Iron Gate, Copco, and JC Boyle Reservoirs)	Field work, supplies, and laboratory costs paid by PacifiCorp. US Bureau of Reclamation provided data QA.

Several other groups and individuals assisted in the program either directly or indirectly. In many cases, they provided assistance through access, fielding phone calls, overseeing field equipment or other tasks that made the program possible. They are acknowledged below.

Kim Rushton, California Department of Fish and Game
Dennis Maria, California Department of Fish and Game
Dave Webb, Shasta Coordinated Resource Management Program
Bob and Jan Klingbeil, Global Resources

Finally, the support of U.S. Bureau of Reclamation staff was paramount to the success of the project. We would like to acknowledge the U.S. Bureau of Reclamation staff at the Klamath Area Office for their professional and courteous manner, their commitment to project objectives, and general support. In particular we would like to acknowledge several staff members. Jason Cameron, Bill Wood, and Lisa Hicks played important roles in the coordination and completion of the field sampling program. Their hard work and attention to detail made all components of the field program successful. Jason Cameron was in charge of the field operations throughout the duration of the project. Bill Wood provided support at the inception of the project and was in charge of field supplied for much of the season. Project management was initially assigned to Larry Dugan. His participation and patience were paramount not only in getting the project off the ground, but in his direct participation the portions of the field work. Upon Mr. Dugan's departure, Mark Buettner assumed project management for the latter half of the project. Computer model applications identified herein were completed, with the exception of benthic

algae, under Mr. Buettner's guidance. Michael Berg provided valuable insight into Datasonde performance and calibration procedures. Support from MP-157 was critical to the monitoring program success. John Fields and his staff in Sacramento provided training, assistance in writing the Quality Assurance Program Plan and providing a Standard Operation Procedure for field sampling, laboratory oversight, data validation, and general support. Finally, we would like to acknowledge Bob Davis for his overall support of this project and patience in seeing it through to completion.

1.2 Semi-Monthly Grab Sampling Program

Subtask Objective: To provide baseline information on main stem and tributary contributions for a representative suite of physical, chemical, and biological water quality constituents. These constituents will be useful in the general characterization of mainstem Klamath River waters, identifying water quality constituents of concern within selected river reaches, and estimating input parameters for water quality models.

The semi-monthly grab sampling program included 10 locations in the Klamath Basin. The sites ranged from Miller Island (River Mile 246) near Klamath Falls to Seiad Valley (River Mile 128.9). The locations are included in Table 1-2.

Table 1-2 Grab sample locations

	Location	River Mile*
1	Klamath River @ Miller Island	246
2	Klamath Straits Drain (KSD) @ Hwy 97	2.0 (240.5)
3	KSD @ Tule Lake Diversion Tunnel	n/a
4	KSD at State Line (Hwy 161)	n/a
5	Klamath River at Keno Bridge	235
6	Klamath River above Copco Reservoir	208
7	Klamath River below Iron Gate Dam	190.1
8	Shasta River	0.5 (176)
9	Scott River	23.4 (143)
10	Klamath River below Seiad Valley (USGS)	128.9

* River mile for location of tributary-main stem confluence provided in parenthesis

Physical constituents, nutrients, algae (as chlorophyll a), biochemical oxygen demand (BOD), and major ions were examined. Hydrolab water quality probes were used to examine water temperature, dissolved oxygen, pH, specific conductance, and redox at each location when grab samples were taken. The remaining constituents were analyzed under laboratory conditions with the exception of turbidity, which is measured with a field turbidimeter. Table 1-3 summarizes the sampled constituents and method of measurement and Table 1-4 outlines the justification/purpose of each constituent in the sampling program. The selection of constituents was based on review of available data (e.g., 1998 and 1999, see appendices), and budget and resource constraints.

Table 1-3 Grab sample water quality program constituents and methods of determination

	Constituent	Method
Physical	Water temperature	Hydrolab
	Dissolved oxygen	Hydrolab
	pH	Hydrolab
	Specific conductance	Hydrolab
	Redox	Hydrolab
	Turbidity	Turbidimeter
Nutrient	Ammonia	Laboratory
	Nitrate+Nitrite	Laboratory
	Total Kjeldahl nitrogen	Laboratory
	Orthophosphate	Laboratory
	Total phosphorous	Laboratory
Major Ions	TDS	Laboratory
	Calcium	Laboratory
	Magnesium	Laboratory
	Bicarbonate	Laboratory
	Carbonate	Laboratory
Other	Biochemical Oxygen Demand (BOD)	Laboratory
	Chlorophyll a	Laboratory

Although certain constituents do not have direct implications for the health of anadromous fish, several are important in characterizing aquatic systems. For example, carbonate and bicarbonate can be used to determine the alkalinity of a system, defining the degree a system is buffered against changes in pH. Changes in pH have a profound impact on the solubility and toxicity of certain constituents, many of which may be harmful to fish (e.g., ammonia). Likewise, calcium and manganese are often used to estimate hardness. The degree of hardness can affect the response of anadromous fish to various toxicants (e.g., trace metals). Thus, initial water quality assessments usually incorporate a wide range of constituents. Future efforts may focus on specific water quality constituents that are deemed important.

Table 1-4 Grab sampling program constituent justification/purpose

Constituent		Justification/Purpose		
		Critical to Define Aquatic System Condition/Processes	A Direct Limiting Factor for Anadromous Fish	Simulation Model Requirement
Physical	Water temperature	X	X	X
	Dissolved oxygen	X	X	X
	pH	X[a]		
	Specific conductance	X		X
	Redox	X		
	Turbidity	X		
Nutrient	Ammonia	X	X	X
	Nitrate+Nitrite	X		X
	Total Kjeldahl nitrogen	X		X
	Orthophosphate	X		X
	Total phosphorous	X		X
Major Ions	TDS	X		X
	Calcium	X[b]		
	Magnesium	X[b]		
	Bicarbonate	X		
	Carbonate	X		
Other	BOD	X		X
	Chlorophyll a	X		X

[a] Unionized ammonia toxicity is dependent on pH and temperature

b Aquatic life criteria for certain trace elements are dependent on hardness

1.3 Datasonde Deployment

<u>Subtask Objective</u>: Determine sub-daily response of physical constituents for aquatic system characterization and model input.

Continuous recording Hydrolab Datasondes were deployed at 13 locations in the Klamath Basin (Table 1-5). These water quality probes measured and recorded water temperature, dissolved oxygen, pH, specific conductance, and redox at 1-hour intervals. To minimize lost dissolved oxygen (DO) data due to bio-fouling of the DO membrane, probes were deployed for one-week intervals.

The probe deployment provided sub-daily response of water temperature, DO, and pH. These data are critical to interpretation and definition of water quality response throughout the river system. Further, the data provide valuable maximum, minimum, and mean values, as well as the rate of change of constituents. Sub-daily data provides:

<u>Temperature:</u>

- Critical thermal maximum/minimum,
- Day to day persistence of thermal maximum/minimum
- Water management impacts (e.g., downstream impacts of reservoir releases)

<u>Dissolved Oxygen:</u>

- Critical minimum DO and persistence of low DO concentrations,

- Day to day persistence of adverse DO conditions
- Water management impacts (e.g., downstream impacts of reservoir releases)

pH:

- Hourly variation in pH provides insight into role of primary production on water quality
- Can assist in identifying toxicity potential for certain constituents (e.g., ammonia, metals)

Further, the diurnal variation of temperature, DO and pH varies seasonally. These variations are valuable to resource managers from both a biological and operations standpoint. Finally, temperature and DO data (main stem and tributaries) are necessary boundary conditions as well as calibration data for simulation models.

Table 1-5 Datasonde deployment locations

	Location	River Mile*
1	Klamath River @ Miller Island	246
2	Klamath Straits Drain (KSD) @ Hwy 97	2.0 (240.5)
3	KSD @ Tule Lake Diversion Tunnel	n/a
4	KSD at State Line (Hwy 161)	n/a
5	Klamath River at Keno Bridge	235
6	Klamath River above Copco Reservoir	208
7	Klamath River below Iron Gate Dam	190.1
8	Shasta River	0.5 (176)
9	Scott River	23.4 (143)
10	Klamath River below Seiad Valley (USGS)	128.9
11	Salmon River	1.0 (66.0)
12	Trinity River near Hoopa	12.4 (43.5)
13	Klamath River near Youngs Bar	≈ 35

* River mile for location of tributary-main stem confluence provided in parenthesis

1.4 Water Temperature Monitoring

Subtask Objective: Collect required sub-daily water temperature data to compliment temperature data collected with water quality probes.

Main stem and tributary water temperature was monitored at five locations in the Klamath River basin to compliment water quality probe data and support simulation modeling. Loggers were programmed to record temperature at 1-hour intervals. Remote loggers deployments included:

- Klamath River at Cottonwood Creek (RM 182)
- Klamath River above Shasta River (RM 176.7)
- Klamath River at Walker Rd. Bridge (RM 156)
- Klamath River above Scott River (RM 143.5)
- Scott River (RM 1)

The temperature logger deployment at the mouth of the Scott River provide insight into the similarity of water temperature between the Datasonde sampling location near Ft. Jones (RM 23.4) and the confluence with the Klamath River (measured at approximately RM 1.0).

1.5 Benthic Algae Sampling

Subtask Objective: Collect necessary data to more completely quantify impact of primary production downstream of Iron Gate Dam. Estimate potential algae growth rates to support simulation modeling.

Benthic algae have been identified as a potentially important component of primary production affecting water quality in the mainstem Klamath River below Iron Gate Dam. To develop the requisite model input data (seasonal growth rates) a field-sampling program for benthic algae was implemented. Artificial substrates were deployed at two locations:

- Klamath River below Iron Gate Dam (RM 190)
- Klamath River near Cottonwood Creek (RM 182)

Quantitative and qualitative methods were employed. Floating periphyton samplers and unglazed ceramic tiles were used to assess algae growth conditions. The floating samplers were employed to reduce the impacts of grazing, while the ceramic tiles were placed on the bed to determine the impacts of growth subject to grazing. The algae samples were collected from the floating samplers for laboratory analysis, while the unglazed ceramic tiles provided a qualitative assessment of changes in substrate composition and impacts of grazing.

Two sampling series of four weeks included:

- June 5-29, 2000
- August 8-28, 2000

Samples were gathered at approximately weekly intervals and processed under laboratory conditions to determine chlorophyll a and ash-free dry weight. These data were used in conjunction with narrative descriptions of ceramic tiles.

1.6 Synoptic Water Quality Surveys

Subtask Objective: Acquire the necessary sub-daily water quality data to explore sub-daily water quality response and support simulation modeling.

To effectively assess diel dissolved oxygen response of the Klamath River below Iron Gate Dam and to support model application, sub-daily grab samples were collected. An abbreviated set of constituents was sampled during the synoptic surveys; however, the sample set was augmented with dissolved organic forms of nitrogen and phosphorous (Table 1-6).

Table 1-6 Synoptic water quality survey constituents and methods of determination

	Constituent	Method
Physical	Water temperature	Hydrolab
	Dissolved oxygen	Hydrolab
	pH	Hydrolab
	Specific conductance	Hydrolab
	Redox	Hydrolab
Nutrient	Ammonia	Laboratory
	Nitrate+nitrite	Laboratory
	Total Kjeldahl nitrogen	Laboratory
	Orthophosphate	Laboratory
	Total phosphorous	Laboratory
	Organic nitrogen (diss.)	Laboratory
	Organic phosphorous (diss.)	Laboratory

Two surveys were completed in the Klamath River between Iron Gate Dam and Seiad Valley: June 5-7 and August 7-9. A third survey was completed in September incase adverse conditions negatively affected one of the first two surveys. The June and September sampling periods were designed to coincide with periods when juvenile and adult fish, respectively, may occupy the study reach. Early August is typically the most adverse period of the summer for anadromous fish.

Samples were gathered three times per day (6 a.m., 11 a.m. and 4 p.m.) for three days at six sites:

- Klamath River below Iron Gate (RM 190)
- Klamath River above Shasta River (176.7)
- Shasta River (RM 0.0)
- Klamath River above Scott River (RM 143.5)
- Scott River RM (0.1)
- Klamath River below Seiad Valley (RM 128.9)

In addition, Datasondes were deployed at the following locations:

- Klamath River above Shasta River (176.7)
- Klamath River above Scott River (RM 143.5)
- Scott River RM (0.1)

These sub-daily samples provide further insight into the role of nutrient availability and the role of primary production in day-to-day water quality conditions in below Iron Gate Dam.

1.7 Trace Elements Screening

Subtask Objective: Provide a preliminary characterization of trace element concentrations at a selected number of sites within the Klamath Basin.

In addition to the semi-monthly grab samples, trace elements and trace metals were screened at monthly intervals at four locations in the basin. Fifteen elements were included in the screening samples (Table 1-7).

Table 1-7 Trace element screening suite constituents

Aluminum	Antimony	Arsenic
Cadmium	Chromium	Copper
Iron	Lead	Magnesium
Mercury	Nickel	Selenium
Silver	Thallium	Zinc

This broad-based screening was intended to determine baseline levels of trace elements and metals at selected locations and to identify those that may be of concern in the aquatic system. Constituents found to have elevated concentrations were identified for potential future monitoring. The locations and impetus for site selection are outlined in Table 1-8.

Table 1-8 Sampling locations and purpose for trace elements and trace metals screening

Location	Purpose
Klamath River at Link Dam (RM 253)	Quantify releases from Upper Klamath Lake
Klamath Straits Drain at Hwy 97	Quantify outflow from Klamath Project operations
Klamath River at Keno Bridge	Quantify outflow from upper basin
Klamath River bel. Iron Gate Dam	Quantify releases to Klamath River below Iron Gate Dam

1.8 Reservoir Water Quality Sampling

Subtask Objective: Obtain water quality data (profiles) in mainstem reservoirs between Keno Dam and Iron Gate Dam.

Because mainstem reservoirs potentially play an important role in the quality of waters released to downstream reaches, reservoir surveys were included in the monitoring program. Specifically, Iron Gate Reservoir (RM 190.2), Copco Reservoir (RM 198), and JC Boyle Reservoir (RM 225) were included in this project. Monitoring consisted of three primary tasks: (1) deployment of temperature loggers at pre-selected depths in the reservoirs; (2) monthly profiles of physical constituents; and (3) water quality grab sampling surveys. Each is outlined below.

Temperature Loggers

Temperature loggers were deployed at selected depths in Iron Gate, Copco, and JC Boyle Reservoir – suspended from the log boom and from upstream of the dam. The loggers recorded at hourly intervals and were downloaded approximately every two months. Loggers were deployed at the surface and every 10 feet in Iron Gate and Copco Reservoir, and at the surface and every 5 feet in JC Boyle. A fourth thermistor string was deployed in Lake Ewauna, upstream of Keno Dam.

Reservoir Profiles

Hydrolab water quality probes were used to conduct monthly profile measurements in each reservoir, commencing in April and concluding in October. Secchi depth was measured at each location. Water temperature, DO, pH, and specific conductance were measured at 1 meter intervals in the photic zone (≈3 times Secchi depth) and at a minimum of 3 meter intervals below the photic zone. Physical constituents sampled in the reservoir profiles are outlined in Table 1-6.

Water Quality Grab Samples

Water quality samples were collected four times in the reservoirs: early May, early June, early August, and mid-September. The early May condition was used to estimate the state of the reservoirs at the beginning of the warming period. The June, August, and September

surveys coincided with the river synoptic river surveys, providing three comprehensive synoptic sampling dates for the Klamath River and reservoir system.

Water quality constituents sampled in the reservoirs included nutrients, BOD, and chlorophyll a, as outlined in Table 1-9. Samples were collected at three representative depths in Iron Gate and Copco reservoirs: epilimnion, metalimnion, and hypolimnion. All epilimnion samples were obtained at a depth of 1 meter. Metalimnion and hypolimnion sample depths were estimated from the hydrolab profiles of water temperature. In the relatively shallow JC Boyle Reservoir, two depths were sampled: 1meter and 8 meters.

These data are used to further characterize seasonal system response, assist in interpretation of water quality in downstream river reaches, and in the case of Iron Gate Reservoir will be useful in further calibration, validation, and application of an existing reservoir water quality models.

Table 1-9 Mainstem reservoir water quality survey constituents and methods of determination

	Constituent	Method
Physical	Water temperature	Hydrolab
	Dissolved oxygen	Hydrolab
	pH	Hydrolab
	Specific conductance	Hydrolab
	Redox	Hydrolab
Nutrient	Ammonia	Laboratory
	Nitrate+nitrite	Laboratory
	Total Kjeldahl nitrogen	Laboratory
	Orthophosphate	Laboratory
	Total phosphorous	Laboratory

2. SITE DESCRIPTIONS

The individual site descriptions for all sampling programs are described in the following sections. The methods of sampling and sample processing are outlined and special circumstances noted.

2.1 Klamath River and Klamath Project Semi-Monthly Grab Sample Site Descriptions

The semi-monthly grab sampling component of the Klamath River water quality 2000 program collected samples at 10 locations within the Klamath Project, the mainstem Klamath River, and principal tributaries (Table 2-1). Attributes of each site are presented below. All samples collected "by hand" refer to dipping bottles directly into the river to be filled.

Table 2-1 Semi-monthly grab sampling locations

Sampling Location	Latitude	Longitude
Tule Lake Tunnel Outlet Canal @ Brownell Rd. Bridge	N41° 55.795'	W121° 36.022'
Klamath Straits Drain (KSD) @ Hwy 97	N42° 4.846'	W121° 50.833'
KSD @ Stateline Rd. (Headworks)	N41° 59.804'	W121° 46.676'
Klamath River at Miller Island	N42° 8.821'	W121° 50.904'
Keno Bridge	N42° 7.627'	W121° 55.700'
Klamath River above Copco Reservoir	N41° 57.910'	W122° 15.390'
Klamath River bel. Iron Gate Dam	N41° 55.865'	W122° 26.517'
Shasta River @ USGS Gage	N41° 49.393'	W122° 35.708'
Scott River @ USGS Gage	N41° 38.429'	W123° 0.867'
Klamath R. at Seiad Valley @ USGS Gage	N41° 50.247'	W123° 11.855'

2.1.1. Tule Lake Outlet Canal

The Tule Lake outlet canal was sampled just below the egress from the tunnel, at the Brownell Road Bridge. The location was just upstream of the Lower Klamath National Wildlife Refuge boundary. Samples were collected with a Van Dorn sampler from the center of the bridge and processed with a churnsplitter.

2.1.2. Klamath Straits Drain at Stateline Road

Also known as Klamath Straits Drain at headworks, the Stateline Road site was located off of Highway 161 at the northern edge of the Lower Klamath National Wildlife Refuge. Samples were collected with a Van Dorn near the drain outflow gates and processed with a churnsplitter.

2.1.3. Klamath Straits Drain at Highway 97

The Klamath Straits Drain was sampled west of Highway 97 and the railroad tracks where the F and F-F channels converge to a single channel. Sampling occurred with a Van Dorn or by filling the churnsplitter directly from the drain from the dividing wall between the two channels, drawing from the channel that was actively being used to convey water to the Klamath River. This site was a quality assurance site and thus all samples were processed with a churnsplitter.

2.1.4. Klamath River at Miller Island

Grab samples at Miller Island were collected from the boat dock by hand. Chlorophyll a was collected in the churnsplitter. There was the option to collect a sufficient volume through dipping (filling) the churnsplitter and processing accordingly.

2.1.5. Klamath River at Keno

Samples were collected from the Keno Bridge using a Van Dorn to collect a sufficient volume that was subsequently processed using a churnsplitter.

2.1.6. Klamath River above Copco Reservoir

The Klamath River was sampled above Copco Reservoir about 3 river miles south of the Oregon-California state line. The sampling site was located immediately upstream of Shovel Creek at a summer crossing (seasonal bridge). Samples were collected using a Van Dorn from the bridge and processing in a churnsplitter, or collecting by hand from the bank. Chlorophyll a was always collected in the churnsplitter. Collecting samples from the bridge with a Van Dorn was problematic due to appreciable velocities in this area.

2.1.7. Klamath River below Iron Gate Dam

The Klamath River was sampled approximately 0.4 miles below Iron Gate Dam at a boat launching site immediately downstream of bridge leading to the fish hatchery and powerhouse. When used as a quality assurance site, river water was collected from the bank by dipping (filling) the churnsplitter. When production sampling occurred, samples were collected by hand and chlorophyll a was always collected in the churnsplitter.

2.1.8. Shasta River

Shasta River sampling occurs at the USGS gage, approximately one mile upstream from the mouth (at the gage house, versus the cable crossing). Access is through a locked gate. Samples were collected by hand from the bank and chlorophyll a samples were always collected in the churnsplitter.

2.1.9. Scott River

The Scott River sampling site was located 23.4 miles upstream from the mouth at the northern end of the Scott Valley at the USGS gage. The sampling site was located at the bottom of a steep bank. Samples were collected by hand from the bank. The Scott River was prone to the largest changes in flow of any mainstem and river sites. Chlorophyll a samples were always collected in the churnsplitter.

2.1.10. Klamath River at Seiad Valley USGS Gage

A USGS Gage and cable crossing clearly delineated this sampling site located a few miles below the community of Seiad Valley. This site was moved from an upstream location used during the 1998 and 1999 sampling due to concerns about samples effectively representing mainstem conditions at summer flows. Samples were collected by hand from the bank and chlorophyll a was always collected in the churnsplitter.

2.2. Klamath River Mainstem Reservoir Grab Sample Site Descriptions

Iron Gate, Copco and JC Boyle reservoirs were sampled at multiple depths to characterize the vertical variation within the water column. Keno Reservoir was not included in this program (see temperature monitoring program for Keno Reservoir). Vertical profiles for water temperature, dissolved oxygen, pH, and specific conductance were collected coincident with the grab sampling program at identical locations.

2.2.1. JC Boyle Reservoir

Sampling occurred from a boat at the mid-point of log boom. Samples were collected at three depths on the first visit, but after determining the depth to be approximately 8 meters at this location, sampling depths were reduced to two – at one meter below the surface and roughly 1 meter off the bottom. Samples for the first three visits were collected with a Van Dorn and processed using a churnsplitter. Thereafter, samples were collected with a pump (see QAPP and SOP for details).

2.2.2. Copco Reservoir

Sampling occurred from a boat at the mid-point of log boom. Samples were collected at three depths with one sample each in the epilimnion, metalimnion, and hypolimnion. The depths were at one meter below the surface (epilimnion) roughly 1 meter off the bottom (hypolimnion), and at an intermediate depth based on a temperature profile to define the metalimnion. Samples for the first three visits were collected with a Van Dorn and processed using a churnsplitter. Thereafter, samples were collected with a pump (see QAPP and SOP for details).

2.2.3. Iron Gate Reservoir

Sampling occurred from a boat at the mid-point of log boom. Samples were collected at three depths with one sample each in the epilimnion, metalimnion, and hypolimnion. The depths were at one meter below the surface (epilimnion) roughly 1 meter off the bottom (hypolimnion), and at an intermediate depth based on a temperature profile to define the metalimnion. Samples for the first three visits were collected with a Van Dorn and processed using a churnsplitter. Thereafter, samples were collected with a pump (see QAPP and SOP for details). The epilimnion sample represented the QA site for the reservoir grab sampling program; samples were processed with a churnsplitter.

2.3. Synoptic Study Grab Sample Site Descriptions

Three synoptic surveys were completed during the 2000 field season: June 5-7, August 7-9, and September 26-29. The June and August surveys required grab sampling at six locations (Table 2-2) three times per day (daybreak, late morning, mid afternoon). Two of the sampling locations, Klamath River below Iron Gate Dam and Klamath River at Seiad Valley USGS Gage were coincident with semi-monthly grab sample locations. These two locations were also used as quality assurance sites. Quality assurance samples were only collected during the late-morning sampling. Datasondes were deployed at all locations where grab samples were collected. The September survey consisted only of Datasonde deployment at the selected sites and did not include grab samples. All locations are addressed below with regard to the synoptic sampling event.

Table 2-2 Synoptic study grab sampling locations

Sampling Location	Latitude	Longitude
Klamath River bel. Iron Gate Dam	N41° 55.865’	W122° 26.517’
Klamath River ab. Shasta River	N41° 49.877’	W122° 35.606’
Shasta River @ USGS Gage	N41° 49.393’	W122° 35.708’
Klamath River ab. Scott River	N41° 46.714’	W123° 2.101’
Scott River at Mouth	N41° 46.734’	W123° 2.223’
Klamath R. at Seiad Valley @ USGS Gage	N41° 50.247’	W123° 11.855’

2.3.1. Klamath River below Iron Gate Dam

The Klamath River was sampled approximately 0.4 miles below Iron Gate Dam at a boat launching site immediately downstream of bridge leading to the fish hatchery and powerhouse. This site was used as a quality assurance site for the synoptic survey. When used as a quality assurance site, river water was collected from the bank by dipping (filling) the churnsplitter. When production sampling occurred, samples were collected by hand; the churnsplitter was used to transport sufficient water for filtered samples.

2.3.2. Klamath River above Shasta River

Sampling occurred from the left bank below the remaining foundation of a bridge abutment, immediately downstream of the Highway 263 bridge. Unfiltered samples were collected by hand from the bank; the churnsplitter was used to transport sufficient water for filtered samples.

2.3.3. Shasta River

During the synoptic survey samples were collected at the fish counting weir approximately 0.5 miles downstream of the USGS gaging station. The sampling location was moved to provide efficient processing of multiple samples from multiple locations three times per day. Unfiltered samples were collected by hand from the bank; the churnsplitter was used to transport sufficient water for filtered samples.

2.3.4. Klamath River above Scott River

Synoptic samples were collected approximately 150 feet above the confluence of the Scott and Klamath Rivers on the left bank during the June synoptic survey. Changing river conditions during the August survey required adopting a new sampling site roughly 500 feet upstream of the confluence with the Scott River. Unfiltered samples were collected by hand from the bank; the churnsplitter was used to transport sufficient water for filtered samples.

2.3.5. Scott River

During the synoptic survey samples were collected approximately 100 feet upstream of the confluence with the Klamath River, immediately downstream of the highway 96 bridge. Unfiltered samples were collected by hand from the bank; the churnsplitter was used to transport sufficient water for filtered samples.

2.3.6. Klamath River at Seiad Valley USGS Gage

A USGS Gage and cable crossing clearly delineate this sampling site located a few miles below the community of Seiad Valley. This site was moved from an upstream location used during the 1998 and 1999 sampling due to concerns about samples effectively representing mainstem conditions at summer flows. This site was used as a quality assurance site for the synoptic survey. When used as a quality assurance site, river water was collected from the bank by dipping (filling) the churnsplitter. When production sampling occurred, samples were collected by hand; the churnsplitter was used to transport sufficient water for filtered samples.

2.4. Klamath River and Klamath Project Datasonde Water Quality Probe Sample Site Descriptions

Datasonde water quality probes were deployed at 13 locations in the study area from Miller Island (RM 246) to below the Trinity River at Youngs Bar (RM 35) (Table 2-3). Most sites were coincident with semi-monthly grabs sample sites. In most cases, probes were deployed in an aluminum canister for protection and attached to the bank with a cable and lock to minimize vandalism.

Table 2-3 Water quality probe deployment locations

Sampling Location	Latitude	Longitude
Klamath River at Miller Island	N42° 8.821'	W121° 50.904'
KSD @ Hwy 97	N42° 4.846'	W121° 50.833'
KSD @ Stateline Rd.	N41° 59.804'	W121° 46.676'
KSD @ Tunnel	N41° 55.795'	W121° 36.022'
Keno Bridge	N42° 7.627'	W121° 55.700'
Klamath River above Copco	N41° 57.910'	W122° 15.390'
Klamath River bel. Iron Gate Dam	N41° 55.894'	W122° 26.394'
Shasta River @ USGS Gage	N41° 49.393'	W122° 35.708'
Scott River @ USGS Gage	N41° 38.429'	W123° 0.867'
Klamath R. at Seiad Valley @ USGS Gage	N41° 50.247'	W123° 11.855'
Salmon River	N41° 22.615'	W123° 28.632'
Trinity River	N41° 3.023'	W123° 40.397'
Klamath River at Youngs Bar	N41° 14.797'	W123° 46.398'

2.4.1. Tule Lake Outlet Canal

The probe was deployed in an aluminum canister secured by a cable and lock to the downstream guardrail of the bridge. The probe was suspended from the guardrail so it was at a depth of approximately one meter.

2.4.2. Klamath Straits Drain at Stateline Road

The probe was deployed in an aluminum canister secured by a lock and cable to a fence post on the South East side of the KSD headworks pool. The probe may not have received direct flow when water was released into the KSD headworks pool from the east and west gates of the Wildlife Refuge. The probe was suspended from the fence post so it was not immersed in the sediment (~ 0.3 meters).

2.4.3. Klamath Straits Drain at Highway 97

At the Klamath Straits Drain the probe deployment site was located approximately 0.2 miles west of the grab sample site, where the drain veered north at Wild Horse Butte. The probe was suspended from a buoy without a protective canister at a depth of approximately one meter.

2.4.4. Klamath River at Miller Island

To effectively represent conditions in this reach of river, the water quality probe was deployed in the middle of the channel. It was suspended from a buoy in a protective canister, approximately one meter below the surface.

2.4.5. Klamath River at Keno

Observations at Keno were made from a probe suspended from a buoy to the left of the center support of the Keno Bridge. The off center placement was to avoid conflict with water recreation activities. The probe was suspended without a protective canister, approximately one meter below the surface.

2.4.6. Klamath River above Copco Reservoir

Location was coincident with grab sampling site. The probe was deployed in an aluminum canister secured to a large tree on the left bank by a cable and lock. The probe rested on the river bottom.

2.4.7. Klamath River below Iron Gate Dam

The probe was located approximately 0.2 miles below Iron Gate Dam within the locked gate of the PacifiCorp facilities (for safety reasons) and upstream of the access bridge to the fish

hatchery. The probe was deployed in an aluminum canister secured to a large tree on the left bank by a cable and lock. The probe rested on the river bottom.

2.4.8. Shasta River

Location was coincident with grab sampling site. The probe was deployed in an aluminum canister secured to a large tree on the left bank by a cable and lock. The probe rested on the river bottom.

2.4.9. Scott River

Location was coincident with grab sampling site. The probe was deployed in an aluminum canister secured to a large tree on the right bank by a cable and lock. The probe rested on the river bottom.

2.4.10. Klamath River at Seiad Valley USGS Gage

Location was coincident with grab sampling site. The probe was deployed in an aluminum canister secured to a large tree on the right bank by a cable and lock. The probe rested on the river bottom.

2.4.11. Salmon River

At the Salmon River the probe was deployed at the USGS Gage. The gage was approximately one mile upstream from the confluence with the Klamath River. The probe was deployed in an aluminum canister secured to a loop of iron rebar extending from a large block of concrete on the left bank by a cable and lock. The probe rested on the river bottom.

2.4.12. Trinity River

The Trinity River site was likewise at a USGS Gage, in Hoopa. The probe was deployed in an aluminum canister secured to a loop of iron rebar extending from a large block of concrete on the left bank at river mile 12.4 on the Trinity River by a cable and lock. The probe rested on the river bottom.

2.4.13. Klamath River at Youngs Bar

The probe was deployed in an aluminum canister secured to the right bank. The probe rested on the river bottom.

In addition to these long-term deployments, water quality probes were deployed at additional locations for the synoptic surveys. Datasondes were deployed at the Klamath River above Shasta River, Klamath River above Scott River, and Scott River at Mouth. Although the Klamath River above Shasta River site was coincident with the synoptic sample site, the Klamath River above Scott River was located approximately 0.5 miles upstream from the grab sample location for safety reasons. Similarly, the probe deployed in the Scott River was located above the highway 97 bridge to place it away from more heavily used areas.

2.5. Water Temperature Sample Site Descriptions

Water temperature was collected at four locations between Iron Gate Dam and Seiad Valley (Table 2-4). The Klamath River at Cottonwood Creek was coincident with the algae study site. Klamath River above Shasta River sampling was coincident with the synoptic grab sample site. Klamath River above Scott River was coincident with the Datasonde deployment site. Finally, temperature monitoring at Scott River was completed approximately one mile upstream from the mouth. The site was located approximately 1000 feet downstream of the Scott River Road bridge and was accessible via a public access road to the river. Water temperature loggers were

deployed between 5 and 30 feet (depending on site conditions) from the bank in steel canisters attached to the shore with braided cable.

Table 2-4 Water temperature logger deployment locations

Sampling Location	Latitude	Longitude
Klamath River ab. Cottonwood Ck.	N41° 53.564'	W122° 32.124'
Ab. Shasta River	N41° 49.877'	W122° 35.606'
Klamath River ab. Scott River	N41° 46.892'	W123° 1.928'
Scott River nr. Mouth (RM 1)	N41° 45.944'	W123° 1.366'

2.6. Algae Sample Site Descriptions

Algae sampling sites were limited to two mainstem Klamath River locations: below Iron Gate Dam and above Cottonwood Creek (Table 2-5). The site below Iron Gate Dam was located on the left bank of the river adjacent to the fish hatchery and just upstream of the hatchery return. This location was across the river and downstream approximately 100 feet from the grab sampling site. The Cottonwood Creek site was coincident with the water temperature monitoring site. Additional site details are addressed under Special Studies.

Table 2-5 Algae study site locations

Sampling Location	Latitude	Longitude
Klamath River bel. Iron Gate Dam	N41° 55.791'	W122° 26.579'
Klamath River ab. Cottonwood Ck.	N41° 53.564'	W122° 32.124'

2.7. Trace Element Screening Sample Site Descriptions

Trace element sampling was completed at four sites in the study region (Table 2-6). All sites were coincident with semi-monthly grab sample locations with the exception of the Link river bridge. Collected from the Link River Bridge approximately 2 miles downstream from Link Dam. Sampling occurred by filling the churnsplitter directly from the river and all samples were then processed with a churnsplitter.

Table 2-6 Trace element grab sample locations

Sampling Location	Latitude	Longitude
Klamath River at Link River Bridge	TBD	TBD
Klamath Straits Drain (KSD) @ Hwy 97	N42° 4.846'	W121° 50.833'
Keno Bridge	N42° 7.627'	W121° 55.700'
Klamath River bel. Iron Gate Dam	N41° 55.865'	W122° 26.517'

3. DATA PROCESSING

Field data required some level of processing or review to ensure data were representative of actual field conditions. Beyond direct examination of field observations, processing typically included review of field notes, sampling methods and field protocols, and identifying the instrumentation employed and analytical methods applied. Because the sampling program utilized several methods to collect a wide variety of parameters on different time scales, several methods were employed. The final data sets presented herein have been reviewed and are considered final, unless otherwise noted.

3.1 Semi-monthly and Synoptic Grab Samples

Grab sample data have undergone data validation by USBR MP157 in accordance with the quality assurance program plan (see Appendices). For specific quality procedures for quality assurance of all analytical samples the reader is referred to USBR (2000). Although metals were collected via grab sampling, they are discussed separately.

Processing of the grab sample data was primarily limited to estimating parameter values below the reporting limit, quantifying the uncertainty associated with selected data, presenting summary statistics, and graphical representation. Incorporation of comprehensive quality assurance samples for field and laboratory assessment not only provided a greater level of confidence and legitimacy to a data set, but also provided a means of assigning uncertainty to the data. For scientific applications, high quality data is an obvious benefit, but the concomitant benefit of quantifying uncertainty in data is invaluable – especially in the Klamath River basin where a wide range of constituent concentrations may be encountered.

A primary issue with nearly all grab sampling programs is the limitations of analytical (i.e., laboratory) methods to detect small concentrations of certain constituents. The result is that some data at certain locations and/or times are presented as "less than" (<) a detection or reporting limit. This data was termed "censored." Table 3-1 illustrates censored data for Klamath River at Miller Island in May 2000. Ammonia (NH_4^+), nitrite plus nitrate ($NO_2^- + NO_3^-$), and biochemical oxygen demand (BOD) data all include censored values (bold). These values were below the reporting limit. It is critical to note that the reporting limit for these methods varied from roughly 1 to 3 times the laboratory method detection limit, depending on the constituent. (The reporting limits and method detection limit statistics are maintained by the laboratory and are updated infrequently, e.g., annually.). That is, the laboratory could detect smaller quantities of a constituent, but not necessarily in a consistent fashion (e.g., consistent with internal laboratory QA). The reporting limit is commonly two to ten times greater than method detection limits to ensure reliable, repeatable laboratory results.

Table 3-1 Klamath River at Miller Island (censored data in bold)

Site	Date	Time	NH_4^+ (mg/l)	TKN (mg/l)	$NO_3^- + NO_2^-$ (mg/l)	TP (mg/l)	PO_4^{3-} (mg/l)	BOD (mg/l)
KRMI	05/01/00	10:30	**<0.05**	0.9	**<0.05**	0.22	0.16	4.0
KRMI	05/09/00	14:36	0.29	0.8	**<0.05**	0.34	0.27	**<3.0**
KRMI	05/23/00	09:15	0.27	0.8	**<0.05**	0.28	0.28	4.0

Data was estimated for samples where the concentration was below the reporting limit (and potentially below the method detection limit as well) to facilitate computation of summary statistics. There are several methods for estimating data below the reporting (or detection) limit including simple methods such as setting all values below the reporting limit to (a) the reporting limit, (b) to zero, (c) to one half of the reporting limit. However, more rigorous methods are presented by Gilliom and Helsel (1986), including estimating censored data assuming that censored observations follow a zero to reporting limit lognormal distribution based on non-censored data. The process is straightforward:

1) Log-normal probability plots (a.k.a. exceedence plots) are constructed for a particular parameter based on the uncensored data.
2) A least squares regression is fit to the data.
3) Values below the reporting limit are calculated using the least squares regression for each plotting position.

For example, to construct the probability plot all values are ranked by magnitude and the plotting position determined by the general equation

$$q_i = \frac{i - a}{n + 1 - 2a} \qquad (1)$$

where q_i is probability plotting position (exceedance probability), i is plotting position (rank), a is plotting position parameter, and n is number of samples. Several formulae based on Equation 1 are available, including Weibull, Median, Blom, Cunnane, and Hazen (Stedinger et al, 1993). A Weibull distribution (a = 0) was used for this project.

Table 3-2 illustrates the $NO_2^- + NO_3^-$ data for Klamath River at Miller Island for the 2000 season. The data have been ranked from low to high, three censored values exist, and plotting position based on Equation 1 is presented.

Table 3-2 Klamath River at Miller Island $NO_2^- + NO_3^-$ data by magnitude with computed plotting position

Rank	Date	Censored Data	Uncensored Data	Plotting Position, q_i
1	05/09/00	<0.05		0.07
2	05/23/00	<0.05		0.13
3	05/01/00	<0.05		0.20
4	10/17/00		0.10	0.27
5	10/31/00		0.13	0.33
6	08/22/00		0.18	0.40
7	06/20/00		0.19	0.47
8	09/26/00		0.26	0.53
9	11/14/20		0.42	0.60
10	09/12/00		0.70	0.67
11	06/06/00		1.69	0.73
12	07/11/00		1.79	0.80
13	07/25/00		2.05	0.87
14	08/08/00		2.30	0.93
n= 14, a = 0				

Figure 3-1 illustrates a log-normal plot with a least-squares regression line and equation for the uncensored data (solid symbols). This equation was used to estimate data values for the remaining three data points below the reporting limit of 0.05 mg/l (open symbols). If the equation returned a value above the reporting limit, the value was set at the reporting limit, as was

the case for the Klamath River at Miller Island $NO_2^- + NO_3^-$ - the calculated value at the 0.20 plotting position (80 percent exceedence) was 0.06 mg/l. The calculated values at the 0.07 and 0.13 plotting positions were 0.03 mg/l and 0.04 mg/l, respectively. As noted in the figure, the least-squares regression relationship provided a good representation of the data. Correlation coefficients were typically greater than 0.9, with the lowest value about 0.85 for all data sets. Standard error of the estimate (i.e., regression coefficients) was not computed. Based on findings of Gilliom and Helsel (1986) and Helsel and Gilliom (1986) data were not estimated below the reporting limit when greater than 50% of the data were censored.

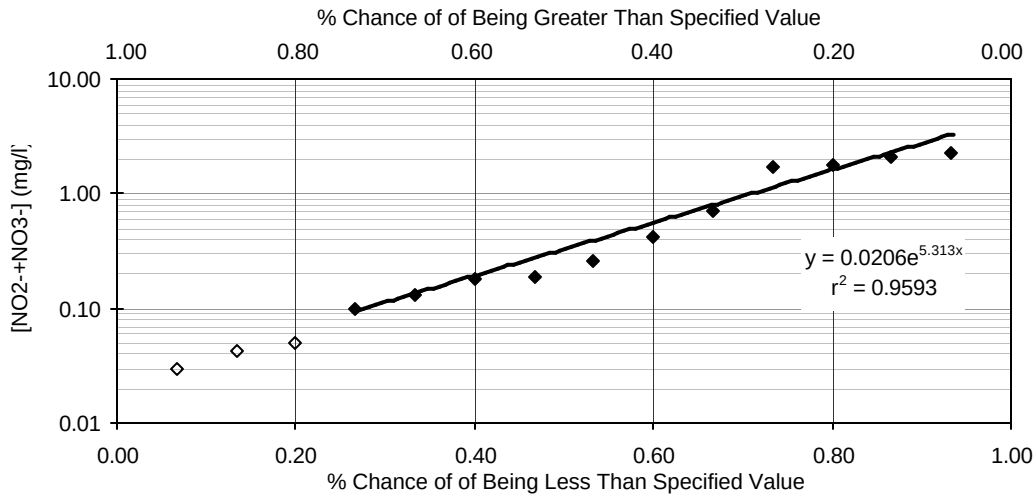


Figure 3-1 Log-normal probability plot, least-squares regression and estimated data for Klamath River at Miller Island $NO_2^- + NO_3^-$

Probability plots provide much more than a means to estimate data below the detection limit. By definition, they provide exceedance probabilities useful in many studies. For example, although based on a single year, Figure 3-1 illustrates that 50 percent of the time $NO_2^- + NO_3^-$ concentrations will exceed approximately 0.3 mg/l, and about 75 percent of the time concentrations will exceed 1.0 mg/l from mid-spring through mid-fall.

3.2 Other Data

To compliment the grab sampling program, water quality probes were used to collect physical measurements of water temperature, dissolved oxygen, electrical conductivity and/or specific conductance, pH, and redox during each sampling run. Turbidity data was also measured. Three turbidity samples were processed for each semi-monthly sampling location and collection, but turbidity was not measured during the synoptic surveys. The probe data, as well as the turbidity data have been reviewed and included in tabular form with the grab sample results. Due to equipment failure and logistical problems, some data were not collected at certain times and/or locations and are thus unavailable.

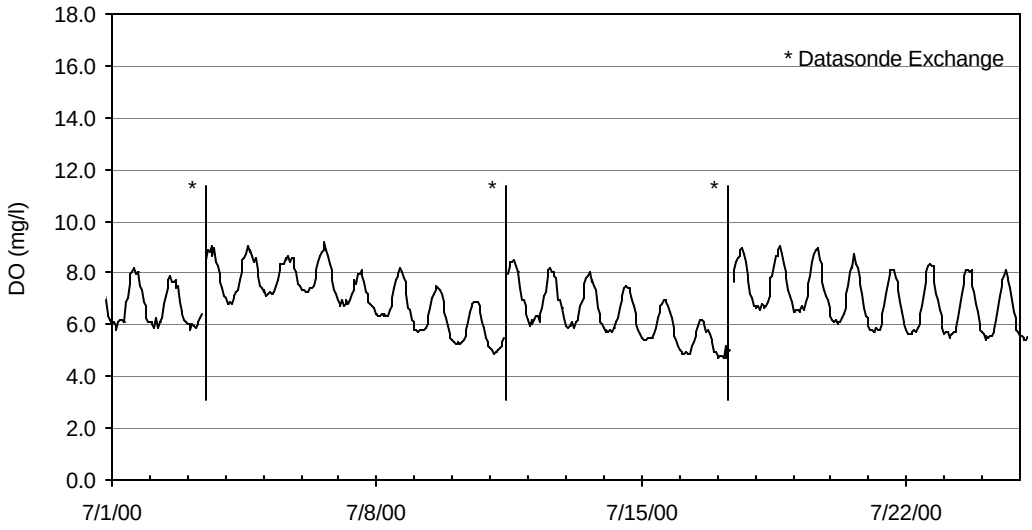
3.2.1 Datasonde

Datasonde parameters collected during the 2000 field season included hourly water temperature, dissolved oxygen, electrical conductivity and/or specific conductance, pH, and redox. Datasondes were exchanged at roughly weekly intervals. Because the probes were generally launched prior to field deployment and allowed to continue recording after retrieval, there was a considerable amount of post processing required.

Some fundamental challenges of collecting data with water quality probes includes probe malfunction, calibration problems/errors, data logging malfunction, and user error (e.g., setting incorrect start time). In addition, probes require a high level of maintenance to obtain reliable, useful data. A lack of regular maintenance, including proper care (calibration, replacing and/or using the proper dissolved oxygen membranes) are common problems in water quality monitoring with these instruments.

Finally, the water quality environment in which the probes were deployed played a critical role in data quality. Throughout much of the Klamath River basin these probes were deployed in enriched systems. The probes experienced water temperatures approaching 30°C (86°F), dissolved oxygen (DO) concentrations ranging from 0 mg/l to over 15 mg/l (with daily variations up to 10 mg/l), and pH levels approaching 10.

A significant problem encountered throughout much of the study area was biofouling of the DO membrane. Recorded DO concentrations typically began to show degradation within 24 to 96 hours. Figure 3-2 illustrates recorded hourly DO at in the Klamath River near Seiad Valley from June 1-25, 2000. Degradation in measured DO occurred immediately in some cases. It is clear this was not an accurate portrayal of system dynamics because each time the probe was exchanged there was a step increase of 2 mg/l to 3 mg/l. This problem was insignificant in the early to mid-spring periods and in the late fall, but during the late spring through early fall period much of the DO data was affected. At sites where DO was severely depressed (e.g. Miller Island), such problems were not usually apparent, probably because there was very little DO



present.

Figure 3-2 Recorded dissolved oxygen concentration, Klamath River at Seiad Valley USGS gage: June 1-25, 2000

In addition to concerns with dissolved oxygen, other parameters also experienced problems. Redox observations typically doubled in value during the one-week deployment periods. It is surmised that this problem was associated with primary production.

A separate limitation of the water quality probes is that individual probes may report different constituent concentrations when placed in the same body of water. Most likely the differences occur due to improper calibration, probe drift, probe malfunction, instrument mishandling, improper membrane, not letting a membrane mature, hardware, and/or age. Regardless of the cause, the result was that probe readings can differ well in excess of factory specifications. An example of this problem is illustrated in recorder pH in the Klamath River near Seiad Valley (Figure 3-3). To address these conditions all probes used in the WQ2000 sampling program were tested simultaneously and their results compared. Details and results of the test are included in the Data Appendix document.

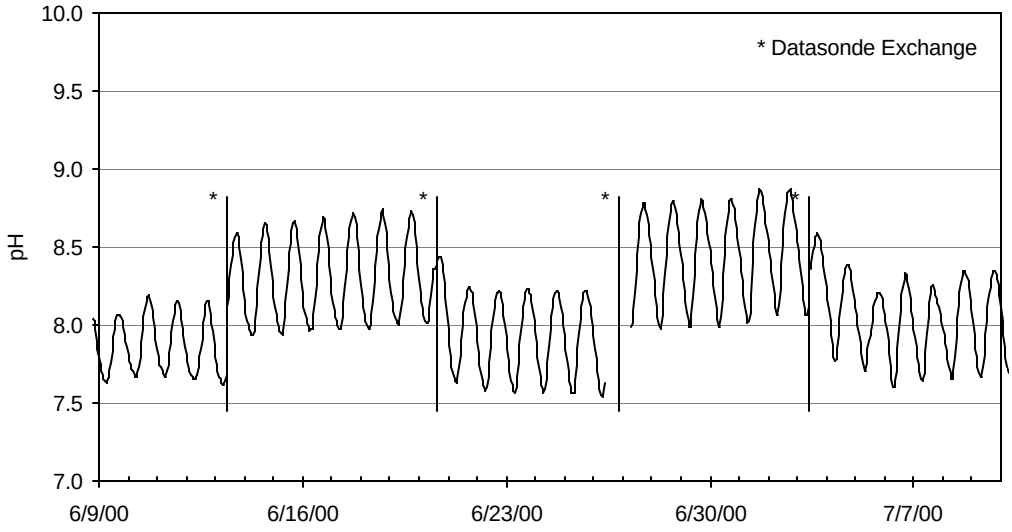


Figure 3-3 Recorded pH, Klamath River at Seiad Valley USGS gage: June 9-July 10, 2000

Although information exists to potentially correct, as well as assign uncertainty to the water quality probe data, no such measures were undertaken. The individual weeklong data sets were examined using field logs to determine precise time of deployment and retrieval and only periods of river deployment were retained. Further, the data were graphed and basic summary statistics (mean, maximum, and minimum values) determined as an evaluation measure. However, due to the large amount of data, post correction of the time series is left to the end user.

3.2.2 Water Temperature

Water temperature data was collected using Onset Corporation Stowaway® temperature loggers. The primary data quality control measure applied to these data was to carefully review and remove observations from the records that occurred prior to deployment and after retrieval. Further, a review was competed to ensure the loggers were not exposed to the atmosphere during deployment, thus recording air temperature instead of water temperature. (The accuracy of these devices is ±0.2°C (0.36°F) at 20°C. All devices were tested prior to field deployment.)

3.2.3 Algae

Algae data were collected over four week periods twice during the summer of 2000. These data did not require any special processing and are presented in discussed in the Special Studies section.

3.3 Program Data

All program data and explanations for data presentation are located in the Klamath River Water Quality 2000 Data Appendix. Table 4-1 lists the reference and title for all data include within the Data Appendix. Further details can be found in the Data Appendix table of contents.

Table 4-1 Data Appendix table of contents

Appendix	Title
A	Semi-Monthly data by sampling site
B	Semi-Monthly data by sampling date
C	Semi-Monthly data by sampling site: summary statistics
D	Semi-Monthly data: graphical representation by site
E	Semi-Monthly data: Probability plots by site
F	Synoptic Survey Data
G	Synoptic Survey Data: summary statistics
H	Synoptic Survey Data: graphical presentation by site
I	Synoptic Survey: DataSonde records
J	Datasonde Data
K	Water Temperature Data
L	Metals and Aquatic Life Criteria
M	Benthic Algae Data
N	Reservoir Water Quality Data: grab samples
O	Reservoir Water Quality Data: grab samples, graphical representation by site
P	Reservoir Profile Data
Q	Reservoir Thermistor Strings
R	River and Reservoir Flow Data
S	Reservoir Stage and Volume Data
T	Meteorological Data
U	DataSonde Population Testing

4. SPECIAL STUDIES

In addition to the baseline sampling program, three special studies were implemented. These included intensive synoptic surveys, algal growth studies, and trace elements screening.

4.1 Synoptic Survey

Previous water quality modeling studies of the Klamath River between Iron Gate Dam to Seiad Valley identified a need for additional data within this study reach to improve water quality characterization and provide supplementary data for modeling. One issue of interest was the sub-daily response of water quality in the river system. To achieve this goal several synoptic studies consisting of grab samples and water quality probe deployment were designed and implemented.

Six sampling locations were designated for intensive study over three day periods. The sites include

- Klamath River below Iron Gate Dam
- Klamath River above Shasta River
- Shasta River
- Klamath River above Scott River
- Scott River
- Klamath River at USGS Gage near Seiad Valley

Grab sampling occurred three times per day with the morning collection between 6:00 a.m. and 8:00 a.m.; mid-day collection between 10:30 a.m. and 1:00 p.m. and afternoon collection between 1:30 p.m. and 3:30 p.m. The morning, mid-day, and afternoon sampling "windows" were target periods. Some samples were not collected within these periods due to travel logistics and shipping schedules (the reader is referred to the Data Appendix where exact sampling times are reported). Datasondes were deployed during the initial sampling visit and retrieved at the end of the three day period. The synoptic surveys were completed June 5-7, August 7-9, and September 27-29, 2000. The September survey consisted only of water quality probes at the selected sites.

Grab samples included ammonia, nitrate+nitrite, total Kjeldahl nitrogen, total phosphorous, orthophosphate, organic nitrogen (dissolved), and organic phosphorous (dissolved). Water quality probes were used to collect water temperature, dissolved oxygen, pH and specific conductance on 30 minute and one-hour intervals. All data are included in the data appendix. Outlined below are details related to these synoptic surveys.

4.1.1 Synoptic Survey: June 5-7, 2000

The June synoptic survey started on June 5 and ran for three consecutive days. During the morning sampling session on the first day the Datasondes were deployed in the Klamath River above the Shasta and Scott Rivers. There was no Datasonde available for the Scott River until the afternoon of the first day. A YSI dissolved oxygen meter was used to take intermittent reading readings at this site during the morning and mid-day sampling sessions. The probe located at the Scott River did not have the protective canister identified in the Datasonde Protocol. All Datasondes were recovered during the afternoon (last) grab sampling effort on June 7. The Datasonde in the Klamath River above the Scott failed to record any data.

The study site experienced warm weather through much of the sampling period, with temperatures ranging from 5°C (41°F) to over 31°C (89°F). High clouds were evident each day

(possibly originating from the approaching cold front). Still, days were mostly sunny and warm with the exception of Wednesday. Wednesday morning clouds were evident early in the day, while conditions remained mild. By late afternoon, a cold front had arrived and by evening scattered showers occurred in the study area.

4.1.2 Synoptic Survey: August 7-9, 2000

The August synoptic survey started on Monday, August 7 and ran for three consecutive days. During the morning sampling session on the first day the Datasondes were deployed in the Klamath River above the Shasta and Scott Rivers and in the Scott River. The Datasonde deployed in the Klamath River above the Scott River was on loan from the North Coast Regional Water Quality Control Board. This probe did not have the protective canister identified in the Datasonde Protocol. All Datasondes were recovered during the afternoon (last) grab sampling effort on August 9.

The study site experienced hot weather through much of the sampling period, with temperatures ranging from about 17°C (63°F) to over 36°C (97°F). Thunderstorm activity and associated showers occurred during the late afternoon and evening of each day. Cloud cover from this activity often lingered into the early morning hours. All days were clear by 9:00 a.m., except August 9, when cloud cover did not clear until approximately 11:30 a.m.

4.1.3 Synoptic Survey: September 27-29, 2000

Upon completion of the first two synoptic surveys it was determined that an additional full water quality survey was not required. During the September survey, no water quality grab samples were collected. However, water quality probes were deployed at the designated synoptic sites that were not covered under the Datasonde deployment program (specifically, Klamath River above the Shasta River, Klamath River above the Scott River, and Scott River at mouth.) The probes were left in place for one week to monitor temperature, dissolved oxygen, pH, and specific conductance.

The study site experienced weather conditions typical of late fall "Indian summer." Temperatures ranged from about 10°C (50°F) to over about 28°C (82°F). Days were warm with cool nights and few clouds.

4.2 Benthic Algae

Primary production in the Klamath River plays a critical role in water quality response, particularly in the spring, summer and fall months. In reservoirs primary producers consist of diverse phytoplankton assemblages. For example, Iron Gate Reservoir includes several species of diatoms (*Stephanodiscus, Synedra,* and *Melosira*); blue green or cyanobacteria (*Aphanizomenon* and *Oscillatoria*), as well as Cryptophyta (*Chrytomonas* and *Chroomonas*), and Chlorophyta (*Schroederia*) (EPA, 1978). Certainly some of these species wash from the reservoirs and lakes into the downstream river reaches. Further, impounded reaches may support considerable phytoplankton populations under certain hydrologic, climatic, and water quality conditions. However, in the free flowing river reaches these planktonic species fare poorly and the dominant forms include periphyton, other benthic algae and rooted aquatic plants.

To support modeling efforts in the reach between Iron Gate Dam and Seiad Valley, a benthic algae study was completed to estimate algal growth rates for water quality simulation. A review of available methods and extensive conversations with United States Geologic Survey staff (pers.

comm. S. Porter, K. Carpenter, T. Brown, L. Brown) led to a preliminary effort to deploy unglazed ceramic tiles on the riverbed. Such artificial substrates have a number of limitations including loss due to high flows, burying (sedimentation), grazing losses, and bias toward communities actively colonizing at the time of placement. However, they can be useful in estimating algal species growth rates over longer periods of time (Porter et al, 1993).

The preliminary artificial substrate consisted of six-inch square tiles attached to 8-inch by 16-inch cinder blocks with epoxy. The tiles were placed in the river on March 22, 2000 to "condition" and "inoculate" the tiles, and assess their efficacy in monitoring algal growth. The clay tiles were conditioned because the tile can exhibit a surface charge phenomenon, and this electrostatic charge can impede algal growth at the outset (S. Porter, pers. comm.). Although the tiles were not to be sampled until June, placing them in the stream several months ahead of time allowed for at least a precursory level of colonization (inoculation). The tiles were left submerged in the river from late March through August, i.e., they were not allowed to desiccate.

Initially, three locations for tile deployment were selected in the Klamath River: below Iron Gate Dam (RM 190), above Cottonwood Creek (RM 182), and above the Shasta River (RM 176). Four tiles (two cinder blocks) were placed at each location. Iron Gate Dam release during deployment was in excess of 3100 cfs precluding placement of tiles more than approximately 20 feet from shore at the Cottonwood Creek and Shasta River sites, only five feet at Iron Gate Dam. Water temperature was approximately 9°C (48°F), emergent shoreline vegetation (cattail, eel grass) was largely absent, and riparian vegetation was dormant. At the time of placement the majority of the bed was colonized by *Cladophora*.

On April 19, 2000 the tiles were examined. At Cottonwood Creek the tiles were completely bare due to heavy grazing by snails. Literally hundreds of snails were observed on the tiles. Grazing was so heavy that attempts to recover algae by scraping the tile with a razor blade yielded no appreciable substrate. In contrast, the tiles below Iron Gate Dam experienced luxuriant growth, with unidentified filamentous algae up to two inches in length. Further, there was no sign of grazing and no snails were observed. However, it was observed that the density of algae varied greatly among the four tiles, with one tile having almost no growth. Finally, it was evident that the Shasta River location had potentially different shading conditions – both topographic and riparian – than the other sites, and the tiles were removed and placed at the Iron Gate Dam and Cottonwood Creek sites. Two sampling periods, one in June and one in August, were selected for sampling. Floating periphyton samplers were added to the program to minimize grazing impacts. Discussion of each sampling effort and results are outlined below.

4.2.1 June 5 - June 30, 2000

Floating periphyton samplers were deployed on June 5 and attached to anchors set on the streambed. All ceramic tiles were removed from the river and vigorously scrubbed with a nylon brush to remove existing algae, then replaced in the river adjacent to the floating samplers. The sites were visited regularly over the first few days to assess deployment conditions. The sites were subsequently visited on June 14, 22, 26, and 29, 2000. It was apparent that floating strands of filamentous algae would catch on the anchor line and foul the samplers. The California Department of Fish and Game assisted in collecting randomly selected microscope slides for laboratory processing from floating samplers and completing the narrative description of conditions present on the ceramic tiles. New slides were placed in the sampler to replace those removed for processing in order to maintain similar flow conditions in and around the sampler throughout the sampling period – these new slides were not sampled. Single slides were placed in 125 ml bottles and shipped to laboratory on dry ice.

During the first weekly visit fouling of the floating samplers appeared to interfere with the samplers. A t-post was installed upstream of the individual samplers to catch the floating debris. This approach was largely successful at all sites.

Results of the June sampling period for dry weight and ash-free dry weight both Iron Gate Dam and Cottonwood Creek sites are presented in Figure 4-1 and Figure 4-2, respectively. Results indicate a steady increase in algal biomass during the sampling period with the exception of the last sample point at Iron Gate Dam, when algae actually died back. The reason for this condition is unknown. One possible explanation may be that the original colonizing algae were dependent on cooler water temperatures. Iron Gate Reservoir and Dam operations serve to moderate temperature to a large degree, resulting in nearly constant temperature over short periods (hours, days), but releases do exhibit seasonal warming during the summer months. As seasonal temperature warmed from about 17°C on June 5 to over 20°C on June 29 the original algae assemblage or a portion of the original alga assemblage may have suffered. Other possible explanations could be disease, parasitism, and changes in environmental conditions (other than temperature).

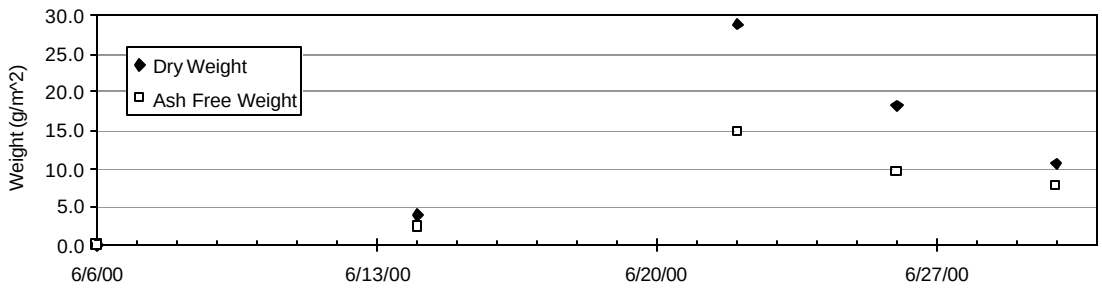


Figure 4-1 Iron Gate Dam dry weight and ash-free dry weight: June, 2000

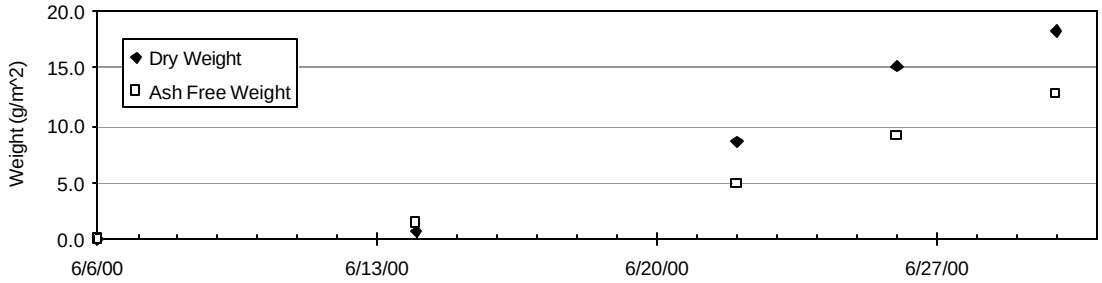


Figure 4-2 Klamath River above Cottonwood Creek dry weight and ash-free dry weight: June, 2000

4.2.2 August 8 - August 28, 2000

Floating periphyton samplers were deployed on August 8th attached to t-posts. As with the previous sampling effort, all ceramic tiles were removed from the river and vigorously scrubbed with a nylon brush to remove existing algae, then replaced in the river adjacent to the floating samplers. The sites were visited regularly over the first few days to assess deployment conditions. The sites were subsequently visited on August 16, 21, 23, and 28, 2000.

Results of the August sampling period for Ash-free dry weight and Chlorophyll a for both Iron Gate Dam and Cottonwood Creek sites are presented in Figure 4-3 and Figure 4-4, respectively. Results at Iron Gate Dam indicate somewhat similar conditions to the June period, except during

this deployment no algae dieback was observed at any time during the period. Results for the Klamath River above Cottonwood Creek are markedly different. Compared with Figure 4-2, above, the growth rate is significantly smaller, and one could argue that, as exhibited by AFDW, that little growth was evident. These findings are discussed further under modeling studies.

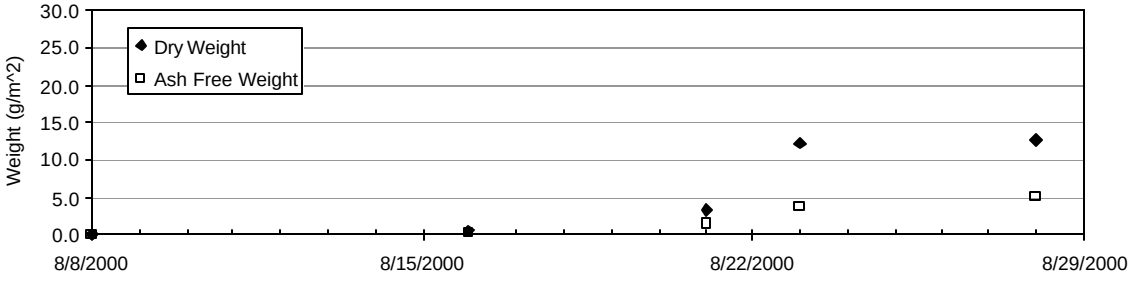


Figure 4-3 Iron Gate Dam dry weight and ash-free dry weight: August, 2000

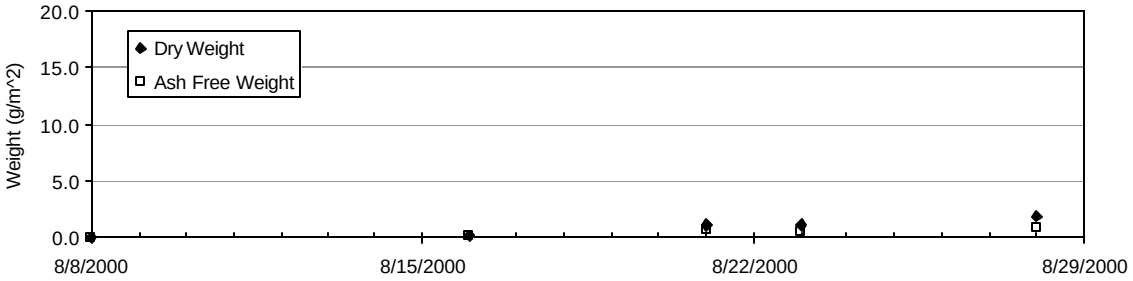


Figure 4-4 Klamath River above Cottonwood Creek dry weight and ash-free dry weight: August, 2000

4.2.3 Species Identification

Limited species identification was carried out during the sampling periods. Macroalgae identified in the study reach included widespread colonization of the riverbed by *Cladophora* and *Potamogeton* (*P. crispus and P. pectinatus)*. Other benthic algae identified included *Ceratophylum* and *Elodea*, two non-endemic species. Artificial substrate was collected from a floating periphyton sampler for algal identification during August. The periphyton community was dominated by pennate diatoms (*Cocconeis, Navicula, Nitzschia, Gomphonema*, and *Fragilaria*). The identified species tended to be on the higher side of trophic status, i.e., they suggest an elevated nutrient content in the water (J. Sweet, pers. comm.).

4.3 Trace Elements and Metals

Trace elements and trace metals were screened at four locations in the basin during the 2000 field season: Link Dam, Klamath Straits Drain at Highway 97, Keno, and below Iron Gate Dam. Samples were collected on May 23, June 20, July 25, and September 26. The fifteen elements included in the screening samples are provided in Table 4-1.

Table 4-1 Trace element screening suite constituents

Aluminum	Antimony	Arsenic
Cadmium	Chromium	Copper
Iron	Lead	Magnesium
Mercury	Nickel	Selenium
Silver	Thallium	Zinc

All of the trace elements were inorganic compounds consisting of metals and nonmetals. Where applicable, freshwater aquatic life criteria were tabulated for each of the constituents. Freshwater aquatic life criteria for certain metals is a function of hardness, in which cases for the appropriate criteria the reader is referred to CEPA, (1998), for specific calculation procedures. Trace element sampling field data are included in the data appendix.

Aluminum, lead, and mercury exceeded freshwater aquatic life criteria during the program. During the first two sampling efforts aluminum exceeded aquatic life limits at all locations. For the latter two sampling dates aluminum was elevated only at Link Dam and in the Klamath Straits Drain. Lead levels were elevated in two samples, in the Klamath River below Iron Gate Dam (5/23/00) and the Klamath River at Keno (6/20/00). There were two instances when the aquatic life criteria were below the reporting limit for lead: Klamath River at Link Dam (5/23/00 and 7/25/00). However, no conclusive evidence can be drawn from these samples. Mercury was elevated for all sampling sites at least once during the 2000 monitoring program; however, Keno experienced levels in excess of the aquatic life criteria throughout the field season. In addition, for silver the aquatic life criteria were below the reporting limit for the entire season at Link Dam.

Concern over these metals varies. Aluminum can be a source of concern in drinking water for both health and human welfare. Aluminum in the form of alum is commonly used as a coagulant in water treatment, and can lead to discoloration in drinking water.

Lead is highly toxic and considered a probable carcinogen. Lead in surface waters can originate from natural sources, certain types of manufacturing (e.g., batteries), and from historic uses including lead paint and leaded gasoline. It has no known beneficial or nutritional effects and tends to accumulate in tissues of man and other animals.

Mercury is widely found in surface waters both naturally and as a byproduct of mining, manufacturing, pesticide production and application, and many other industries. A primary concern with mercury, beyond its well documented toxic effects, is bioaccumulation in the food chain. Both drinking water and aquatic life criteria exist for mercury.

Silver is a nonessential, non-beneficial element for humans, but is systemically toxic to aquatic life. Bioaccumulation, although apparently harmless in humans (at levels below drinking water standards), is a concern with fish life.

5. MODELING: ASSESSMENT AND APPLICATIONS

5.1 *Model Assessment*

One component of the project was updating, as necessary, the existing water quality model for the Klamath River mainstem between Iron Gate Reservoir and Seiad Valley. This included an investigation for improving representation of benthic algae in the model as well as incorporating year 2000 data in model calibration and validation. During the benthic algae monitoring study it became apparent that the Klamath River benthic community was not only extremely complex, but also poorly understood. The sampling effort provided the first concrete values on growth rates, and the dynamic processes that were observed in the system. Most notable were grazing by mollusks and invertebrates and the apparent shift of algal species below Iron Gate Dam as the river temperature changed. Further, respiration rate, another model parameter was not measured.

To further evaluate the options for representing benthic algae in simulation models a literature review was completed (see attached appendix). The findings identify important parameters in modeling benthic algae, associated biomass, dissolved oxygen and nutrient effects, and the overall importance of benthic communities. Fundamentally, rivers are different environments than lakes, wherein phytoplankton (free floating) algae typically dominate. The relatively fast moving water of river systems with short residence times prove a challenge to modelers aiming to represent these processes. Selected water quality models include logic to represent benthic algae; however, all struggle to characterize the diversity of benthic communities and their complexity and dynamics.

The current model, RMA-11, presumes that algae grow in accordance with a growth rate, respiration (and mortality) rate, and are limited by light and nutrients. Nutrient limitation is based on inorganic nitrogen and phosphorous forms. This fairly simple formulation incorporates only a single “bulk” community (represented by one set of parameters, i.e., it does not look at individual species) and does not directly account for losses by grazing, scour, senescence and sloughing, etc. Further, the selected initial conditions can affect simulated algal biomass at future time steps. Nonetheless, the model has provided considerable insight into the potential dynamics of primary production on water quality conditions in the Klamath River between Iron Gate Dam and Seiad Valley.

There are models available that provide a wider range of input parameters to represent the benthic community and its response on water quality. However, these models often require a large amount of data, or include simplifications of other processes that make them infeasible for most practical applications. Gathering information on the benthic community at a sufficient number of locations over a long period (e.g., spring through fall) would be required.

One available methodology may provide improved results with modest data collection costs, and at a minimum would provide additional data to the existing formulation. The general model representations follow a similar vein to that presented in RMA-11, that is the representation of a bulk community, but in this methodology algal biomass is calibrated to dissolved oxygen concentrations under steady-state conditions. Using a simulation model algal biomass is estimated consistent with dissolved oxygen observations and algal photosynthesis. Respiration rates are calculated based on the estimated algal mass accounting for stream re-aeration. Some

models accommodate grazing and sloughing as well. By calibrating to dissolved oxygen the model aggregates all benthic processes into a "bulk" community. The limitation of the methodology is that it is most readily adaptable to steady-state conditions, while the conditions of interest in many cases are highly dynamic. Nonetheless, with systematic data collection over a broad reach of river, it is plausible that sufficient data could be gathered to represent a dynamic system response in space and time. Any such water quality study should include a corresponding ecological component to characterize the flora and fauna of the benthic community.

The model was applied under various conditions with the existing logic. The findings illustrate a system that is highly dynamic in space and time – results that are consistent with information from the field program. Based on these simulations and the results from the field monitoring program, it was determined that incorporating additional logic into the model without the appropriate data would be imprudent at this time. Although dissolved oxygen probes were in place during the 2000 field season, there are insufficient data to address the highly spatial variability of algal growth in the system. Further, additional fieldwork is necessary to further quantify photosynthesis and respiration (e.g., completion of light an dark bottle tests in tandem with water quality probes), sloughing studies, and grazing impacts. Upon completion of this data a complete update of the model, including calibration should be undertaken. Because model applications (see below) were predominately limited to water temperature response, water quality calibration was not revisited at this time (the model is already calibrated for temperature). Recommendations for these studies can be found in the conclusion of the report.

5.2 Model Application

The models and model output were used for various studies during the project period. The principal studies included examining the temperature impact of flow changes in the Klamath River below Iron Gate Dam during summer months. Two studies were completed; the first examined a specific flow change during the late summer and early fall months (August and September), while the second looked at a broader range of flows and cumulative effects over the June through September period.

5.2.1 Late Summer and Early Fall Flow Change: Iron Gate Dam to Seiad Valley

Varying the flow rate in the river can directly influence water temperature through increased transit time, varied depth and width, and altering the impact of tributary contributions. Model results illustrate that daily maximum temperatures are greater at a flow rate of 1030 cfs than at 1330 cfs for all days of the month – up to 1°C (1.8°F) greater at Seiad Valley. Daily minimum temperatures at Seiad Valley are lower at a flow rate of 1030 cfs than at 1330 cfs for all days of the month – up to 0.8°C (1.4°F) lower. The lower flow rate has a longer transit time – on the order of 6 to 8 hours longer between Iron Gate Dam and Seiad Valley. With shorter days and longer nights, the smaller thermal mass and depth associated with the 1030 cfs flow rate allows the river to heat and cool at a more rapid rate, leading to greater diurnal temperature swings in the river (~1.3°C / 2.3°F). Daily mean data tend to mask these conditions, thus hourly simulations were implemented. Flow changes (i.e., withdrawal rate) have the potential to affect the thermal structure of Iron Gate Reservoir as well.

It is apparent that reduced flows can lead to increases in mean daily water temperatures. However, short-term meteorological conditions play a significant role. Clear sky conditions can result in increased daily mean temperatures on the order of a few tenths of a degree Celsius between Iron Gate Dam and Seiad Valley for a flow change from 1330 cfs to 1030 cfs. However, when conditions cool (e.g., cold front), such as can occur during September, the lower flow

scenario exhibits cooler water temperatures. The lower flow rate leads to extended exposure to cool conditions, and the smaller thermal mass cools more quickly.

5.2.2 Impact of Normal, Dry, and Critically Dry Hydrological conditions on Water Temperature: June – September

Temperature dynamics in the Klamath River below Iron Gate Dam are affected by upstream reservoirs, local meteorological conditions, regulation of releases to the Klamath River, quantity of release to the Klamath River and tributary contributions. Some principal findings include:

- Under drought conditions tributary contributions are typically small.
- Under typical summer time flows, re-regulation produces predictable "nodes" of minimum temperature variation separated by a one-day travel time in the river (at mean velocity). This phenomenon, apparent in sub-daily data and simulations, are critical in interpreting sub-daily water temperature information.
- Seasonal changes are apparent in the system as well as short term climatic meteorological conditions.
- Iron Gate Reservoir (and possibly Copco Reservoir) affect the thermal regime of the downstream river in three principle ways (under current operating conditions):
    - In mid-to late spring Iron Gate Dam releases are often slightly below equilibrium temperature, maintaining a slight cool water "benefit" for releases to the Klamath River.
    - In summer, there is minimal cool water benefit to the Iron Gate release (with respect to anadromous fishes). The release is only marginally below equilibrium temperature; however, the release does moderate the daily maximum and minimum temperature.
    - In fall, for short periods, the Iron Gate release can be warmer than equilibrium temperature. Under such conditions, the release is a heat source to the river. This condition is probably short lived.

Dissolved oxygen (DO) dynamics in the Klamath River below Iron Gate Dam were also simulated. The response of DO in the river downstream of Iron Gate Dam is a complex function of flow, release water quality, and primary production. A few notable findings suggest that:

- Simulated mean daily dissolved oxygen (as depicted in longitudinal profiles) is fairly constant throughout most of the summer throughout the river reach. However, in the fall, DO releases from Iron Gate dam begin to decrease to levels well below saturation.
- Further examination of the daily mean DO profiles illustrates that there is potentially appreciable primary production immediately below Iron Gate Dam, shown by a slightly increased daily mean DO.
- Examination of the simulated time series suggests that seasonally (and spatially) primary production directly and appreciably impacts sub-daily dissolved oxygen levels.
- The various flow regimes had a modest impact on daily mean DO concentration. The lower flows did produce a slightly higher mean daily DO, possibly due to increased aeration at shallower depths. Sub-daily data were more highly variable between alternatives, but these data have not been critically assessed at this time to provide an explanation for this response.

Simulated dissolved oxygen results have not been used in any quantitative manner. However, several of the above results are supported by field data.

Additional work under this task included review of various documents submitted to or prepared by USBR.

5.2.3 Algae Simulations

As noted above in the section on the benthic algae special studies, growth rates at the Cottonwood Creek site decreased dramatically during the August 2000 sampling period when compared to June 2000 (compare Figure 4-2 and Figure 4-4). These findings prompted a review of previous simulations of benthic algae in the Klamath River below Iron Gate Dam. Deas (2000) presented results from a simulation of longitudinal benthic algae biomass, reproduced below.

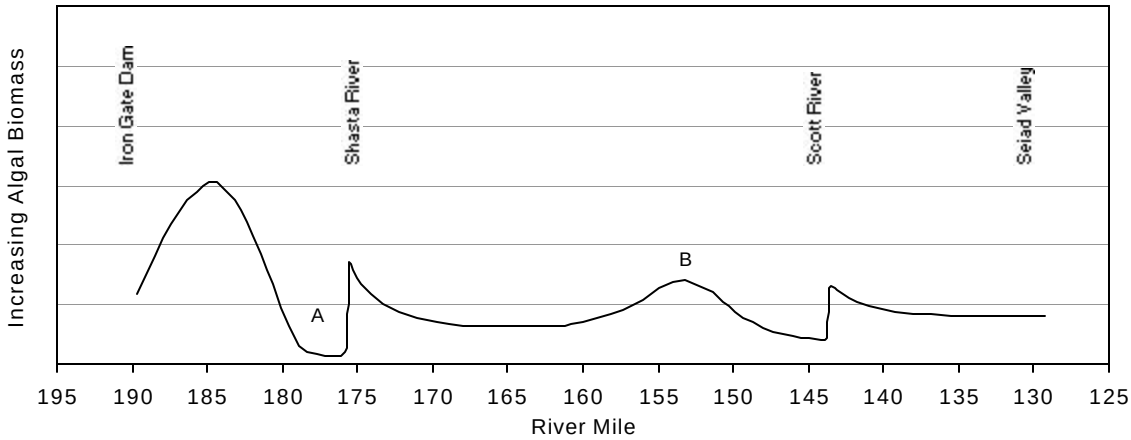


Figure 5-1 Hypothetical longitudinal profile of mean daily algal biomass in midsummer (from Deas, 2000)

The vertical axis in Figure 5-1 represents relative mean daily algal biomass (only a relative scale is presented because lack of field data precluded calibration of the model for attached algae), and the horizontal axis represents river mile with downstream progressing from left to right: Iron Gate Dam to Seiad Valley.

This simulation suggested a marked peak in algal biomass in the vicinity of RM 185 due to readily available nutrients from Iron Gate Reservoir releases. Further, assuming reservoir releases supply a relatively constant source of nutrients to the river, by mid-summer, algal biomass in the immediate downstream reach would approach equilibrium with respect to available nutrients. That is, biomass could potentially increase up to the point of effectively capturing the bulk of the nutrients. Thus, immediately downstream of this peak is a depression in algal biomass due to lack of available nutrients, labeled point A in Figure 5-1.

The original presentation of Figure 5-1 represented a hypothetical response using data from the month of June. Additional simulations were completed for the month of August to determine if the model would possibly capture a seasonal component to growth rate at Cottonwood Creek. Figure 5.2 presents relative algal biomass derived from model simulations for the months of June and August for the 15 miles of the Klamath River below Iron Gate Dam. Although this work is preliminary, these simulation results roughly correspond to field growth rate data from June and August. That is, in June the algal distribution is broad and extends beyond Cottonwood Creek, located at approximately RM 182.However, in August the distribution does not extend as far downstream. The results show a decrease in algal biomass through time, suggesting a reduction in standing crop. Review of Figure 4.4 wherein field data illustrate that growth rate at the Klamath River site near Cottonwood Creek is negligible, are consistent with such a condition.

At this time the results are suggestive, but form only a working hypothesis. Additional field work and modeling are required to further characterize the spatial and temporal algal dynamics below Iron Gate Dam, and to determine their impact on nutrient uptake, dissolved oxygen concentration, and unionized ammonia fractions, as well as the role of upstream reservoir water quality and operations. A literature review of mathematical modeling of benthic algae in general purpose water quality models was completed within this project to identify potential future approaches to simulating algae in the riverine system. Complete description of the logic and previous model applications are presented in Deas and Orlob (1999).

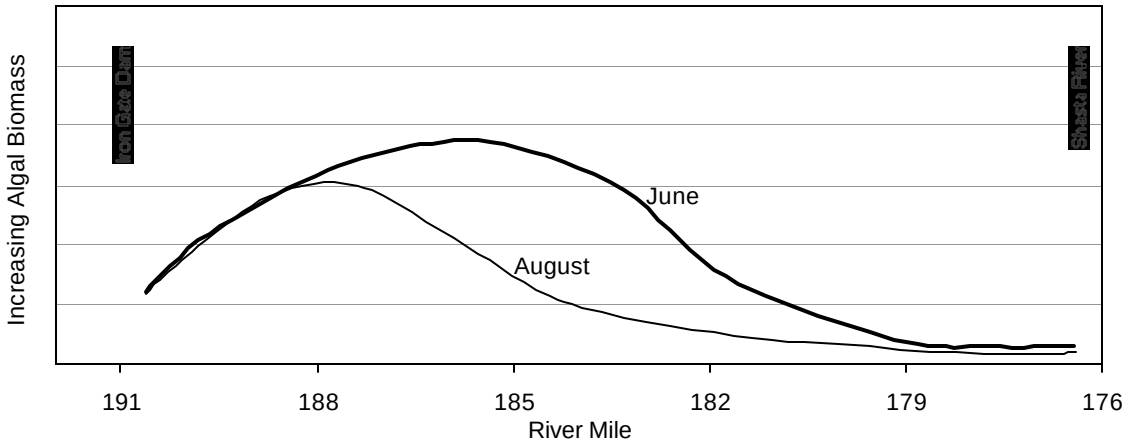


Figure 5-2 Hypothetical longitudinal profile of mean daily algal biomass in June and August

6. CONCLUSIONS AND RECOMMENDATIONS

The project objective to implement a basin wide program to collect baseline data was achieved. Through the semimonthly grab sampling program, deployment of water quality probes, and deployment of remote logging thermistors (loggers). Sampling was completed inn river reaches as well as within mainstem reservoirs. Additional information was collected through special studies, including algae studies, trace elements sampling, and intensive synoptic water quality surveys. This report presents the data form these programs, the techniques used to process the data, as well as supporting documentation on sampling protocols, quality assurances procedures, and appropriate documentation. Although this report by and large focuses primarily on field data, where analysis was completed or information obtained, attempts were made to document the information and findings.

Several findings and recommendation were identified during the project period and subsequent write-up. These are outlined below without regard to order of importance.

- Implementation of a quality assurance project plan and standard operating procedures (SOP) for field sampling provided consistent monitoring methods and allowed multiple agencies to sample in a consistent manner throughout the basin.
  Recommendation: USBR should maintain a QAPP and SOP for field sampling and seek to extend the application of uniform sampling procedures throughout the basin through sharing of the QAPP and SOP developed jointly by MP-157 and the Klamath Area Office staff.

- Implementation of external quality assurance samples (duplicates, spikes, blanks, and rinseate blanks) provided significantly improved confidence in the laboratory data.
  Recommendation: Although there is a cost associated with external quality assurance both in increased field supplies, additional laboratory samples, and in-house staff time to process the results, these quality assurance samples should be continued because the result is a high quality data set with uncertainty explicitly quantified.

- Monitoring with DataSondes illustrated that long-term collection of physical parameters is possible, albeit with certain limitations. Dissolved oxygen probes suffered from biofouling in a matter of days at many locations within the river. Additionally, ORP probes showed signs of drift during the week long deployments. The frequency of deploying and retrieving the water quality probes is problematic at a basin-wide scale. Limited resources (personnel) and shipping/transportation schedules restrict the deployments period to roughly a week. Finally, it was apparent that there was variation among the individual instruments when measuring pH, and dissolved oxygen.
  Recommendations:
  - Maintain the DataSonde deployment in selected locations.
  - Maintain Datasonde calibration and maintenance procedures to ensure probes are functioning properly and quantify uncertainty associated with individual sensors.
  - Complete pilot studies to determine the time/cost saving associated wherein field staff visit the sites more frequently (e.g., every 3 to 4 days) to clean the dissolved oxygen membrane and reduce download frequency to two weeks. Certain locations require a boat and increasing site visit frequency may be infeasible.
  - consider a pilot study to determine if completing Winkler titrations may assist in correcting dissolved oxygen data that have been affected by biofouling.
  - Testing the instruments in a single body of water prior to and at the end of each field season can quantify variation among probes. With regard to DataSonde

testing, it is recommended that a more rigorous statistical analysis be completed on the results.

- Coordination among multiple agencies can greatly improve the understanding of water quality conditions and response in large basins such as the Klamath River. Reclamation worked with PacifiCorp, the United States Forest Service, and the Yurok Tribe during the 2000 sampling season. In early 2001, and attempt was made to coordinate monitoring within the basin between Link Dam and the Pacific Ocean, including all major tributaries (Shasta, Scott, and Salmon Rivers). The objective of coordination was to identify consistent sampling locations and times, reduce redundant monitoring, identify available resources, introduce a minimum level of quality assurance and standard operating procedures, and share information. Attendance during the April 2001 coordination meeting held at US Fish and Wildlife Service was attended by over 40 people representing nearly every federal, state, tribal, and watershed group in the basin. Nonetheless, without funding the volunteer effort failed to successfully meet the objectives outlined above. Recommendation: Reclamation should seek to pursue coordination when opportunities arise. To some degree this has been done: Reclamation has shared the QAPP and SOP developed during the 2000 monitoring effort with any interested party in the basin. To the extent feasible, the Reclamation should work with other agencies to identify the potential for a basin-wide water quality coordinator position (not within the US Bureau of Reclamation) to encourage basin-wide coordination of monitoring efforts. Such a position, funded by all participants in the basin, would provide a critical role in ensuring that spatial and temporal water quality sampling be completed in a logical and appropriate fashion, that data quality assurance and sampling procedures be standardized, and that well defined methods for data dissemination are adopted. The result would lead to basin-wide water quality data that would be readily comparable across space and time versus the current efforts that are typically redundant, sample different parameters, include variable sampling times and locations, and utilize different analytical or measurement methods.

- All attempts were made to identify sites that were representative of mainstem conditions for the 2000 field sampling program. However, conditions at sampling sites may vary through time and under different hydrologic, meteorological, and water quality conditions.
  Recommendation: Continue to observe conditions at sampling sites and to carry out small scale studies, as resources allow, characterizing spatial (e.g., lateral and vertical) and temporal variations (e.g., seasonal and/or operational) at existing and proposed sampling sites. Document findings to support sampling methods and to assist in data interpretation.

- The benthic algae survey provided appreciable new information about the benthic flora and fauna. This information was not formally discussed herein primarily because it was much more complex than could be accommodated by the study plan. A brief review of the narrative descriptions of the conditions of the periphyton samplers and the unglazed ceramic tiles suggests that more detailed studies be completed to characterize these important processes.
  Recommendation: Because the primary impetus behind the 2000 field sampling program was to address anadromous fisheries downstream of Iron Gate Dam, and because the benthic flora and fauna play an integral role in the lifecycle of anadromous fisheries, it is recommended that additional work be completed to characterize the benthic community. The spatial and temporal variability of this community no doubt plays a vital role in

water quality throughout the system. A comprehensive study defining algal species present, estimates of biomass (e.g., through direct measurement, light and dark bottle test, or other means), identification of mollusks and invertebrate assemblages that graze on algae, and additional growth rate studies should be carried out over multiple field seasons to define the spatial and temporal variability of algae and its potential role in water quality. Reservoir operations, water quality, as well as the fate of phytoplankton (that is washed out of mainstem reservoirs) on downstream river reaches should be included.

- It is not uncommon for water quality monitoring programs to be funded, designed, and implemented, only to find that the field data is not processed and presented in a formal report.
  Recommendation: Data processing and reporting should be an integral part of any sampling program. Data dissemination procedures should be identified early in the sampling program design such that information can be available to interested parties.

- The model simulations provided insight into potential benthic algae dynamics; however, insufficient data are available to completely characterize the water quality response of the various components potentially affecting water quality (e.g., macroinvertebrate or mollusk grazing on benthic algae).
  Recommendation: continue to explore model formulations and approaches to more effectively characterize water quality response within critical reaches of the Klamath River system. This may include specific field studies designing to acquire critical information necessary to characterize physical, chemical, and biological processes. Temporal and spatial characteristics make this a challenging task.

- Field data indicate that mainstem reservoirs experience oxygen concentrations that deviate from saturation. Keno Reservoir, Copco Reservoir, and Iron Gate Reservoir all experience anoxic persistent conditions, which may lead to sediment nutrient release and thus internal nutrient cycling.
  Recommendation: to determine the potential for reduced conditions, oxidation-reduction potential (ORP) should be collected in all mainstem reservoirs when physical profiles are collected with water quality probes (e.g., DataSonde).

- Metals data were collected and are presented herein; however, as a stand alone data set there usefulness is limited.
  Recommendation: Review year 2000 field data in light of other sources of information concerning metals in the Klamath Basin and Klamath Project area.

- Adaptive management is a critical part of aquatic resource management. Although there are many definitions of adaptive management, a pragmatic approach consists of two steps: 1) conduct experiments to increase the knowledge of the system, and 2) plan to change based on the findings of first step.
  Recommendation: Identify components of the water quality monitoring program, possibly augmented by data or computer simulation models, to assist in adaptive management of water resources in the Klamath Basin.

7. REFERENCES AND ADDITIONAL RESOURCES

7.1 References

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7.2 Personal Communications

Stephan Porter, United States Geological Survey (Denver)
Jim Sweet, Aquatic Analysts
K. Carpenter, United States Geological Survey
T. Brown, United States Geological Survey
L. Brown, United States Geological Survey

7.3 Additional Resources

Several sources of water quality data and related discussions are available for the project area. These include, but are not limited to the references listed below. In certain cases, field and laboratory protocols are not included in the documentation and care should be used in interpretation.

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7.3.2 Electronic Sources

EPA STORET

Various CD ROMS available for purchase: e.g., Earthinfo, Hydrodata, etc.

APPENDIX A: REVIEW OF EXISTING DATA

The review of the existing water quality data for the 1998 and 1999 field program was instrumental in design and implementation of the to 2000 field program. The initiation of a large water quality monitoring program is a substantial task, and the efforts of USBR and USGS-BRD provided a solid foundation upon which to build. Four fundamental findings resulted from the review of the 1998 and 1999 data:

- A clear need existed for formal lab oversight and external quality assurance, as well as standard operating procedures for field sampling (grab samples and water quality probes (Datasondes))
- That sufficient data had been collected to allow a reduction in sampling parameters to accommodate the increased costs of QA processes and procedures.
- A need to expand the metals sampling from a limited set (four metals of concern) to a screening of fifteen trace elements.
- That results for certain constituents were erroneous or unreliable.

Review of the data demonstrated that confidence in the data varied widely. Because a formal QA program was not in place the data set should be used with caution. In light of the findings of the 2000 field program, much of the data is probably useful, but lacking QA (1998 and 1999 data) the 2000 data are not readily comparable. In addition, after review of field data and laboratory procedures certain data were found to be un-useable and it is recommended that they be discarded. These data include all metals data from 1998 and Cadmium from 1999. Two pieces of correspondence related to this topic are included below: (1) Memo from M. Deas of Watercourse Engineering, Inc. to L. Dugan of the U.S. Bureau of Reclamation, (2) Memo from MP-157 (U.B. Bureau of Reclamation, formerly MP 470) concerning laboratory performance.

Date: 4-7-00

TO: Larry Dugan

FR: Mike Deas

RE: Laboratory Selection

The purpose of this memo is to review some of the reasons for the recent decision to drop the USBR Lab located in Boise, Idaho and switch to a commercial lab (At this juncture we have selected Basic Laboratories in Redding, California).

Three critical points:

1) During initial review of the 1998 and 1999 water quality sampling data, it was apparent that there were possible quality control concerns (e.g., severe contamination, no formal data validation). These were not identified as field or laboratory issues.
2) Subsequently, USBR Sacramento completed a lab audit of the Boulder City (NV) lab where trace metals were processed. There were QA issues identified and based on these findings, I have recommended dropping all metals from the 1998 data set. Further, based on a methodology that was insufficient to supply the resolution necessary for cadmium reporting, I recommended that cadmium be dropped from the 1999 data set. We are still reviewing the remaining metals.
3) The recent audit of the Boise Lab, where the balance of work was to be completed (nutrients, major ions), several items were noted as requiring improvement. I will defer to the USBR Sacramento Audit Report for details. One finding was that documentation was insufficient, e.g., documentation on calibration methods was inadequate. Based on this, the legal defensibility of samples processed at this lab from 1998 and 1999 appears to have been compromised. As I understand it, last year the lab refused an audit.

In sum, nearly all of the data from the last two years has been compromised to some degree. The Boulder City lab has cooperated with USBR Sacramento and the QA group is confident that they can complete the work up to the required standards. The Boise Lab has been less responsive.

I encourage and support the selection of a commercial lab for nutrients given the

- short time line to implement the field monitoring
- lack of positive response from the Boise Lab
- desire to have a scientifically useful and defensible data obtained in the 2000 water quality sampling program (inability to apply the 1998 and 1999 data sets to legally defensible scientific analyses)
- it is not appreciably more expensive to move to the commercial lab

4-10-00

MP 470 is involved in the QA portion of the Klamath Basin Water Quality Monitoring Project. One of MP470's responsibilities in the project is to procure a laboratory that will be able to analyze a majority of the parameters for the project in a timely manner and provide supporting quality control data and documentation.

At the onset of the project, the program manager selected the USBR Pacific Northwest Regional laboratory (PNR lab) to analyze the nutrient parameters while the USBR Lower Colorado Regional laboratory (LCR lab) was selected to analyze the metal parameters.

The following concerns were raised in regard to the USBR Pacific Northwest Regional laboratory:

1. Uncertainty if the PNR lab could handle the workload from the project – especially the synoptic work.

2. The PNR lab was not able to perform the following analysis- BOD, chlorophyll a, and macrophyte analysis.

3. With the project slated to start in a few weeks, the PNR lab could not make a commitment if they could perform the work for the project.

4. Laboratory cost was based on hourly charges and a fixed dollar amount could not be derived for budgetary purposes. The alternative lab provided guaranteed analytical cost per project quote.

5. All re-analysis were to be charged at full cost; with budgetary constraints the project could go over allocated funds. The alternative lab provided reanalysis at no additional charge if the analytical results were different.

6. The PNR lab did not routinely provide QC summary reports for their data and this would have delayed data verification. The alternative lab provided QC summary reports with all of their data packages.

7. The PNR lab had an average turn around time of one month while the alternative lab had an average turn around time of 10 days.

8. If the PNR lab were able to perform the routine sampling events, splitting the routine work from the synoptic sampling events between two laboratories would introduce more analytical variances.

APPENDIX B: QUALITY ASSURANCE PROGRAM PLAN (QAPP)

Project/Task Organization

The Klamath Basin Water Quality Monitoring Program was operated out of the Klamath Falls Office of the Bureau of Reclamation (KF-Reclamation). This office was responsible for overall field operations, sampling, and monitoring in the upper watershed. The Regional Office in Sacramento provided planning and quality assurance (QA) support. The U.S. Forest Service (USFS) provided field sampling and monitoring assistance in the lower watershed. PacifiCorp (PPL) completed field sampling and monitoring at JC Boyle, Copco and Iron Gate Reservoirs. The Hoopa Valley and Yurok Tribes provided monitoring assistance in the Trinity River and the Klamath River below the Trinity River.

Problem Definition/Background

This program provided baseline information on main stem and tributary contributions on the Klamath River for a representative suite of physical, chemical and biological water quality constituents. These constituents were used to characterize water quality in the mainstem Klamath River, identify water quality constituents of concern within selected river reaches and tributaries, and estimate input parameters for water quality models. Water quality issues affecting anadromous fish in the watershed were of special concern.

To achieve these objectives selected physical constituents were measured sub-daily with continuously deployed water quality probes. Chemical and biological sampling occurred at frequencies ranging from several hours to semi-monthly.

Project/Task Description

Sample Sites and Programs: This program monitored mainstem Klamath River and major tributary water quality from Link Dam near Klamath Falls to Young's Bar below the Trinity River approximately 35 river miles from the Pacific Ocean. Six sampling sub-programs were included within this reach:

- Semi-monthly grab samples (Grab)
- 3-day synoptic water quality surveys (Synoptic)
- Continuous deployment of water quality probes (Sonde)
- Benthic algae bulk growth rate study (Algae)
- Water temperature study (Temp)
- Reservoir water quality sampling (Reservoir)

Table B-1 identifies site locations and sampling sub-program. River miles for the mainstem locations refer to distance from the mouth (ocean), while river miles on tributaries refer to distance upstream from the confluence with the Klamath River.

Table B-1 Sample sites and associated water quality sub-programs

Site #	Name	KR-RM	Grab	Synoptic	Sonde	Algae	Temp	Reservoir
1	Klamath River at Link Dam	255	USBR[1]					
2	Miller Island	246	USBR		USBR			
3	KSD at Hwy. 97 (RM 2)	240.5	USBR		USBR			
4	KSD at Hwy. 161	240.5	USBR		USBR			
5	KSD at Diversion Tunnel	240.5	USBR		USBR			
6	KR at Keno Bridge	235	USBR		USBR			
7	JC Boyle Reservoir	226						PPL
8	KR above Copco	208	USFS		USFS			
9	Copco Reservoir	198						PPL
10	Iron Gate Reservoir	190.2						PPL
11	KR bel Iron Gate Dam	190.1	USFS	USBR	USFS	USBR		
12	KR at Cottonwood Cr.	182				USBR	USBR	
13	KR above Shasta R	176.7		USBR	USBR[2]		USBR	
14	Shasta R (RM 0.0)	176		USBR				
15	Shasta R (RM 0.5)	176	USFS		USFS			
16	KR at Walker Rd. Bridge	156					USBR	
17	KR above Scott R	143.5		USBR	USBR[2]		USBR	
18	Scott R (RM 0.0)	143		USBR	USBR[2]			
19	Scott River (RM 1)	143					USBR	
20	Scott River (@USGS gage) (RM 23.4)	143	USFS		USFS			
21	KR below Seiad Valley (@USGS gage)	128.9	USFS	USBR	USFS			
22	Salmon River (@USGS gage) RM 1.0	66			USFS			
23	Trinity R nr Hoopa (@USGS gage) RM 12.4	43.5			Hoopa			
24	KR near Young's Bar	35			Yurok			

[1] Includes monthly trace elements screening suite

[2] Only during synoptic survey

Data Quality Objectives for Measurement Data

Scope of Work

This program was scheduled to run between April and December 2000. Chemical, biological, and physical parameters impacting the water quality for aquatic life in the river were measured. Uninterrupted physical measurements were interrelated with the operation of dams. The low concentration of dissolved oxygen and high water temperature has impaired this watershed. High turbidity and nutrient loading correlate to water degradation. The hardness of the water influenced the toxicity of cadmium, chromium, copper, lead, nickel, silver, and zinc to aquatic life.

Data Assessment

Table B-2 summarizes the acceptance levels for the external check samples submitted to the laboratories with the production samples. All external check samples submitted to the laboratories were double-blind (sample was not identified as an external check sample). To evaluate external QA check samples, the Bureau of Reclamation's Environmental Monitoring Branch in Sacramento, CA followed protocol outlined in their QA SOP (USBR, 2000). Part of this assessment process may have involved the reanalysis of external QA check samples for project parameters or the whole project for certain parameters if external QA check sample results were not confirmed upon reanalysis. The laboratory's quality control (QC) check samples must also meet certain levels of acceptability when analyzed with the production samples. Part of the data assessment process involved checking these laboratory QC check sample results to ensure they were within acceptable ranges. If a laboratory QC check sample failed to demonstrate an acceptable result, the anomaly was explained with a footnote or included in the case narrative section of the data report. In order to ensure data quality, QA personnel assessed laboratory data packages to determine if all samples were analyzed within the holding times.

Table B-2 Data quality objectives

Parameters	Reporting Limit (mg/l)	Accuracy (% Recovery)	Precision (% RPD)	Completeness (%)	Corrective Actions
Ammonia	0.05 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
BOD	3 mg/l	78% - 128%	Not Established	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Chlorophyll a	10 mg/m3	No Criteria	Not Established	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Benthic Algae: Chlor a	11 mg/m3	No Criteria	Not Established	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Benthic Algae: AFDW	Not Established	No Criteria	Not Established	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Nitrate + Nitrite as N	0.05 mg/l	75%-125%	0%-20%	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Ortho Phosphorus	0.05 mg/l	75%-125%	0%-20%	90%	Re-analyze sample and if not confirmed Re-analyze the batch
TKN	0.2 mg/l	75%-125%	0%-20%	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Total Phosphorus	0.05 mg/l	75%-125%	0%-20%	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Alkalinity	1.4 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Organic Nitrogen	Not Established	No Criteria	Not Established	Not Established	
Organic Phosphorous	Not Established	No Criteria	Not Established	Not Established	
Aluminum	0.02 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Antimony	0.001mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Arsenic	0.001 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Cadmium	0.0005 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Calcium	0.1 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Chromium	0.001 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Copper	0.0003 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Iron	0.05 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Lead	0.001 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Magnesium	0.1 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Mercury	0.005 ug/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Nickel	0.001 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Selenium	0.001 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Silver	0.001 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
TDS	2 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Thallium	0.001 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch
Zinc	0.010 mg/l	80%-120%	[>5x RL] = 0%-20% [≤ 5x RL] difference within ± RL	90%	Re-analyze sample and if not confirmed Re-analyze the batch

RL = Reporting Limit [ ] = If concentration of determination is....

Sampling Process Design (Experimental Design)

This program was divided into six different sub-programs; each designed to provide an overall assessment of the Klamath River watershed and data for modeling the basin.

Semi-monthly Grab Samples

Water quality grab samples were collected twice a month between May 1 and November 15, 2000. The TDS, alkalinity, nutrients, chlorophyll a, and BOD were measured. The turbidity was measured using a portable instrument when the grab sample was collected. Klamath Falls' personnel collected samples from the upper most five grab-sample sites and the US Forest Service collected samples at Copco Reservoir, KR below Iron Gate Dam, Shasta River, Scott River, and KR below Seiad Valley. Once a month, the trace elements potentially important to aquatic life (Ag, Al, Ar, Cd, Cr, Cu, Fe, Hg, Mg, Ni, Pb, Se, Sb, Tl, and Zn) plus Ca and Mg were sampled at Hwy 97 KSD, Link Dam, Keno Bridge, and below Iron Gate Dam. Three QA samples were added to the production samples to document lab accuracy. The environmental water for the QA samples was collected at KSD at Hwy 97. Also, a rinseate blank was prepared alternately each sampling period by the two field sampling groups to check sampling practices. Entries into the field logbooks, field sheets, and chain of custody (COC) were completed in the field. Samples were stored in ice-chests containing blue-ice at 4° C. The completed COC was placed in a zip-lock plastic bag in the ice-chest and mailed or delivered to lab.

3-Day Synoptic Water Quality Surveys

Synoptic monitoring measured the diurnal changes in nutrient as well as physical parameters. Three synoptic sampling periods occurred: June 5-7, August 7-9, and September 10-12 (the September survey did not include grab samples). Nutrient levels (including organic nitrogen and organic phosphorous) and physical parameters were measured at the synoptic sites three time a day at approximately 6:00 AM, 11:00 A.M., and 4:00 P.M. at six locations for a period of three days, as per Table B-1. Datasondes at the synoptic sites recorded physical measurements continuously (hourly) during this program. Three (3) QA samples were included with each day's sampling. The samples were retained on site until the end of each day and then mailed to the lab. A liter of water containing suspended chlorophyll a was collected in a light inhibited bottle and place in ice chest.

Continuous Deployment of Water Quality Probes

Physical parameters were measured hourly with Hydrolab Datasondes at 13 sites (see Table B-1). Parameters included temperature, dissolved oxygen, pH, specific conductance, and redox. Datasondes were exchanged each week, and transported to Klamath Fall's field-operations center in Klamath Falls, where they were downloaded, cleaned, calibrated, and readied for field deployment the following week. The upper basin sites were serviced by USBR; while USFS serviced probes from "above Copco Reservoir" to the "Salmon River." The Hoopa and Yurok Tribes serviced "Trinity River" and "Klamath River at Young's Bar," respectively. Table B-1 outlines the programs, locations, and agency in charge.

Benthic Algae Bulk Growth Rate Study

The benthic algae monitoring program occurred at two sites and samples were collected during three, four- to five-week sampling periods in May, July, and September. Artificial substrates in the form of ceramic tiles and glass slides were used to monitor algal growth. The ceramic tiles were used for qualitative analyses, while the glass slides were collected and sent to a laboratory for chlorophyll a and ash free dry weight. Floating periphyton samplers were used to hold the glass slides suspended in the river to minimize grazing impacts. Ceramic tiles were placed in the river for a minimum of several days

prior to the initial sampling. At the commencement of each sampling period the substrates were scrubbed clean with a nylon brush. Sites were visited weekly and substrate conditions on the tiles were photographed and reported in a narrative. Four slides were removed from the periphyton samplers: one for chlorophyll a analysis and three for ash-free dry weight determination. The glass slides intended for laboratory analysis were placed in glass bottles wrapped in aluminum foil and transported to the laboratory on dry ice. Nitrogen nutrients and orthophosphate were also collected for this program. Between sampling periods, the ceramic tiles remain in the river, but the periphyton samplers were removed. The process was repeated for the next sampling period.

Water Temperature Study

Water temperature was monitored with remote logging thermocouples at five locations in the Klamath River and tributaries between Iron Gate Dam and Seiad Valley (See Table B-1). Logger sampling frequency was one hour. These data were intended to augment Datasonde deployments and provide information for temperature analysis and modeling.

Reservoir Water Quality Sampling

Surveys of the three reservoirs consisted of monthly depth profiles of the same physical parameters measured in the rivers at the surface and at one to two meter intervals above and below the photic boundary. In addition, temperature loggers recorded at hourly intervals at multiple depths in each reservoir. Finally, water quality sampling of JC Boyle, Copco, and Iron Gate Reservoirs occurred May, early June, early August, and mid-September. Nutrient, BOD, and chlorophyll a was collected at three depths corresponding to a representative epilimnion, metalimnion, and hypolimnion sample. Due to its relative shallow depth, JC Boyle was only sampled at two depths (near-surface and near-bottom). The monthly profiles and temperature loggers continued through November.

Chemical and Biological Constituents of Interest

Chemical and biological water quality constituents of interest that require laboratory analysis were limited to the semi-monthly-nonmetal and monthly-metal grab samples (Grab), 3-day synoptic water quality surveys (SS), benthic algae bulk growth rate study (Algae), and reservoir water quality sampling (Reservoir) as shown in Table B-3.

Sampling Method Requirements

For field sampling protocol, the "Klamath River Water Quality Standard Field Sampling Operating Procedure" was used.

All water samples were collected using the grab-sample method. A ***churn splitter or sample bottle (for unfiltered samples)*** was used to collect water from the river's shore. A van Dorn or Kemmerer was used to collect water from bridges and reservoirs. Before use, the churn splitter was rinsed three times with environmental water and water was run through the push valve. The van Dorn or Kemmerer or pump (reservoir only) was also rinsed in the river or reservoir three times before use. The Field SOP instructs how the monitoring and sampling was performed and associated procedures for documenting the field activities. Water samples designated as "dissolved" (filtered) were first pumped through a 0.45um filter.

A Datasonde was used to measure the physical parameters (pH, specific conductance, dissolved oxygen, turbidity and water temperature) of the environmental water. A turbidity meter was used to measure this physical parameter.

Table B-3 Sampling sub-programs and chemical constituents requiring laboratory analysis

Constituent	Grab	S.S.	Sonde	Algae	Temp	Reservoir
Aquatic Life Metals	X					
Hg	X					
NH_4	X	X				X
Total Kjeldahl N	X	X				X
$NO_2 + NO_3$	X	X				X
Total P	X	X				X
Ortho PO_4	X	X				X
Organic P dissolved		X				
Organic N dissolved		X				
TDS	X					
Ca, Mg	X					
HCO_3, CO_3 (Alkalinity)	X					
BOD	X					X
Chlorophyll A	X					X
Benthic algae (Chlor a and AFDW)				X		

Sample Handling and Custody Requirements

Water samples were collected in high-density polyethylene (HDPE) bottles and preserved according to EPA, Standard Methods, or other approved analytical methodology. Samples collected in the field were labeled with:

- Sample identification
- Preservatives used
- Constituent analyses required
- Date and time sampled
- Samplers initials

Sample volume was based on analytical requirements and listed in Table B-4. Upon collection in the field, water and biological samples were placed in ice chests with a temperature of four degrees Celsius. All samples collected in the field required a chain of custody sheet and a field sheet. The chain of custody sheet and the field sheet clearly documented all the samples collected during that sampling period, associated sample identification numbers, and the date and time of collection for each sample. The COC was placed in the ice chest in a zip-lock plastic bag. A custody seal was attached to the ice chest by the field sampler. The ice chests were then given to a commercial package carrier or laboratory courier. The original COC sheet was kept on file at the laboratory and the other copy was returned to the USBR Regional Office.

Analytical Method Requirements

The analyses selected were based on previous analyses of basin water and identified requirements for water quality models. The criteria limits for freshwater aquatic life were used to select the methods of analyses. The USBR - Lower Colorado Regional Laboratory in Boulder City, NV was responsible for analyzing the water samples for TDS, calcium, magnesium, carbonate, bicarbonate, aluminum, antimony, arsenic, cadmium, chromium, copper, iron, lead, nickel, selenium, silver, thallium, and zinc. The samples requiring TKN, ammonia, nitrate + nitrite as N, total P, ortho P, BOD, chlorophyll-A, organic phosphorus, organic nitrogen, and benthic algae were sent to Basic Laboratory, located in Redding, CA. NEL Laboratories, located in Reno, NV performed mercury analysis. The methods presented in Table B-4 were utilized to determine the concentrations of these analyses in the water samples.

Table B-4 Analytical methods

Inorganic Parameters	EPA	SM	Other
Aluminum	6010		
Antimony	6020		
Arsenic	6020		
Cadmium	6020		
Chromium	6020		
Copper	6020		
Iron	6020		
Lead	6020		
Nickel	6010		
Mercury	7470A		
Selenium	6020		
Silver	6020		
Thallium	6020		
Zinc	6020		
Ammonia		4500 NH3	
Total Kjeldahl Nitrogen		4500 NORG	
Nitrate + Nitrite, as N		4500 NO3	
Ortho-Phosphate		4500 P	
Total phosphorus		4500 P	
Organic Nitrogen (dissolved)		4500	
Organic Phosphorus (dissolved)		4500	
Bicarbonate			USDA, bk60, p98 & 146
Carbonate			USDA, bk60, p98 & 146
TDS		2540C	
Calcium	6010		
Magnesium	6010		
BOD		5210	
Chlorophyll A		10200H	
Benthic algae		10400b 3a	

Sample Bottle Requirements

The bottles used to collect the specified constituents, including required preservative and hold times are presented in Table B-5. Labels were attached to bottles and information about the samples written on

labels with waterproof ink. High-density polyethylene (HDPE) bottles were used. The sample bottles used for trace metals and mercury were “level 1" certified to ensure bottle contamination did not effect analytical results. All bottles were rinsed three times with the environmental water prior to filling with sample. Any filtration required was done from the churn splitter in the field. All acid preservation required was done in field after sample collection. The chlorophyll a sample bottle was wrapped with aluminum foil after sample collection to prevent light from affecting the sample. The benthic algae samples were placed (individually) in 125 ml bottles for transportation and wrapped in aluminum foil to prevent light from affecting the sample.

Table B-5 Sample filter requirements, bottle volumes, preservatives, and hold times

Test	Filtered	Container	Preservatives	Hold Time
Trace Metals (total)	N	500 ml	4^oC, HNO_3	6 months
Mercury (total)	N	250 ml	4^oC, HNO_3	28 days
NH4, (NO2+NO3)N, TKN, total P	N	1,000 ml	4^oC, H_2SO_4	28 days
Ortho Phosphate	N	500 ml	4^oC, none	48 hours
Organic P	Y	500 ml	4^oC, none	48 hours
Organic N	Y	500 ml	4^oC, none	48 hours
Total Alkalinity	N	250 ml	4^oC, none	14 days
TDS	Y	250 ml	4^oC, none	14 days
Ca, Mg	Y	250 ml	4^oC, HNO_3	6 months
BOD	N	1,000 ml	4^oC, none	24 hours
Chlorophyll A	N	1,000 ml	4^oC, none	48 hours
Benthic algae	n/a	Alumin. foil wrap Glass slide	Dry Ice	48 hours

Quality Control Requirements

To check laboratory accuracy, precision, and contamination, field personnel incorporated one blank sample, one duplicate sample, and one spike sample or one QA reference sample per sampling period for the routine phase and per day for the synoptic survey. Field samplers labeled these external QA check samples with identifications similar to production samples so that they could pass as double blind samples. The QA Officer ensured that field personnel properly prepare external QA check samples. The Klamath office and the Forest Service alternated including a rinsate blank of their field sampling equipment each sampling period. The rinsate blank included a sample bottle for each constituent. The laboratories incorporated their own QC check samples, including spikes, duplicates and blanks, to ensure data reliability. For specific rates of laboratory QC check sample incorporations, one needs to refer to the laboratory QA manual. Laboratory QC check sample results were reported to the client as QC summary reports.

The specific standard operating procedures used by the Lower Colorado Regional Laboratory, Basic Laboratory, and NEL Laboratories to analyze the samples for this project can be found in their QA manuals.

Instrument Calibration and Frequency

The laboratory performed instrument calibrations following the procedures and frequencies stated in the analytical methods for each parameter.

Each Datasonde instrument was calibrated before each day it was used in the field. These calibrations followed the manufacturer's instructions as outlined in the calibration procedures outlined in the appendix. Field personnel recorded Datasonde calibrations on calibration sheets, which were filed at the USBR Klamath Basin area office.

Assessment and Response Actions

Review of field activities was the responsibility of the Project Manager, in conjunction with Reclamation's Environmental Monitoring Branch (MP-157) located in Sacramento, CA. Performance of the field crew was evaluated once a year.

Prior to selecting a laboratory as a participant in this program, their analytical skill was evaluated through the use of performance samples. After demonstrating acceptable results on these performance samples, a system audit was performed on these laboratories. The system audit consisted of first reviewing the laboratory's QA manual and EPA WP/WS performance study results for the past three years. After reviewing these documents, a USBR audit team visited the laboratories to make certain they had everything in place to perform the work.

Management and MP-157 were notified of any changes to the sampling plan or the QAPP.

Data Review, Validation and Verification Requirements

The Bureau of Reclamation's Environmental Monitoring Branch in Sacramento, CA. (RO-Reclamation) reviewed and verified all data generated from this program. RO-Reclamation followed protocol outlined in their QA SOP (revised November 1999) to review and verify the data from this program.

The laboratory's QC check samples must meet certain levels of acceptability when analyzed with the production samples. These levels of acceptability were established using control charts or set at certain limits found in the methods. Part of the data verification process involved checking these laboratory QC check sample results to ensure they were within acceptable ranges. If a laboratory QC check sample failed to demonstrate an acceptable result, the anomaly was explained with a footnote or included in the case narrative section of the data report. In order to ensure data quality, QA personnel assessed laboratory data packages to determine if all samples were analyzed within there holding times.

This project's goal was 100% completeness for samples submitted for testing to the laboratories.

Review and Verification Methods

When RO-Reclamation incorporates external quality assurance (QA) check samples into a batch of production samples submitted to a laboratory, the laboratory must meet certain standards of acceptance on these QA check samples for the data to be approved as reliable. For this project, the standards of acceptability for the external QA check samples were:

Duplicates: For values > 5X Reporting Limit, RPD $\leq$ 20%
For values $\leq$ 5X Reporting Limit, values may vary $\pm$ 1X Reporting Limit
(Duplicates constitute at least 10 percent of the samples)

Spikes: Recovery should be 80%-120%
Limit does not apply when sample value exceeds spike concentration by $\geq$ 5 times
(Spikes constitute at least 5 percent of the samples)

Reference Materials: Recovery should be 80%-120% of certified value for values $\geq$ 20X Reporting Limit
For values < 20X Reporting Limit, recovery should be $\pm$ 2X Reporting Limit from the certified value

Blanks: Blank concentration should be less than 10% of lowest sample concentration or less than two times the reporting limit.
(Blanks constitute at least 5 percent of the samples)

Reclamation used the following equations to validate data:

Relative percent difference: A statistic for evaluating the precision of a replicate set. For replicate results X1 and X2:

$$RPD=((X1-X2)/(X1+X2/2))x100$$

Completeness: The amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under correct normal operations. It is usually expressed as a percentage:

$$\% \text{ completeness} = V/n \times 100$$

where: V= number of measurements judged valid
n = total number of measurements

Percent recovery: A measure of accuracy determined from comparison of a reported spike value to its true spike concentration:

% Rec. =((observed conc.-sample conc.)/(true spike conc.)) x 100

Accuracy: Accuracy is a measure of the bias inherent in a system or the degree of agreement of a measurement with an accepted reference or true value. It is most frequently expressed as percent recovery.

Precision: A measurement of mutual agreement (or variability) among individual measurements of the same property, usually under prescribed similar conditions.

Precision is usually expressed in terms of relative percent difference, but can be expressed in terms of range.

Range: The difference between the largest and smallest numbers in a set of numbers.

All data entered into tables by RO-Reclamation were subjected to a thorough secondary review before being released to clients.

Reconciliation with Data Quality Objectives (DQO)

After each sampling event, calculations and determinations for precision, completeness and accuracy were made immediately and corrective actions implemented if needed. If data quality indicators did not meet the project's specifications, data may have been discarded and re-sampling may have occurred. The cause of failure will be evaluated. If the cause was due to equipment failure, calibration/maintenance techniques will be reassessed and improved. If the problem is determined to be a sampling error, team members will be retrained. If the problem is laboratory related, the laboratory program manager will be contacted and corrective actions implemented. Any limitations on data use will be detailed in both interim and final reports and other documentation as needed.

This QAPP will be revised if DQO failure occurs while following protocol. Revisions will be submitted to the review team, including the quality assurance group and technical advisors for approval.

APPENDIX C: FIELD SAMPLING SOP FOR KLAMATH BASIN BASELINE MONITORING PROGRAM

Basic Checklist

Prior to leaving the office

- Assemble sampling equipment - see Klamath Basin Program Equipment & Supplies List
- Check all sampling equipment
- Carry cell phone and telephone number directory
- Check bottles needed for sampling - see Grab and Synoptic Bottles Lists below (Table , Table C-2)
- Check chemicals and blue ice (Table , Table)
- Test equipment batteries and carry spares
- Calibrate instruments against standards
- Prepare analysis forms
- Have "Sharpie pen" for labels and ball point pens for writing
- Pack field notebook, field sheets, and chain of custody (COC) sheets

At sampling site

- Label bottles
- Collect all necessary samples (See Bottle List below)
- Filter and preserve samples correctly
- Store samples properly
- Prepare field logbook, COC sheet, and field sheet.
- Prepare shipping coolers and mailing forms

After sampling

- Recheck calibration of equipment
- Clean and store field equipment

Grab Sample

1. The churn splitter is used to collect a water grab sample. Care is exercised not to disturb the bottom sediment while sampling. Avoid surface debris while collecting. The churn splitter is rinsed with environmental water three times prior to collecting sample and water is run through the pour spout. Do not disturb the location where sample is to be taken from with discarded rinse water. If the sample is collected from the bank of the river, the water should be collected from a location of good flow. If walking into the river is required, collect from a location up-stream of wader.
2. The preferred method of collecting whole (unfiltered) samples is to dip the sample bottle with mouth pointed up-stream, in the river current. The bottle is rinsed three times with environmental before collection. When sampling in system reservoirs collect environmental water from the desired depth for rinsing the bottles. If sample bottles are pre-preserved do not rinse with environmental water. Filtered and QA samples must be collected in a churn splitter.

Table C-1 Grab sample bottle list

Constituents	Bottle	Preparation	Lab
Trace Elements: (with the exception of Hg, see below)	500 ml HDPE **(level one)**	2 ml $HN0_3$	LC Reg.
Nutrients:NH4,(NO_2+NO_3) as N,TKN, Total P	1,000 ml HDPE	4 ml $H2SO_4$	Basic
Total Alkalinity: CO_3 + HCO_3	250 ml HDPE	none	LC Reg.
Mercury (hg)	250 ml HDPE **(level one)**	1 ml $HN0_3$	NEL
Ortho PO_4	500 ml HDPE	none	Basic
BOD	1,000 ml HDPE	none	Basic
Chlorophyll A	1,000 Glass	Amber	Basic
Ca + Mg	250 ml HDPE	**filter then** 1 ml $HN0_3$	LC Reg.
TDS	250 ml HDPE	**filter**	LC Reg.

Table C-2 Synoptic survey bottle list

Constituents	Bottle	Preparation	Lab
Nutrients:NH_4,(NO_2+NO_3)as N,TKN, Total P	1,000 ml HDPE	4 ml H_2SO_4	Basic
Ortho PO_4	500 ml HDPE	none	Basic
Organic P	500 ml HDPE	**filter**	Basic
Organic N	500 ml HDPE	**filter**	Basic

Van Dorn, Suspended-Sediment Water, and Kemmerer Sampler

The suspended-sediment water sampler, van Dorn, or Kemmerer (water sampler) is used to collect samples from a reservoir or from a bridge. Rinse the water sampler with environmental water three times at all sampling sites prior to use. In reservoirs it is not feasible to rinse the water sampler with environmental water three times because the sampler must pass vertically through the water column en route to the desired depth. However, it is advisable to sample shallow depths first, and rinsing three times with near surface environmental water prior to the surface sample.

The suspended sediment water sampler is lowered to the desire depth at a constant rate and then raised. The water collected in the sample bottle is poured into the churn splitter. The other water samplers are lowered, the trigger mechanism is activated, and then raised to the surface and the water is poured into a churn splitter. The water sampler is cleaned after use in the field by 1) carefully inspecting and removing any foreign material, 2) rinsing exterior, 3) rinsing interior three times with de-ionized water.

Reservoir Sampling with a Pump

Under certain circumstances reservoir samples will be completed using a pump to draw water from various depths. The pump is a battery operated 12v DC submersible pump (Ben Meadows Model DC60,

ABS body, stainless steel propellers and chemically inert seals) fitted with 30 m of 3/8" ID Tygon tubing. Prior to sampling and between sampling depths within a reservoir, the pump and tubing assembly should be rinsed with 5 liters of environmental water (5 tube volumes). Sampling can be carried out directly to the sample bottles for all but the QA samples, in which case water is pumped to a churn splitter and QA samples drawn accordingly. Pump assembly and tubing is cleaned by pumping a minimum of 2L of DI water through the pumping system between sample locations. Equipment is cleaned at the end of the sampling day by pumping a minimum of 2L of DI water through pumping system.

Churn Splitter

The churn allows different sub-sample volumes to be obtained from the composite sample while still maintaining the same basic chemical and physical properties of the original sample. The volume of the churn splitter limits the volume of sample that can be divided. Suspended inorganic sediments coarser than 62 micrometers (um) cannot be split. Samples may be taken from a plastic (Nalgene™) churn splitter for analysis of all dissolved and suspended inorganic constituents except suspended sediment (>62 um), organic compounds (including TOC, SOC, DOC, oil and grease, and pesticides), bacteria and dissolved oxygen. A Teflon™ lined churn splitter is required for organic compound constituents. Organic P and N can be collected and dispensed from Nalgene™ churn splitter.

Sub-samples totaling 10 liters may be withdrawn from the 14-liter churn, whereas, up to 5 liters may be withdrawn from the 8-liter churn. The 4 liters remaining in the 14-liter churn and the 3 liters remaining in the 8-liter churn should not be used for total, total recoverable, or suspended material (i.e., unfiltered) sub-samples because they will not be representative. However, the sample mixture remaining in either churn may be used for filtered sub-samples for the determination of dissolved constituents.

The procedure for cleaning and use of the churn splitter is as follows:

1. The Klamath Falls office will clean the churn splitters between sampling events. They will use gloves while doing this. After removing foreign material from churn splitter with nylon brush and soap & water, the churn splitter is rinsed with water.

2. Pour about 200 ml of dilute (i.e. 6%) nitric acid into churn splitter and wet all inside surfaces of churn splitter with dilute acid. Acid is run through the pour spout. Decant dilute acid down drain with good flow of water.

3. Rinse the churn splitter with DI water three times. Drain DI water from the spout during each rinse. The churn splitter is now ready for field use.

4. Label all the sub-sample containers. Set aside the **TDS** and **Ca & Mg** (Organic Nitrogen and Organic Phosphorous for the synoptic survey) bottles that will contain filtered environmental water. The remaining bottles (unfiltered samples) are rinsed with environmental water when the churn splitter is rinsed, see step 5 below. Only rinse the bottles that will contain water collected at the current site. Do not rinse bottles that have been pre-preserved.

5. The churn splitter is rinsed with environmental water three times in the field at the first site and at each subsequent site prior to sampling. For reservoir sampling, the churn is rinsed three times with environmental water collected from the desired sampling depth. Drain environmental water through pour spout. Rinse bottles with environmental water (as per step 4, above). This activity can be done

while collecting sample at river or reservoir. Between river sampling sites and between reservoir sampling depths the churn is rinsed three times with DI water.

6. If QA samples are not collected at a site, then a maximum of 5 liters are required at each site. Fill the churn splitter to have enough water for all samples. The last 3 to 4 liters of sample in churn cannot be used for non-filtered samples (i.e. total, total recoverable, or suspended material sample). It is important to completely fill the 8-liter churn splitter to have adequate water supply.

7. At the QA site on KSD @ Hwy 97 and Iron Gate Reservoir epilimnion, the churn splitter must be filled more than once. Duplicate and triplicate (spike or reference) samples are collected. Two sample bottles (duplicate and regular) are filled from the same churn-splitter volume for each of the constituents. No spike is available for chlorophyll a. For some of the constituents, three sample bottles of environmental water are filled from one-volume of churn-splitter water; these triplicate water samples are collected in bottles for mercury, trace metals, Mg & Ca, ortho phosphate, and nutrients. All three bottles for these constituents must be collected from the same churn-splitter volume. The Klamath Falls field sampler adds a spike volume to the triplicate sample bottle of environmental water for these constituents. A third bottle of environmental water is not collected for alkalinity, BOD, and TDS spike samples; a reference solution is poured into the triplicate bottle by the sampler from the Klamath Office for these constituents.

8. It is sometimes necessary to composite water into churn splitter from a sampling devise. A van Dorn, kemmerer, or a suspended sediment sampler can be used from a bridge or a boat. Where a churn splitter cannot be filled with one of these samplers from the shore or boat without disturbing the sampling area, one sample bottle is used repeatedly to fill the churn splitter. Swirl water in sample bottle prior to pouring into the churn splitter in order to minimize the amount of suspended material lost in transferring from the bottle to the churn. This swirling procedure is used when collecting water in the churn splitter from other samplers also. As stated in above, it is preferred to collect unfiltered environmental water directly into a sample bottle. QA samples (regular, duplicate, and triplicate) must be dispensed from a churn splitter.

9. Churn the sample at a uniform rate of about 9 inches per second (in/s). The disc should touch the bottom of the tank on every stroke and the stroke length should be as long as possible without breaking the water surface. If the churning rate is significantly greater than 9 in/s or if the disc breaks the water surface, excessive air is introduced into the sample and may change the dissolved gases, bicarbonate, pH, and other characteristics of the sample. On the other hand, inadequate stirring may result in non-representative sub-samples.

10. After churning the sample in the splitter for about 10 strokes to assure uniform dispersion of the suspended material, begin the withdrawal of sub-samples. As sub-samples are withdrawn and the volume of sample in the churn decreases, maintain the churning rate of about 9 in/s. If a break in withdrawals is necessary, the stirring rate must be reestablished (i.e., 10 strokes) before withdrawals are continued.

11. While operating the churn, withdraw an adequate volume of sample to field rinse bottles for total, total recoverable, and suspended material sub samples (rinse each bottle three times).

12. Withdraw sub-samples for total, total recoverable, or suspended analyses first. The first sub-sample withdrawn should be the largest sub-sample required (usually 1 liter of the sample).

13. After all the required total or suspended material sub-samples have been withdrawn, the sample remaining in the churn may be filtered for sub-samples required for dissolved constituents. Remember to field rinse bottles three times with filtered sample water prior to filling. Procedures for filtering and preserving samples are described later.

14. After all filtered sub-samples have been withdrawn, empty the churn and clean the mixing tank and churning disc thoroughly with de-ionized water.

Filtering Water Samples

Water samples are filtered using a 0.45um inline filter and a peristaltic pump. The inlet sample line to the pump is placed in the churn splitter and the inline filter is attached to the exit sample line of the pump. About a 500-ml of water is pumped through filter before any water is collected. This water should not be used to rinse sample bottles. After using pump at each sample, discard inline filter and pump about a 500-ml of DI water through tubing.

If the peristaltic pump fails or is unusable for any reason, samples can be filtered with the filter syringe. The filter syringe is used as follows: Disassemble a clean 100-ml syringe. Place a new green filter on the end of the syringe. Wash the inside of syringe and barrel with environmental water three times and discard water. Fill sample barrel with sample water. Push 10-15 ml of water through the syringe and rinse the sample bottle. Shake sample bottle and discard water. Now fill the sample bottle with filtered water using the syringe-filter procedure. Refill the syringe if more sample water is needed and the filter has not plugged. If filter is plugged, use a new filter and continue.

Water Sample Preservation

Physical preservation techniques are used for all samples and include cooling and keeping sample out of sunlight. Water samples are also preserved with chemicals to prevent degradation of the constituent before they are analyzed. Specific requirements for the field preservation of samples are contained Table C-1.

Trace Elements and Metals

Preserve trace elements and metals in water for 6 months hold time with nitric acid; mercury has a hold time of only 28 days. One ml of 70% nitric acid is used with each 250 ml of sample. The sample is also chilled to $4^{o}C$ in field.

Nutrients

The NH4, NO_2 + NO_3, TKN, and total P sample in a 1,000 ml bottle require 4 ml of H_2SO_4 and have a hold time of 28 days.

Chlorophyll a, Orthophosphate, BOD and Organic P and N

Chlorophyll a, orthophosphate, BOD, and organic P and N samples have 48-hour hold times. Refrigerate or chill water samples and delivered to the lab within *hold time*. Chlorophyll a samples are immediately wrapped with aluminum foil to keep sunlight from sample and stored in the dark.

Other Water Samples

Refrigerate or chill water samples and delivered to the lab within *hold time*. These samples are not preserved chemically and have a hold time as shown on the Bottle List.

If in doubt about any sample, it is best to keep it chilled and out of the sunlight.

Dispensing Acid from Ampoule for Preserving Samples

Rubber latex or vinyl gloves and safety glasses are worn to prevent acid from contacting hands or eyes while preserving samples with acid.

Sample Handling and Transportation

Sample handling and transportation vary depending upon the analysis requested, sample preservation requirements, and the distance to the laboratory. However, once preserved, some samples will remain stable for long periods. Samples with short hold times should be mailed by overnight courier or mail service. All samples on this program will be shipped on the day they are collected. (If samples are not shipped on the day they are collected they must be delivered in person to the labs the following day.)

When shipping samples, it is preferable to pack them in an ice chest. This provides protection, insulation, and containment in case of breakage or spillage. When shipping samples that require chilling, pack plenty of frozen "blue" ice with the sample. Seal ice chests securely with duct or packing tape to ensure they do not accidentally open.

Sample Quality Control and Assurance

Objective

Quality control of samples during collection, processing, and transportation is an integral part of any sample-quality-control program. Quality control procedures are used to assess potential sampling and analytical bias.

Techniques

Rinseate Blanks
A rinseate blank tests sampling equipment for chemical contamination. After sampling equipment has been cleaned between sites, the rinseate blank is collected. Rinseate blanks are prepared by pouring DI water onto sample collection equipment and wetting all internal surfaces. The rinseate water is then collected into churn splitter. Collect sample bottles for each constituent that is part of program. The sample bottles are washed three times with the reinstate water before collection. Filtered constituents are collected using a peristaltic pump and filter. Preservation is added to samples requiring it. A rinseate blank has a QA abbreviation of "RB".

Production Samples
A production sample measures chemical concentrations in the environmental water and has the QA abbreviation of "P".

Duplicate Samples
A split sample is a portion or sub-sample of a total sample. This sample is used to determine analytical precision within a laboratory. In contrast to duplicate samples, replicate samples refer to two or more discrete samples collected at the same location and time. A duplicate sample has a QA abbreviation of "D".

Regular Samples
A regular sample is a production sample and has an associated duplicate. A regular sample has a QA abbreviation of "R".

Triplicate Sample (Field Spikes and Reference Solutions)
These are chemical solutions prepared by MP-157's QA group and are added to specified volumes of environmental water or directly to sample bottle. A graduated cylinder is used to measure the volume of environmental water used. When adding the prepared chemical solutions (e.g., vial) to environmental water, rinse vials with environmental water and add to sample bottle to ensure all chemical solution is included in sample. It is important to maintain the proper volume when carrying out this step. Note lot number of reference solutions in field note book.

In some cases, the triplicate (reference solution)is not mixed with environmental sample, but used to fill the bottle completely. A Triplicate sample has a QA abbreviation of "S".

Standards
Standards or reference materials are used for calibration of equipment that measures an environmental parameter. Use of reference standards is an integral component of quality control. Both water-quality-field equipment and laboratory equipment must be periodically calibrated to assure the instruments accuracy. The automated water quality field equipment, such as Hydrolab, Foxboro, Hach and Turner turbidity meters require regular calibration. The manufacturer's instructions for calibration and standardization should be closely followed.

Sample Description

1. Sample Identification Number
   A unique sample identification number is used for samples collected at different sites. The same number is used for all constituents collected. A letter prefix of "KBWQ" identifies this program as Klamath Basin Water Quality Program. A four digit number is used to identify site and sample period. These sample identification numbers are pre-selected by the Klamath Office.

2. Field books, chain of custody, and field sheets are written with waterproof ink. Any corrections made to these documents are lined out and initialed and dated. Unused lines in notebook and COC are lined out and notebooks signed by samplers.

3. A field notebook contains enough pages for all sampling dates. Field personnel during sampling carry the retained-field logbook. Past physical measurements and observations are compared to current conditions.

Field Log Sheets

Field personnel complete field sheets. This documents the collection of a sample, sample number, field analyses performed, and the laboratory analyses requested. The person who collected the sample signs the Field Sheet.
Field Sheets include

- Sample identification information (including Field ID)
- Field Measurements
- Sample Types
- Comments

Field sheets provide a convenient system for tracking the monitoring and analysis requests for each site in a particular project. Further, the field ID provides the cross-reference to laboratory results and sampling locations.

Chain of Custody

A chain of custody (COC) accompanies all samples to record possession of samples. Field identification, date and time of collection, laboratory identification, type, and contents as well as other information are recorded on these forms. Throughout sample collection and transport all samples collected are kept in a secured area, an area accessible only to authorized personnel. Upon completion of field collection the COC sheet is delivered to the lab with the samples. Chain of custody sheets are also legally binding and act as a work order for a laboratory. It is critical that the field identification number is properly recorded on both the field sheets and COC forms. Sample collectors, individuals transferring samples, and those receiving samples, all sign the COC. The forms are in triplicate and field personnel should not remove any forms.

Field Notebook

A bound field logbook is used to record field sample collection, field observation, sample treatment, and other pertinent information necessary to reconstruct the sample collection processes. All entries are made in ink. Field logbooks are kept by field crew and on file when the program is complete. All field books are returned to the Klamath Falls USBR Office.

Ringed Field and Calibration Binder

A ringed binder is used to store field sheets and calibration sheets. The binder can be used to store level one clean-bottle certificates, acid purity certificates in ampoules, and contamination certificates of in-line filters, and other appropriate certificates and papers.

Security Shipping Seals

A security seal is attached across the ice chests lid and side. The seal is signed and dated by the sampling personnel. The seal is attached so that it must be broken when the container is opened.

Klamath Basin Program Equipment & Supplies List

Equipment

- Churn splitter
- Peristaltic pump & tubing
- Rope
- Hip waders
- Long handle sampling vessel
- Van Dorn, Kemmerer with messenger
- Cell phone and telephone numbers
- Camera
- Turbidity meter & standards
- Knife
- Clip board
- Notepad
- Safety glasses
- Hydrolab Surveyor 3 and cables
- Sample bottles
- Syringe and filters
- Ice chests and blue ice

Supplies

- Spike solutions (QA samples)
- Rubber latex or vinyl gloves
- 12 in line filters for five sites
- Bottle labels
- Sharpie pens
- Ball point pens
- Maps
- COC sheet
- Field sheet
- Calibration sheet
- 6 data sheets for 5 sites
- Zip bag for COC sheet
- Duct or packing tape
- FedEx or Cal Overnight shipping labels or forms
- 5 to 10 gallons of DI water
- 1-quart plastic cube for used acid ampoules
- Squeeze bottle for DI water
- Brush for equipment cleaning
- Paper towels
- Plastic bucket
- Aluminum foil

Bottle List [for each sample site or QA sample]

- 3 1,000 ml HDPE for BOD, chlorophyll a, and nutrients(NH4, NO2+NO3, TKN, and total P)

- 1 500 ml HDPE **level one** for trace metals
- 1 500 ml HDPE for ortho phosphate
- 1 250 ml HDPE **level one** for Hg
- 3 250 ml HDPE for Ca & Mg, total alkalinity, and TDS

Acid ampoules (each grab site)
- 1 4-ml sulfuric acid for nutrients (or equivalent)
- 4 1-ml nitric acid for trace metals(uses 2), Hg(use 1), and Ca & Mg(use 1),

Laboratory Addresses

NEL Laboratories
4759 Longley Lane, Suite 106
Reno Nevada 89502
1-800-368-5221

Parameter: Hg

Lower Colorado Regional Laboratory
400 Railroad Ave.
Boulder City, Nevada 89005
702-293-8598

Parameters: Ca & Mg, TDS, Total Metals(Al, Cd, Cu, Ni, Pb), Alkalinity (carbonate and bicarbonate)

Basic Laboratory
2218 Railroad Ave
Redding California, 96001
530-243-7234

Parameters: Nutrients (Total P, NO2 + NO3 as N, NH4, TKN), ortho - PO4, BOD, and Chlorophyll A

USBR Addresses:

U.S. Bureau of Reclamation	U.S. Bureau of Reclamation
Klamath Basin Office	Regional Office
6600 Washburn Way,	2800 Cottage Way,
Klamath Falls, OR 97603	Sacramento, CA 95825
541-883-6935	916–978-5285

Calibration and deployment protocols are outlined below.

Calibration Protocol

Hydrolab DataSonde 3 & H2O Calibration Protocol

INTRODUCTION:
Ensure that maintenance is conducted on a weekly basis. Store the instruments with a cup filled 2/3 with deionized water and be certain to always place the LISREF cap on the instrument when not in use. The success and quality of a water quality instrument depends on scheduled maintenance. This is a fundamental understanding if we are to deploy instruments that must meet a high degree of both precision and accuracy. Standards are vital to help ensure that a basis for comparison is not compromised because of introduced sampling bias. As science professionals we are required to uphold the integrity of data required to make statistical representations. The following is provided as a supplemental reference to be used when calibrating hydrolabs. Always refer to the manufacturer=s specifications listed for each parameter. For additional information please refer to the Department of the Interior USGS Western Region Field Manual.

Order of Calibration Sequence:

1st Specific Conductance Sensor
2nd Dissolved Oxygen Sensor
3rd pH Sensor
4th ORP (Redox) Sensor

Specific Conductance Calibration:
Note: It is highly recommended to use PROCOMM PLUS software to calibrate your hydrolab. This is currently the industry standard employed to calibrate hydrolabs. Before calibration, ensure that the calibration standards have not expired. Be very careful during cleaning not to sand, grind down, or deform the six pins which could damage the pins resulting in a flat surface. Very lightly apply only enough force or pressure required to lightly buff and remove residue. The sensor pins must be clean and free of any salt or crystalline residue before attempting a calibration. If the instrument will not calibrate, clean the six pins with isopropyl rubbing alcohol, rinse with deionized water and try again. Bracket the conductivity of your local water with two conductivity standards. Calibrate with a Conductivity Standard that is nearest in value to that of expected sample site. Perform a linearity check with the half-value Standard afterwards. Example: Upper Klamath Lake Specific Conductance is approximately 105 µS/cm. Select a 147 µS/cm Standard and then select a half-value Standard of 74.0 µS/cm.

FIRST: Triple rinse the sensors with deionized water.
Next: Prerinse with the upper Conductivity Standard.
Next: Completely fill the calibration cup above the D.O. membrane with the Conductivity Standard.
Pour slowly to prevent bubbles from forming on the sensors.
Next: Allow the Conductivity sensor 3-5 minutes to stabilize.
Next: Record the *Initial Value* in the calibration log.
Next: Select ***(C)alibrate*** (from the ProcommPlus menu)

Next: Select ***Specific (C)onductance/Resistivity***.

Next: Type the Conductivity Standard value and then press **Enter**. Example: Type ***147*** µS/cm and then press the ***Enter*** key**.**

Next: Record the *Actual Value* in the calibration log.

Next: Discard the 147 standard and rinse with deionized water.

Next: Rinse with deionized water again.

Next: Prerinse with the half-value standard.

Next: Completely fill the calibration up above the D.O. membrane with the half-value standard.

Remember that this is **Not** an actual calibration. You only record the half-point value in the calibration log.

Next: Allow 3-5 minutes for the reading to stabilize.

Next: Record the half-point value in the calibration log.

LAST: Discard the Conductivity Standard and rinse with deionized water. Do not **ENTER** a calibration value for the half-value Standard. Simply record the reading.

Specific Conductance is now calibrated.

Dissolved Oxygen:

Note: Ensure that the dissolved oxygen membrane is free from bubbles, scratches and deformations. Both D.O. electrolyte and membranes should be changed on a weekly basis. Allow fresh membranes to sit overnight before attempting a calibration. Frequent membrane and electrolyte changes will help ensure accuracy and reduce bio-fouling on the membrane. Calibrate with deionized water that is at room air temperature, so that both the water and the air are very nearly the same temperature. Try to keep the temperature within one or two degrees celsius. This is a very important consideration when calibrating D.O. and should be strictly adhered to. (See Dissolved Oxygen Laboratory Calibration.) **Important:** You should consider a recalibration if the atmospheric pressure exceeds 20 mmHg at the deployment site. It will be necessary because the laboratory or room calibration value might have changed considerably due to a significant increase or decrease in elevation. This is because 20 mmHg corresponds to over 0.2 mg/L change in the value, which exceeds the manufacturer parameter specification accuracy listed for dissolved oxygen. If this is the case recalibrate the D.O. sensor only. (See Dissolved Oxygen Field Calibration.)

Obtaining Barometric Pressure:

Note: Obtain an accurate atmospheric pressure reading from a reputable source. Call your local weather station, look up your local weather page on the internet or purchase a quality barometer. Mercury barometers are very accurate.

FIRST. Determine the elevation at your site. Obtain an accurate vertical control monument that is nearest to the site by locating the nearest USGS monument. Otherwise, look on a USGS quad map. Try to establish your site elevation within approximately fifty vertical feet (50). Example: 4100 feet

Next: Obtain the barometric pressure corrected to sea level for your site. This will already be corrected to sea level for your area. Call the local weather station, look on the internet or purchase a quality barometer.

Next: Convert the barometric pressure corrected to sea level that you obtained in inches of mercury (inHg) to millimeters of mercury (mmHg). Example**:** You obtain 30.11 inches of

mercury from your weather station. Convert this value to millimeters. Now you will do the conversion. Multiply 30.11 by 25.4.

30.11 * 25.4 = *764.79 mmHg*

Next: Adjust the pressure to the elevation at your site. Example: Elevation is 4100 feet. Compute the difference in pressure at your site. In this example because we are 4100 vertical feet above sea level we need to subtract the difference in pressure. Barometric pressure decreases approximately 2.6 mmHg for every 100 vertical feet that is gained. Multiply 0.026 by 4100

0.026 * 4100 = *106.6 mmHg*

Next: Compute the **Actual Local Barometric Pressure** at your site. Example: Subtract the difference in pressure between your site and sea level. 764.79 minus 106.6

764.79 mmHg - 106.6 mmHg = ***658.19 mmHg***

This is the **Actual Local Barometric Pressure value** that you will type and **ENTER** during the D.O. calibration.

LAST: Compute the **Altitude Correction Factor**. Divide your **Actual Local Barometric Pressure** **(658.19 mmHg)** by the standard barometric pressure at sea level **(760 mmHg)**

Example: 658.19 mmHg divided by 760 mmHg

658.19 / 760 = ***0.8660***

***You have successfully obtained the Actual Local Barometric Pressure and the Altitude Correction Factor at your site. Retain both the* Actual Local Barometric Pressure *and the* Altitude Correction Factor *numbers for use later when calibrating D.O for your hydrolab instrument*.**

Dissolved Oxygen Laboratory Calibration:

Note: Please see the D.O. computation form.

FIRST: Triple rinse the calibration cup with deionized water.

Next: Slowly fill the calibration cup with deionized water to one-cm below the o-ring and membrane.

Next: Gently dry the membrane with a soft tissue.

Next: Allow the D.O. sensor 5-7 minutes to stabilize.

Next: Record the water temperature.

Next: Record the *Initial D.O. Value* reading from the hydrolab.

Next: Refer to the D.O. SATURATION VALUES Table and locate the recorded water temperature of your hydrolab sensor in the table. (See D.O. SATURATION VALUES Table) Example: ***21.3*** **degrees Celsius** corresponds to a table value which equals ***8.83***

Next: Multiply the corresponding temperature reference value by the **Altitude Correction Factor** that you obtained earlier of **0.8660**

Next: Compute the oxygen concentration value. Example: Multiply **8.83** by **0.8660**

8.83 * 0.8660 = ***7.65 mg/L***

Next: Record the *Computed D.O. Value* in the calibration log.

Next: Press ***(C)alibrate***

Next: Press ***(O)xygen***

Next: Type the *Computed D.O. Value*. Example: Type ***7.65*** mg/L and then Press the ***ENTER*** key.

Next: Allow the D.O. sensor 3-5 minutes to stabilize.

LAST: Record the *Actual D.O. Value* in the calibration log.

Dissolved Oxygen is now calibrated

pH Calibration:

Note: Ensure that the pH buffer solutions have not expired. Select a pH 7 buffer and another buffer that is close to the value of your sampling site. Ensure that electrolyte is changed on a weekly basis. If equipped with a LISREF sensor be sure to keep the protective cap filled with electrolyte when not in use. Select a pH sensor that will accurately sample the water at the sampling site. Generally water that is less than approximately 150 ms/cm should be sampled with the hydrolab LISREF pH sensor. Use the Standard Reference pH sensor to sample water that is greater than this value. When ordering your pH sensor purchase the proper sensor.

FIRST: Triple rinse the sensors with distilled water.

Next: Prerinse with the 7.00 buffer.

Next: Slowly fill the calibration cup above the D.O. membrane. Be careful to prevent bubbles.

Next: Allow the pH sensor 3-5 minutes to stabilize.

Next: Record the *Initial Value* in the calibration log.

Next: Select ***(C)alibrate***

Next: Select ***(p)H***

Next: Record the temperature of the pH 7 buffer solution.

Next: Refer to the buffer solution container or a pH Standard Table and find the value of the buffer at the recorded temperature.

Next: Record this as the *Chart Value* in the calibration log. Example: pH 7 buffer at 20 degrees Celsius is equal to a *Chart Value* of 7.02 pH units.

Next: Type ***7.02*** and then press the ***ENTER*** key.

Next: Allow the reading 3-5 minutes to stabilize.

Next: Record the *Actual Value* in the calibration log.

Next: Discard the pH 7.02 buffer and then rinse with deionized water.

Next: Rinse with deionized water again.

Next: Prerinse with pH 10 buffer. Example: Upper Klamath Lake is near 10.00 pH units.

Next: Slowly fill the calibration cup above the D.O. membrane. Be careful to prevent bubbles.

Next: Allow the pH sensor 3-5 minutes to stabilize.

Next: Record the *Initial Value* in the calibration log.

Next: Select ***(C)alibrate***

Next: Select ***(p)H***

Next: Record the temperature of the pH 10 buffer solution.

Next: Refer to the buffer solution container or a pH Standard Table and find the value of the buffer at the recorded temperature.

Next: Record this as the *Chart Value* in the calibration log. Example: pH 10 buffer at 20 degrees Celsius is equal to a *Chart Value* of 10.05 pH units.
Next: Type ***10.05*** and then press the ***ENTER*** key.
Next: Allow the reading 3-5 minutes to stabilize.
Next: Record the *Actual Value* in the calibration log.
LAST: Discard the pH 10.05 buffer and then rinse with deionized water.

pH is now calibrated.

ORP (Redox) Calibration:

Note: Calibrate ORP at least once a month. Calibrate ORP with Zobell=s Redox Solution Theoretical Potential. Ensure that the calibration Solution has not expired. The units expressed for Redox are expressed in milliVolts (mV).

FIRST: Triple rinse with deionized water.
Next: Prerinse the sensors with Zobell=s Redox Solution.
Next: Slowly fill the calibration cup above the membrane
Next: Allow the reading to stabilize.
Next: Record the *Initial Value* in the calibration log.
Next: Record the *Chart Value* in the calibration log.
Next: Select **(C)alibrate**
Next: Select **(R)edox**
Next: Type ***229 mV*** and then press the ***ENTER*** key.
Next: Record the *Actual Value* in the calibration log.
LAST: Triple rinse with deionized water.

Dissolved Oxygen Field Calibration:

Note: Professionals engaged in collecting water quality data should consider doing a recalibration for D.O. only if the deployment site is 20 mmHg greater than the laboratory or office calibration site. If you are deploying instruments at relatively higher or lower elevations of approximately 750 feet in elevation difference you should probably reconsider doing a D.O. calibration. Barometric pressure greater than 20 mmHg corresponds to a 0.2 mg/L change in the D.O. concentration value which can equal or exceed the manufacturer=s specification listed for accuracy. Bring along a gallon of deionized water if you will need to recalibrate.

FIRST: Obtain the **Actual Local Barometric Pressure.**
(See **Obtaining Barometric pressure)**
Next: Obtain the **Altitude Correction Factor**. (See **Obtaining Barometric Pressure)**
Next: Proceed in the same manner as the **Dissolved Oxygen Laboratory Calibration.**
LAST: Record the values in your yellow field notebook and make notes accordingly.

Post Calibration Check:

Note: The post calibration check is not an actual calibration. It is simply a procedure to record information pertinent to the instrument. The information provided by the post calibration check can be used to help professionals realize approximate drift values and deployment logging intervals. As a result, professionals may increase or decrease the logging intervals to obtain the best possible accuracy. Most importantly, it serves as a good measure of performance.

Specific Conductance Post Calibration Check:

FIRST: Rinse with deionized water.

Next: Completely fill the calibration cup above the D.O. membrane with the Conductivity Standard used to calibrate the instrument. Example: Check with the 147 µS/cm standard. Do **Not** check against the half-Value standard. Pour slowly to prevent bubbles from forming on the sensors.
Next: Allow the Conductivity sensor 3-5 minutes to stabilize.
Next: Record the post calibration check value in the calibration log.
LAST: Discard the Conductivity Standard and rinse with deionized water.

Dissolved Oxygen Post Calibration Check:

FIRST: Rinse with deionized water.
Next: Gently dry the membrane with a soft tissue.
Next: Allow the D.O. sensor 5-7 minutes to stabilize
Next: Record the water temperature.
Next: Refer to the D.O. SATURATION VALUES Table and locate the recorded water temperature of your hydrolab sensor in the table. (See D.O. SATURATION VALUES Table) Example: ***21.3*** **degrees Celsius** corresponds to a table value which equals ***8.83***
Next: Multiply the corresponding temperature reference value by the **Altitude Correction Factor** that you obtained earlier of **0.8660**
Next: Compute the oxygen concentration value. Example: Multiply **8.83** by **0.8660**
8.83 * 0.8660 = ***7.65 mg/L***
Next: Record the *Computed D.O. Value* in the calibration log.
LAST: Record the *Actual D.O. Value* in the calibration log.

pH Post Calibration Check:

FIRST: Rinse the sensors with distilled water.
Next: Slowly fill the calibration cup above the D.O. membrane with pH 10 buffer.
Next: Allow the pH sensor 3-5 minutes to stabilize.
Next: Record the temperature of the pH 10 buffer solution.
Next: Refer to the buffer solution container or a pH Standard Table and find the value of the buffer at the recorded temperature.
Next: Record this as the *Chart Value* in the calibration log. Example: pH 10 buffer at 20 degrees Celsius is equal to a *Chart Value* of 10.05 pH units.
Next: Record the *Actual Value* in the calibration log.
LAST: Discard the pH 10.05 buffer and then rinse with deionized water.

ORP Post Calibration Check:

FIRST: Rinse the sensors with distilled water.
Next: Slowly fill the calibration cup above the D.O. membrane with Zobell=s Redox Solution.
Next: Allow the ORP sensor 3-5 minutes to stabilize.
Next: Record the *Chart Value* in the calibration log.
Next: Record the *Actual Value* in the calibration log.
LAST: Triple rinse the sensors with deionized water.

KBAO Disclaimer:

The data included within contains the following provisions: The data is unadjusted

raw data as collected by the Bureau of Reclamation Klamath Basin Area Office. Data has been edited only to remove bias data that was captured due to both early and late deployment and retrieval times. Some of the possible factors affecting data quality include, but are not limited to the following: Calibration, maintenance, length of deployment, presence of biological organisms and sensor failure. Calibrations primarily include: *Specific Conductance, Dissolved Oxygen, pH and Redox.*

Bureau of Reclamation
Klamath Basin Area Office
Klamath Falls, Oregon

Calibration Log

Proceed from left to right top to bottom.

Unit Serial Number:
Calibration Date: _____
Post Cal. Check Date: _____

Unit Type:
Technician: _____
Log Site/Logging Interval _____

Parameters:	Range µs/cm	Calibration Points µs/cm	Calibration Values µs/cm	Linearity Points µs/cm (Half-Value Standard)	Post Calibration Check µs/cm
Specific Conductivity (1 Point Calibration)	0→150 150→1500 1500→10000	147 _____ _____	Initial Value _____ Standard Value _____ Actual Value _____	74	_____

DO (1 Point Calibration)

Refer To The D.O. SATURATION Values Table When Computing D.O. Concentration Values

Air: ℃ Altitude: Feet
Water: ℃ Barometer: mmHg

Post Cal Air: ℃ Post Cal Altitude: Feet
Post Cal Water: ℃ Post Cal Barometer: mmHg

Membrane	Method	Initial Value	Computed D.O. Value	Actual Value	Post Calibration Check Computed	Post Calibration Check Actual
Standard	mg/L %SAT	mg/L %SAT	mg/L %SAT	mg/L %SAT		
Low Flow	mg/L %SAT	mg/L %SAT	mg/L %SAT	mg/L %SAT		

DO (1 Point Calibration At Site If Necessary)

Refer To The D.O. SATURATION Values Table When Computing D.O. Concentration Values

Air: ℃ Altitude: Feet
Water: ℃ Barometer: mmHg

Post Cal Air: ℃ Post Cal Altitude: Feet
Post Cal Water: ℃ Post Cal Barometer: mmHg

Membrane	Method	Initial Value	Computed D.O. Value	Actual Value	Post Calibration Check Computed	Post Calibration Check Actual
Standard	mg/L %SAT	mg/L %SAT	mg/L %SAT	mg/L %SAT		
Low Flow	mg/L %SAT	mg/L %SAT	mg/L %SAT	mg/L %SAT		

pH (2 Point Calibration)	7-10	7 ___℃	Initial Value: _____ Chart Value: _____ Actual Value:_____	10 ____°C	Initial Value: _____ Chart Value: _____ Actual Value:_____	Post Calibration Check Temperature °C Chart Value _____ Actual Value _____

ORP (1 Point Calibration)	Redox Solution	Zobell's Redox Solution Theoretical Potential in mV	Post Calibration Check With Zobell 's Redox Solution + 429 mV
	Temperature_____°C	Initial Value _____ mV Chart Value _____ mV Actual Value _____ mV	Chart Value _____ mV Actual Value _____ mV

Temperature Certified N.I.S.T. Precision Thermometer _____ ℃
Instrument Temperature Reading _____ °C

Notes:

- Before starting the calibration, remember to check the maintenance log. The unit should be maintained before calibration.
- Make sure that all data in the unit's memory is backed up properly and safely before proceeding with the maintenance or logging setup.

Field Deployment Protocol

Required Supplies

- pH Reference electrolyte
- Datasonde sensor guard (if replacing a Datasonde unit, use the sensor guard from the unit being replaced)
- Keys to unlock Datasonde protective casing
- Keys for access to deployment locations (e.g., Shasta River)
- Marine lubricant/anti-corrosion spray
- Bound field notebook
- Waterproof pen (e.g., Sharpie)
- Field data sheets (and clipboard)
- Camera and film
- A copy of the Datasonde deployment protocol

Procedures

Office

- Review field equipment list
- Obtain a recently calibrated Hydrolab Datasonde unit. This will be delivered by a courier service or by Bureau of Reclamation (BOR) personnel.

Field (repeated at each deployment site)

Prior to Removing Deployed Probe

- At the deployment site, record the time and any environmental and/or site conditions in the logbook (e.g., precipitation, river turbidity).
- Record "new/ingoing" probe number in the logbook and note probe condition.
- Record existing in-stream condition of "old" (to be retrieved) probe – conditions as they are when you arrive at the site (e.g., "The Hydrolab Datasonde protective casing was out of the water and on the riverbank. The casing was completely dry and looked like it had been out of the water for some time. There is no observable damage to the probes" OR " The casing was buried in sediment").
- At a minimum monthly photographs are required at each site to monitor conditions.
- If necessary (and possible) photograph conditions at the site to further document changes. Photographs can be used to document any conditions found at the site (e.g., probe, locks, cables, river, casing, etc.). In all cases note photograph number on data sheet for future cross-reference.

Probe Removal and Re-deployment

- Remove the deployed Datasonde protective casing from the river. Note anything that looks unusual or suspicious.
- Remove the lock on the Datasondeprotective casing, **only** after the casing has been taken to a level or secure location away from the riverbank. This is to reduce the risk of the unlocked Datasonde casing from falling/sliding into the river. If the lock is difficult to open or if there is corrosion present, spray the lock with marine lubricant/anti-corrosion spray.

- Remove the "old/retrieved" Datasonde unit (the unit being replaced) from the protective casing. Carefully inspect the probe and casing assembly: note probe condition and/or anything that looks unusual or suspicious.
- Remove the sensor guard from the "old/retrieved" Datasonde unit. **Caution!** The probes are now completely exposed and are at the greatest risk of being damaged. Set the unit on its side in a secure location (e.g., place the probe out of harms way from "new" probe deployment work and do not allow it to roll/slide, possibly damaging the probe).
- Remove the storage cup from the "new/ingoing" Datasonde unit (the unit just received from the courier service or from BOR personnel). Set the storage cup on the ground.
- Remove the black pH reference cap from the "new/ingoing" Datasonde unit. Set the "new/ingoing" Datasonde unit on its side in a secure place.
- Place the black pH reference cap onto the "old/retrieved" Datasonde unit, *make sure the pH reference cap is full of pH electrolyte*.
- Place the storage cup full of water onto the "old/retrieved" Datasonde unit. Set the unit on its side in a secure place.
- Carefully place the sensor guard onto the "new" Datasonde unit. When putting the sensor guard on a unit be aware of the glass probes. They are fragile and can break from a light impact with the sensor guard.
- Gently slide the "new" Datasonde unit with the sensor guard into the protective casing, close the case, and replace the lock.
- Carefully deploy the "new" Datasonde unit and protective casing into the river. The objective is to place the probe in a well-mixed area, most representative of mainstem conditions. Look for objects and undesirable substrate conditions **before** you deploy the unit in the water. That is,
    - Avoid large rocks that may damage the instrument during deployment
    - Avoid submerged logs/debris where the probe could get snagged
    - Avoid deposits of fine sediment
    - Avoid slow backwater areas, side channels, and other areas not representative of mainstem conditions

Record the "old/retrieved" Datasonde number on the field sheet
Record the "new/ingoing" deployment condition prior to leaving site (under "Comments/Remarks"):

- distance from shore
- depth
- estimated velocity
- substrate condition
- riparian vegetation
- etc.

Post-Field Review

- Review logbooks for completeness. Do not hesitate to utilize extra pages in the logbook if necessary. Do not skip pages.
- Review field notes and notify USBR- Klamath Falls of potentially important findings (e.g., probe condition, vandalism, major changes in environmental conditions at site that may affect sampling).
- After each deployment copy logbook entries and send copies to USBR-Klamath Falls.
- Review available materials and supplies and notify USBR-Klamath Falls if additional materials and supplies are required.

APPENDIX E: TEMPERATURE MONITORING PROTOCOL

Water temperature monitoring provides information for multiple purposes. The quality, frequency, format, and accessibility of temperature data is important to effective application of scientific methods to studies of biological, ecological, and water quality conditions in the system. Outlined herein are the protocols for water temperature monitoring.

Objective

Monitor water temperatures in river systems to more completely define the thermal regime over space and time. Sufficient detail is required to capture diurnal changes in mainstem water temperature, to determine seasonal changes in thermal regime, to monitor season-to-season changes in water temperatures.

Equipment

To fulfill the objective of the monitoring program, remote logging thermistors are deployed to record time series of temperatures at various locations in the river. Such logging thermistors ("loggers") can record information at various, user-specified intervals and can be deployed for long periods of time.

Onset Stowaways® temperature devices in waterproof cases are employed. These devices are economical, have a high reliability and an acceptable accuracy (±0.2°C or ±0.4°F). The response time in water is sufficient (less than 15 minutes) for hourly measurements. If other logger brands/types are used they should have a similar accuracy and response time.

Equipment Protocol

New Loggers: all new loggers are inventoried, by serial number. The logger number, date of purchase, attributes (memory size, battery life, etc.) are included. Equipment should be properly labeled. Using permanent marker write the logger serial number on the inside and outside of the cannister, include the date for battery replacement purposes.

New Loggers: all new loggers are tested prior to field deployment to assure they function properly.

Existing Loggers: each year the logger inventory is examined to determine if:

a) a logger needs to be replaced (e.g., replacing a out of date logger, or a logger is lost/fails),
b) if the battery replacement is required (write month and year on battery),
c) if equipment needs to be maintained (frayed cord, degraded case, degrade "O" ring, properly lubricated "O" ring, relabeled case, cracked case, etc.).

Deployment Design

Deployment includes defining the deployment locations, recording season, recording interval, download frequency, and maintaining a deployment log.

Deployment Locations

Deployment locations should be the same year-to-year to provide a consistent representation of the river. This does not imply inflexibility, but it should be a goal. Also, there may be sites that hold special interest for select studies or for short-term requirements that can be monitored as

needed. Locations may be monitored year-round or seasonal. Locations may be prioritized in terms of importance when making monitoring decisions.

For this study, temperature loggers are deployed at:
1) Klamath River above Cottonwood Creek (RM 182)
2) Klamath River above Shasta River (RM 176.7)
3) Klamath River at Walker Road Bridge (RM 156)
4) Klamath River above Scott River (RM 143.5)
5) Scott River (RM 1.0)

Recording Season
In order to ensure successful retrieval of devices special care must be used during winter months. Deployment and retrieval are functions of weather and runoff conditions and staff availability. Safety is always the first priority.

For this study the deployment season ranges from April into November, 2000.

Recording Interval
To effectively record daily maximum and minimum temperatures and to represent the diurnal cycle data is recorded hourly and on the hour. For ease of data manipulation and presentation, as well as data comparison all loggers should be programmed to start at a fixed time – e.g., midnight. "Trigger starting in the field should be avoided if necessary. It is vital to ensure that the time on the computer is correct when launching loggers!

For this project the deployment interval is 1 hour.

Download Frequency
Download frequency is often governed by budget and time constraints. For practical reasons, download frequency is on the once per quarter (approximately 3 month intervals). This time frame allows flexibility in planning, while minimizing the risk of lost data – a loss of a few months of data is better than losing an entire year. Certain loggers may have a higher priority for download to minimize loss of data. Other download frequencies can be selected depending on available personnel. The selected loggers (with 8Kb of memory) will record for over 300 days at 1-hour intervals. This allows some flexibility during the winter season when access to loggers may be difficult, but quarterly downloads should be maintained to the extent possible.

For this study the download frequency is roughly 2 months.

Deployment Log
The deployment log is a running record of loggers. Should include, but is not limited to

- Logger serial number,
- Date of deployment,
- Location of deployment (general),
- Time of deployment,
- Recording interval,
- Approximate depth,
- Estimate of water velocity (should not be standing water)
- Distance from bank (right and left bank designations are made looking in the downstream direction),

- Memory available (e.g., how many days can it be left in the field: assume 300 days for loggers with 8Kb of memory),
- Download filename,
- Complete physical description of deployment site, benchmarking with a tape measure to a well described object if necessary, and if possible photographs,
- Condition of the logger,
- Flow conditions or changes in flow,
- If photographs are taken, note number of photo in camera (occasional photo-documentation is valuable)
- Any conditions which may affect the temperature record.

On occasion, the deployment log should be photocopied to provide a backup in case the log is lost. A sample data sheet is shown in Table E-1.

Table E-1 Sample temperature monitoring data sheet

Water Temperature Monitoring
Date: _____ Field Personnel: _____
Time: _____ _____

Location	Time:	Logger # Removed	Logger # Deployed	Tw	Tair	Approx. Depth (ft)	Distance fr. bank (ft)	Velocity >1 ft/sec (Y/N)	Condition @ Retrieval	Changes in Re-deployment
Download filename:										
Download filename:										
Download filename:										
Download filename:										

Field Notes

Field Deployment Protocol

Field deployment protocol includes where to deploy the logger and field downloading procedures.

Logger Deployment

Loggers should be deployed in areas that are representative of main-stem temperatures. If loggers are deployed for other reasons (e.g., stratification in impoundments/deep pools, influence of return flows, backwaters) those reasons should be clearly stated in the deployment log. Careful placement is required in locations where water level fluctuations may affect temperature readings should flows significantly decrease. If a logger is moved for any reason (e.g., flow

change) it should be noted in the deployment log. Personnel deploying equipment should always be denoted in the log.

Loggers are deployed in protective iron pipe containers, attached to the bank with braided stainless steel cable. The cable may be attached to a natural structure or to framing stakes driven into the bank. Framing stakes should be driven in to full depth if possible and should be placed out of harms way. Cable lengths vary, but are typically 10 to 15 feet in length. Often less cable is required. In such a case carefully coil the cable on the bank – do not leave excess cable in the river. Rarely will more cable be required. Attaching two cables together for a deployment more distant from the bank is discouraged.

Safety is always a paramount issue. Loggers should not be located in areas where there is risk to life or limb. Conditions may change throughout the year, what once was a benign riffle may be dangerous at high flows. Likewise, landowner permission is a pre-requisite prior to deployment. *If conditions are deemed unsafe do not attempt to deploy or retrieve a logger. Always err on the side of caution.*

Logger Downloading

In the field, loggers are downloaded using a laptop computer (PC). Supplies include a well-charged battery for the PC, appropriate cables to link the logger to the PC, diskettes to save files if necessary, appropriate equipment to retrieve and access the logger (wrenches, channel locks) and the deployment log. Downloaded files should be saved to the computer and the filenames noted in the deployment log. If a logger is replaced (i.e., lost logger) the new number should be denoted in the record. The person performing the download should include their name in the log.

Field Quality Control

If desired, temperature loggers can be checked against calibration thermometers in the field. This step may not be required if the loggers were properly tested prior to deployment. It is time intensive, requiring a separate trip to all locations to measure water temperature. It has been found that the selected devices (ONSET Stowaways) have been highly reliable. If a location is of special concern, this measure can be taken. No special measures were taken for this study.

Removal of Field Deployment Equipment

At the termination of the fieldwork, all materials will be removed from the field. No debris should be discarded in the field.

Data Management

Data management consists of transferring downloaded files to the PC and to diskette for backup, examination of the data, and updating the data inventory.

Data Transfer and Backup

Once the data is retrieved from the loggers, all raw data files are downloaded to the PC diskette. This is the master data set – the original data from the field. Presumably, all analyses using the data can be re-created from these data sets. The diskettes should be properly labeled and stored. PC files should be well organized with a “table of contents” file defining how and where all files are stored.

A copy of the files should be sent to the appropriate personnel and agencies to ensure timely review of the data.

For this project he data will be compiled in electronic format and supplied to the US Bureau of Reclamation – Klamath Area Office.

Examination of Data

Once the data is downloaded, the data should be examined to determine if the record is reliable. The most direct method is to plot the data and critically examine the water temperature trace. Common problems include

- logger failure (PC can't find the logger file),
- thermistor failure (negative temperatures),
- improper launching of the logger (no data),
- exposure to air (excessive temperatures),
- not in mainstem (increased temperature – usually associated with a flow change)
- affected by local conditions (e.g., filling to draining of an impoundment).

It is helpful to review the data in concert with available flow and air temperature information. It is also useful to compare loggers to determine if a particular logger is not in agreement with nearby loggers.

Updating Data Inventory

The data inventory defines all of the temperature data, filenames, record starting and ending dates, missing data, logger failures/losses. Further, the data included herein are different than the "raw" field data because they have been reviewed for completeness, erroneous temperatures have been deleted (e.g., air temperatures prior to deployment), and the data set has been documented as representative of water temperature in the system. It is paramount that this file be maintained, as it is the basis of the data management system.

Data Interpretation

Data use and interpretation is the ultimate goal of the water temperature monitoring program. There is potential for a wide variety of application of temperature data. There is uncertainty associated with all data, which should be taken into account during interpretation. Uncertainty may include logger accuracy, placement of loggers, correct time of measurements, and human error. By using reliable equipment, testing devices prior to deployment, predetermined deployment and downloading protocols, maintaining a complete and accurate deployment log, archiving raw data, and keeping an up-to-date data inventory, such errors can be minimized, or at least their magnitude documented. The result is that data can be applied to monitoring programs and scientific studies with a greater degree of confidence.

Summary of River Water Temperature Monitoring

Field Equipment

- 8K Stowaway Loggers and waterproof cases (or appropriate loggers): Record serial #s on interior and exterior of cases with permanent pen. (Spare loggers should not be deployed for purposes other than those defined in the study.)
- "O" ring lubricant

- Boxcar Software (to launch and download)
- replacement batteries

Field Equipment Checklist

Caution: do not work at waters edge except as necessary to remove and deploy equipment. To reduce loss of equipment and for safety concerns move back from the stream to complete field work

- PC laptop (with charged battery and power cord (AC power may be available in the field at certain locations, e.g., campground))
- Logger download cable
- Log book or log sheets
- Permanent pens/markers (spare)
- Maps
- Photo album showing deployment locations (so you can find the place again)
- Camera with spare film
- Spare loggers
- Spare canisters with appropriate bolts
- Spare cables and hardware (Shackles, sleeves, ferrules, etc.)
- Spare form stakes
- Zip ties
- Mallet
- Wrenches to open canisters: suggest two crescent wrenches in case bolts/nuts are variable size
- Cutters to cut zip tie
- Channel locks to open the logger
- Spare "O" ring lubricant
- Rags – plenty of them
- First aid kit
- It is helpful to bring along other tools: Screwdrivers, pliers, knife, etc.

Locations

List of Locations (See above)

Frequency

Note frequency: "Data will be recorded at _____ (e.g., hourly) intervals."

Schedule

The deployment schedule is designed with variable flow conditions in mind. The deployment, download and retrieval schedule includes field dates and locations. The schedule is meant to provide guidance and should be adapted to changing conditions, as it is almost certain that changes will be required to effectively monitor water temperature. Large flows, low flows, sudden flow changes, or other unforeseen circumstances may warrant trips to the field to check, move, and or replace loggers.

Deploy: Date (MM/DD/YY): _____
Download #1: Date (MM/DD/YY): _____
Download #2: Date (MM/DD/YY): _____
Download #3: Date (MM/DD/YY): _____

.
.

Download #n: Date (MM/DD/YY): _____
Retrieve: Date (MM/DD/YY): _____

APPENDIX F: BENTHIC ALGAE SAMPLING

Objective

Determine bulk primary production growth rates for the Klamath River below Iron Gate Dam for use in numerical models

Locations

Benthic algae are sampled at two locations in the Klamath River below Iron Gate Dam:
1) Below Iron Gate Dam (RM 190)
2) Above Cottonwood Creek (RM 182)

These locations have approximately the same aspect and stream velocities and depths during the late spring through summer periods.

Frequency

There are two sampling series during the 2000 season occurring in late-May, late-July, and early-September. Deployments will consist of weekly samples for a period of 3 to 6 weeks depending on rate of growth.

General Method

Two methods are employed to assess algal growth in the Klamath River. The first method is strictly qualitative observation. Artificial substrate consisting of 6 inch square, unglazed ceramic tiles attached to 8 inch by 18 inch cinder blocks are assessed at weekly intervals and their condition described in a narrative. Two tiles occupy each block. The tiles are photographed to provide visual documentation of changes through the sampling period. These qualitative observations provide insight on colonization, variations in algal assemblages, impacts of grazing, spatial variability, and general seasonal changes. No lab work is associated with this task.

The second method also utilizes artificial substrate. Periphyton samplers consisting of a floating slide rack and glass microscope slides are employed. Three samplers are deployed at each site (24 total slides). All samplers are placed, exposed, and handled in nearly as identical fashion as possible. The exposure period is 3 to 6 weeks during all sampling events. Four samples are collected for each sampling event and location. Ideally, samples are collected at weekly intervals, but if conditions are such that growth is sparse or excessive, sampling periods may be varied. However, the total number of samples be collected shall not be less than three nor more than five.

Deployment

Deployment for sampling studies shall take place in waters between 2 and 3 feet deep where velocities are between 1 and 3 feet per second. All samplers are placed within the same geomorphic channel unit (e.g., run, riffle or pool). Deployment of artificial substrate differs for the ceramic tiles and glass slides.

Ceramic Tiles
Tiles are deployed in the river a minimum of two weeks prior to initial sampling to allow tiles to saturate and, to some degree, become colonized with algae. Substrate remains in the river between sampling series. It is important to maintain depth and velocity considerations during these non-sampling periods, but not critical. Tiles shall not deployed in areas subject to sedimentation, desiccating, and excessive shading. Prior to sampling event all tiles are scrubbed clean with a nylon brush. The cinder block is cleaned as well to minimize fouling from adjacent benthic algae.

Six to twelve tiles are deployed at each location (3 to 6 cinder blocks). Blocks may be moved during sampling events if they have shifted (e.g., turned over) or flow changes have changed conditions sufficiently to warrant re-deployment consistent with the depth and velocity criteria. Locations where riparian or topographic shading is appreciable are avoided. All tiles are cleaned prior to the sampling deployment as noted above in substrate preparation. To the extent possible tiles are deployed at approximately equal depths and equal stream velocities. Tiles are deployed, if possible, with their long axis normal to the principal flow direction. Document the initial position of each tile and changes that occur during the sampling event. Sampling locations are coincident with the floating periphyton samplers.

If possible, a temporary staff gage, consisting of a wooden stake near the river's margin, is set up to compare relative variations in stage through out each sampling period. At the site below Iron Gate Dam changes in stage can be estimated from the USGS gage located approximately 200 yards downstream of the sampling site. All sites are photographed during each visit. A deployment field sheet is included below. One sheet is used for each site.

If tiles have moved, are missing, damaged or if conditions have changed, redeployment may be necessary. Redeployment should occur locally and similar conditions maintained. If redeployment is necessary, the appropriate documentation in the field data sheets must be completed. Photographs should be taken to document conditions.

Tiles shall <u>not</u> be re-deployed if water clarity changes. Further, site conditions are assessed during each visit to ensure that neither riparian vegetation (e.g., grasses, shrubs) nor adjacent benthic algae have grown to the extent to impair growth on the artificial substrate. It may be necessary to periodically clean benthic algae from the cinder block.

Floating Periphyton Samplers
Artificial substrate for the floating periphyton sampler consists of a floating rack containing glass microscope slides. Slides are cleaned with a damp cloth followed by rinsing 3 times with deionized (DI) water. Clean slides prior to deployment in rack. Ensure no debris or other foreign matter is in rack or on slides. Number each sampler as per site location as well as the sampler slide rack (i.e., number slide rack slots sequentially 1 through 8).

Three samplers are deployed at each location. Each sampler is anchored to the bottom with cable or nylon rope. All samplers are placed in as near as equivalent conditions as possible. Floating samplers and ceramic tiles are placed in the coincident locations. Document and photograph all deployments.

If samplers have moved, been vandalized, or flow conditions have changed, it may be necessary to move the device. All attempts should be made to maintain conditions outlined above. Document changes and photograph prior to and after re-deployment.

Field Sampling

Sampling procedures are as follows:

Ceramic Tiles

1) At each site the tiles are examined in situ. Record any observable characteristics prior to removing from stream. Note variability, any benthic fauna, if adjacent natural or artificial substrates are "interfering" with the artificial substrate. Photograph if possible.
2) Retrieve cinder block containing representative tiles.
   a) Use caution not to disturb the benthic algae on the tiles or cinder block.
   b) Note condition of tile: broken, obvious grazing (presence of grazers), debris attached, sediment, etc.
3) Photograph the tiles, noting photograph number, include a sketch (with referenced photo #) and provide a brief narrative describing
   - Sampling site,
   - Sampling date
   - Personnel
   - Conditions (weather, flow)
   - Depth of substrate
   - Approximate water velocity (if a flow meter is available determine velocity at 0.6D and 10 cm above bottom)
   - Condition of substrate (amount of growth, variability, color, etc)
   - Grazing
   - Other benthic fauna

   It may be useful to place the tiles in a few inches of water to more clearly see the condition of the substrate. Take previous field logs and photographs on each trip to more completely assess changes in algae status. *Consistency and completeness is critical to the narrative/description.*
4) Do not remove and flora or fauna from the substrate.
5) Replace the substrate with as little disturbance as possible. If there is substantial debris or sediment on tile or block gently remove (by hand) and/or wash.

Floating Periphyton Sampler: Glass Slides

Slides are collected and placed intact in high density polyethylene (HDPE) bottles. Bottles are washed 3 times with deionized water (swirl sufficiently with cap on and discard – repeat). Bottles and caps are allowed to air dry (prepare prior to going into field). All bottles are wrapped with aluminum foil immediately upon sample collection.

Chlorophyll a: slides are placed in HDPE described above. Label bottles appropriately for chlorophyll a analysis. Label bottles appropriately for chlorophyll a analysis. Wrap bottles in aluminum foil. Place on dry ice and transport to the laboratory.

Dry and Ash Free Weight (AFDW): slides are placed in HDPE described above. Label bottles appropriately for dry and ash-free weight. Fill in all appropriate label information. Wrap bottles in aluminum foil. Place on dry ice and transport to the laboratory.

At each of the two sampling locations four slides are collected:

- One slide for chlorophyll a and (one bottle – one slide per bottle)
- Three slides for AFDW (triplicate: three bottles – one slide per bottle)

The slides to be removed will be determined prior to going to the field. Retrieve the sampler from the river and process (remove) samples at the shoreline to reduce risk of lost slides/samples. To ensure consistent deployment location, leave anchor in river and retrieve only the sampler. Remove excessive algae attached to the sampler and process slide in clean plastic tub. If material is accidentally scraped/lost from slide recover as possible from the tub and placed in the sample bottle. (Use a clean razor blade to retrieve algae biomass from tub.)

Once a slide is removed from the floating rack, a new slide is deployed in the slot. This new slide is only to ensure consistent flow conditions within the floating sampler assembly and will not employed as an artificial substrate sample location.

Check rack to ensure slide carriage is properly engaged (to avoid loss of slides), inspect sampler for damage, and return rack to river. Make sure rack is placed with shield facing upstream; clean excessive benthic algae growth from anchor line.

Laboratory Procedures

Chlorophyll a (Standard Methods: 19th Ed. 1995, 10200 H, 10300 C))

1) Remove material from both faces of the slide with razor blade or rubber policeman
2) See Standard Methods: 19th Ed. 1995, 10200 H.

Dry and Ash-Free Weight (Standard Methods: 19th Ed. 1995, 10300C)

1) Remove material from both faces of the slide with razor blade or rubber policeman. *Do not process on slides unless high temperature slides are used and specifically noted on sample collection bottles.*
2) See Standard Methods: 19th Ed. 1995, 10300 C.5. **NOTE**: *Do not process on slides unless high temperature slides are used and specifically noted on sample collection bottles. If in doubt remove material and process in crucible.*
3) Report dry and ash-free weights per area of sampled surface.

Shipping and Handling

Dry Ice

All samples are to be placed on dry ice. Each container should include only a microscope slide and minimal water. Dry ice shipments will arrive on Tuesday or Wednesday of the appropriate week. The shipments should have sufficient dry ice (if not disturbed) to accommodate Wednesday sampling and Wednesday shipping to the Redding Laboratory. Do not handle dry ice. The container should be opened and samples placed within and immediately sealed. There should be little or no reason to "repackage" the contents, e.g., dry ice.

Field Data Sheets, Field Log Sheets, and Chain of Custody

Field data sheets and field log sheets should be filled out completely by field personnel. Prior to shipping, information from the field log sheet is transferred to the chain of custody (COC) forms. Copies are made of all documents and the originals sent to:

US Bureau of Reclamation – Regional Office
Attn: Victor Stokmanis
2800 Cottage Way
Sacramento CA, 95825

Shipping

Include the COC in a plastic bag inside the container. Package securely and send to

Basic Laboratory
2218 Railroad Avenue
Redding CA 96001

Retain the pink copy of the COC.

Field Equipment

- Floating periphyton samplers (7), properly labeled with clean slides
- Spare slides
- Anchor cable/rope
- Split rings
- Anchors
- Pre-cleaned bottles for sample slides
- Deionized water (squirt bottle)
- Ceramic tile/Cinder blocks (in river)
- Field book/data sheets
- Permanent pens
- Camera and film
- Polaroid camera and film
- Plastic tub
- Razor blades
- Waders
- Current meter (flow and depth)
- Thermometer
- Dry ice
- Small ice chest
- Duct Tape (to seal ice chests)
- Protocol
- Shipping forms
- Chain of custody forms (and plastic bag for shipping)
- Field log

Attachments: Field Data Sheets, Labels, and Field Log

Attached Algae Survey: Field Sampling Sheet

Site Information	
Site Name:	Date: (MM/DD/YY)
Site Identification Number:	
Sampling Team:	Time:

Deployment Status						
Sampler and Tile Deployment (two tiles per block)	Sampler ID #	Number of Blocks	Blocks Cleaned (circle)	Depth (2 to 3 ft) (ft)	Velocity (1 to 3 fps) (fps)	Distance from Bank (ft)
Sampler 1			Y N			
Sampler 2			Y N			
Sampler 3			Y N			

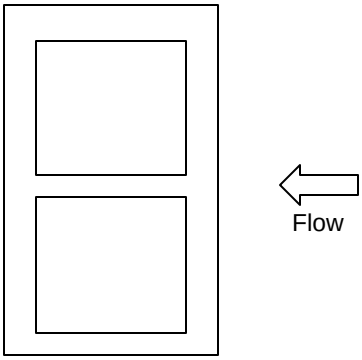
Substrate Condition

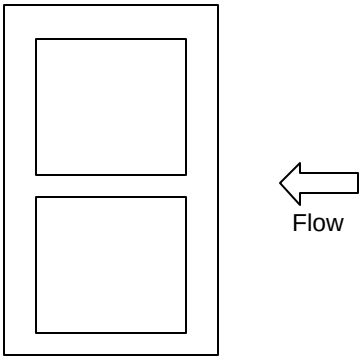
Photograph Site	
1. Across Stream	Y N
2. Downstream	Y N
3. Stream Bed	Y N
4. Tile - subsurface	Y N
5. Other: _____	Y N
6. Other:	Y N

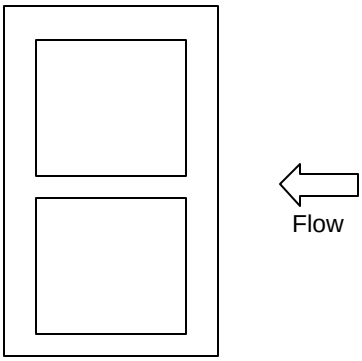
Field Conditions			
Clouds (%):	Wind:	Precipitation:	
Other conditions:			
Stream Stage (from datum) (ft):	Velocity (fps):		
Water temperature (C):	Other: (e.g., DO, pH, etc.)		
Water clarity (circle): very turbid	turbid	slightly turbid	clear
Riparian shading (circle):	exposed	partially shaded	shade
Topographic shading (circle):	appreciable	moderate	small
Remarks			
			Sheet 1 of 3

Sampling Information: Ceramic Tiles Narrative

When using schematics, please label and refer to figures appropriately





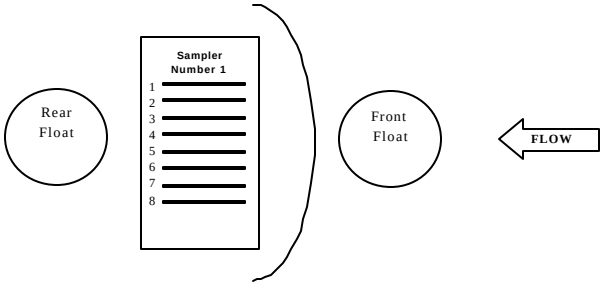


Sheet 2 of 3

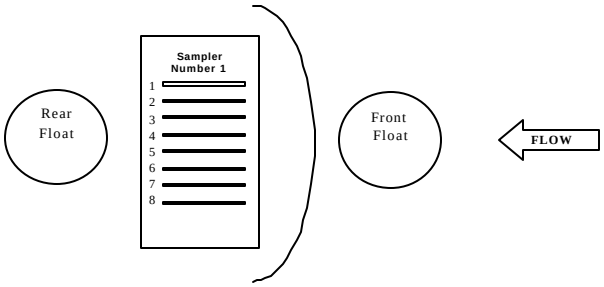
Floating Sampler Collection: Microscope Slides

For each sampler denote which slides were collected for Chlorophyll a and AFDW on the appropriate schematics. Provide observations/notes as applicable.

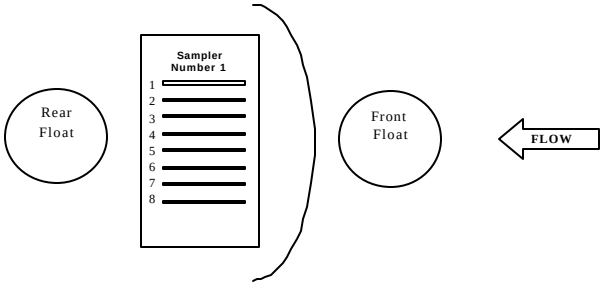
Sampler #1



Sampler #2



Sampler #3



Samples:	Sample ID #	Foil Wrap	Dry Ice	Comments
Chlorophyll a				
Ash-Free Dry Mass				
Ash-Free Dry Mass				
Ash-Free Dry Mass				

Notes

Sheet 3 of 3

Sample Label

Sample Label

Date:	Time:	Collected By:
Sampling Site:		
Sample Type:		
Test Required:		Preservative:

Completed Label

Date: **5/1/00**	Time: **13:30**	Collected By: J. Smith, F Henry
Sampling Site: **KRALG-001**		
Sample Type: **Artificial substrate: one glass slide**		
Test Required: **Chlorophyll a**		Preservative: **Foil wrap/Dry Ice**

Field Log

Sample identification				**Field Measurements**					**Sample Types**		
Field ID#	Site Name	Date (mm/dd/yy)	QA Type	Tw (C)	DO (mg/l)	Cond (uS/cm)	pH	Redox mV	Chl a	AFDW	Other

Remarks

Project Name:_____ Collected By: _____

_____

R - Regular Sample S - Spike
RB - Rinseate Blank D - Duplicate
B - Blank

Klamath River Modeling Framework to Support the PacifiCorp Federal Energy Regulatory Commission Hydropower Relicensing Application

- Appendices -

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March 9, 2004

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A Klamath River Water Quality Modeling Framework[1]

A.1 Introduction

As identified in subtask 1.3, Water Quality Analysis and Modeling Needs Assessment and Scoping Process, the objectives of water quality analysis and modeling are to:

- Determine what analysis and modeling tools are needed to assess Project water quality effects and compliance with water quality standards and objectives
- Determine the appropriate geographic scope for the needed analysis and modeling tools
- Clarify specifically how water quality compliance will be determined for the Project using such tools
- Develop plans for completing this analysis and modeling
- Ensure appropriate analytical coordination with larger-scale analyses and modeling that PacifiCorp assumes will be conducted by the agencies as a key part of TMDL water quality
- management planning in the basin
- Support subsequent assessment (including in other studies or during license application preparation) of the Project's potential effects on water quality and possible measures to protect, enhance, and mitigate where necessary.

In response to these objectives, as well as feedback from other stakeholders and interested parties in the Klamath River system a modeling framework has been developed, and is presented herein.

A.2 Klamath River Modeling Framework

The Klamath River system from Upper Klamath Lake to below Iron Gate Dam is a complex of river reaches and reservoirs. There are four major impoundments: Lake Ewuana/Keno Reservoir, JC Boyle Reservoir, Copco Reservoir, and Iron Gate Reservoir. Free-flowing river reaches occur between the impoundments with the exception of Copco Dam and Iron Gate Reservoir (Figure 1).

The diversity among the reservoir operations, inflows and diversions, morphology, and water quality characteristics is considerable. The river reaches vary in a similar manner. To effectively represent the flow and water quality characteristics of these reservoir and river reaches the models must be able to accommodate a wide range of conditions. Outlined herein are the general characteristics of each reservoir and river reach, the selected model, modeling parameters, and data needs. The framework of models is adaptable to modeling system components individually or as an integrated system, and is capable of representing a without project condition. An appendix includes descriptions of the various model attributes.

[1] This is the original framework submitted as part of subtask 1.3. Modifications have been made. Although not comprehensive, notes have been added to this section to identify significant changes.

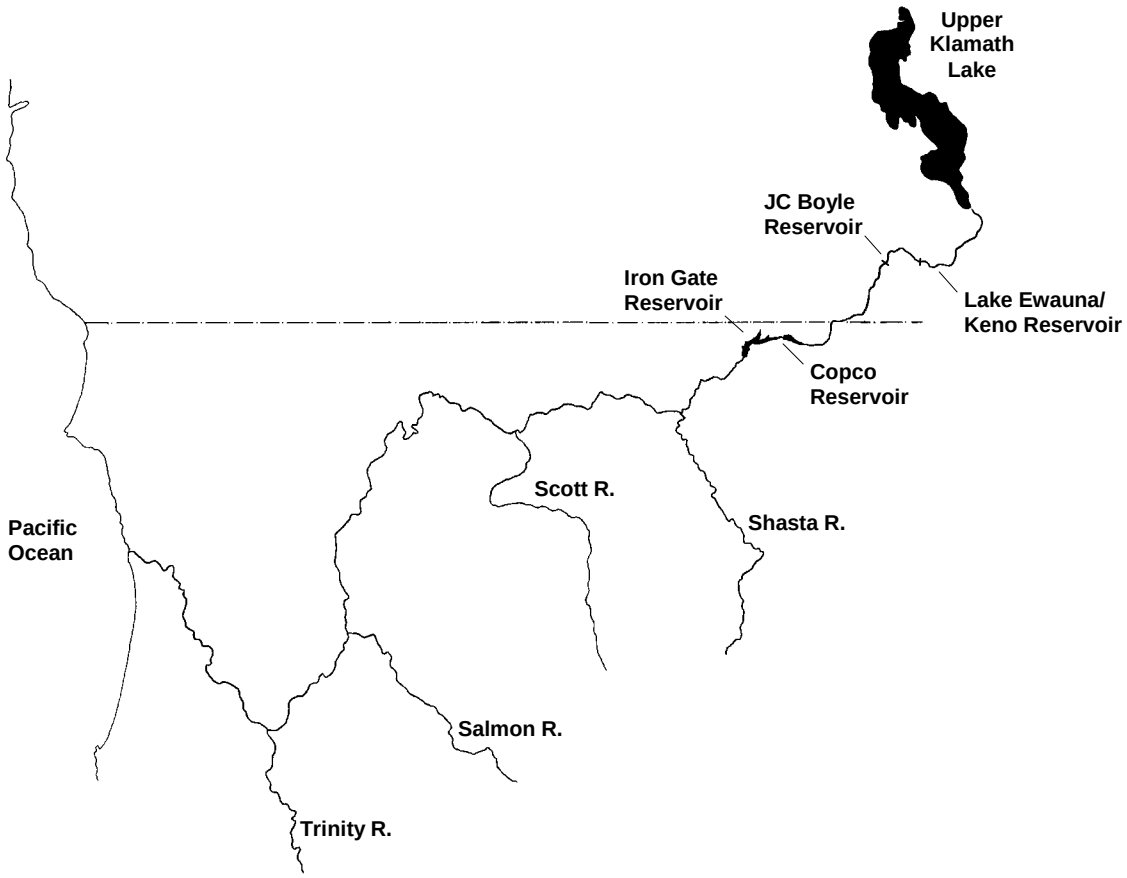


Figure 1. Klamath River System

A.2.1 Models

Four models are proposed for use to represent the various reservoir and river reaches in the Klamath Basin throughout the study area: CE-QUAL-W2, WQRRS[2], RMA-2 and RMA-11. These models are full water quality models capable of simulating water temperature as well as a wide range of water quality parameters in reservoirs and rivers. Although there are a range of models available, these were selected for several reasons

- They are physically-based numerical models capable of simulating a wide range of water quality conditions under dynamic conditions
- The models have been widely applied and have been widely tested
- They have been or are actively being used in the Klamath Basin
- The codes are not proprietary and are thus readily available for review

The reservoir models that will be used include the U.S. Army Corps of Engineers (USACE) model CEQUAL-W2, and the USACE model WQRRS. CEQUAL-W2 is a two dimensional, longitudinal and vertical representation of a water body. WQRRS is a

[2] WQRRS was not selected as a final model for includion in the modeling framework. CE-QUAL-W2 was used for all reservoir systems.

one-dimensional vertical representation for stratified or well-mixed reservoirs. The river reaches will be modeled with a set of models, RMA-2 will be used to represent the hydrodynamic flow regime and the output (velocity, depth, etc.) will be used as input for the stream water quality model RMA-11.

The reservoir models will run on daily and/or sub-daily time steps. Certain reaches have been identified as requiring time steps on the order of an hour (e.g., JC Boyle full flow reach).

Model descriptions and general information is included in the appendix. It is presumed that these more complex models will be supported with simpler process-based or statistical models.

Interfacing the Models
Modeling the Klamath River reaches and reservoirs will be completed using different models for reservoir and river reaches. The process of interfacing or linking the models is a matter of writing separate computer programs to process the output from one model (e.g., river model) such that it forms the input to the subsequent model (e.g., reservoir model): a necessary, but straightforward task[3]. The end result is a model framework that can be used to examine individual reaches, or larger sections of the river and reservoir system.

A.2.2 Analyses

The system will be modeled for flow and water quality throughout the study area. Table 1 identifies the specific parameters that will be simulated in each reach. Physical, chemical, or biological information is unavailable or system response unknown in certain reaches. The selected models are capable of addressing these issues and can be used to test sensitivity of these processes and parameters as well as identify the need for additional data collection.

[3] This task was not funded, thus no formal software was developed to interface the models. Data transfer was done via spreadsheet manipulation.

Table 1 Water quality parameters selected for simulation in each reach of the study area, and selected model for sub-reach

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	SOD	Phyto-plankton	Attached Algae[2]	Model
Link R	●	●	●	●	●		TBD	●	RMA-2/11
Lake Ewauna/Keno	●	●	●	●	●	●	●		CE-QUAL-W2
Keno Dam to JC Boyle	●	●	●	●	●		TBD	●	RMA-2/11
JC Boyle	●	●	●	●	●	●	●		WQRRS[3]/ RMA-2/11
Bypass Reach	●	●	●	●	●			●	RMA-2/11
JC Boyle Full Flow Reach	●	●	●	●	●			●	RMA-2/11
Copco Reservoir	●	●	●	●	●	●	●		WQRRS[3]
Iron Gate Reservoir	●	●	●	●	●	●	●		WQRRS[3]
Klamath River below IGD	●	●	●	●	●			●	RMA-2/11

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Attached algae modeling will be completed if required to simulate system response. In some of the short reaches it may not be necessary

[3] Final model applied to these systems was CE-QUAL-W2 (Update: Change from original framework)

Other water quality processes may be represented as well, e.g., specific conductance.

A.3 Model Representations and Required Information

A brief description of each reach, modeling approach, data requirements, and additional field studies for all of the study reaches are outlined below. Much of the data required to implement, test, and calibrate/validate the model will come from existing data sets. Additional seasonal monitoring and multiple day synoptic surveys are planned to provide other necessary information.

A.3.1 Link River

The Link River reach extends 1.2 miles from Link Dam to Lake Ewauna. This short river reach has no tributaries and a moderate gradient. Flows are generally stable, but can vary over short time periods. Water quality in the reach is dominated by upstream Upper Klamath Lake conditions. The transit time is on the order of hours.

A.3.1.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

A.3.1.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Calibration/Validation Data

Model calibration and validation will use data from the Link River above Lake Ewauna site, as well as the appropriate powerhouse return flow. Boundary conditions and calibration/validation data are summarized in Table 2.

Table 2 Link River boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
Link Dam	H/D	H	H/D	G	G	G		Yes	No
Powerhouse #1 and #2[4]	H/D	H	H/D	G	G	G		Yes	No
Link R ab. Lake Ewauna	H/D	H	H/D	G				Yes[5]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response. Phytoplankton may be represented in this reach to reflect influx from Upper Klamath Lake.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] Powerhouse return flow quality will be estimated using Link Dam data

[5] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

A.3.1.3 Additional Field Studies

- Synoptic surveys to characterize conditions for model calibration and validation

A.3.2 Link River to Keno Dam

Lake Ewauna/Keno Reservoir are formed by Keno Dam. Lake Ewauna is a wide, relatively shallow body of water from about RM 251 to 253, while Keno reservoir is a narrower reach between RM 233 and 251. The impoundment is approximately 20 miles in length and served both as a supply and discharge point for municipal, industrial, and agricultural uses. This reach experiences a wide range of water quality conditions and is one of the more complex and least understood system in the study area.

A.3.2.1 Modeling Approach

Lake Ewauna/Keno Reservoir will be modeled with CE-QUAL-W2.

A.3.2.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- Bathymetric survey of reach (PacifiCorp)
- UTM or Lat/Long description of reach (USGS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), (USGS)

Initial Conditions

- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Calibration/Validation Data

Model calibration and validation will use data at a minimum of five locations within the study reach. Boundary conditions and calibration/validation data are summarized in Table 2.

A.3.2.3 Additional Field Studies

The US Bureau of Reclamation will be sampling Lake Ewauna and Keno Reservoir at two week intervals at roughly a dozen locations. It is expected that these data may be augmented with additional studies, possibly including sediment analysis and phytoplankton studies. These special studies are still under consideration.

Table 3 Lake Ewauna/Keno Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae	Other[2]	Boundary Condition	Cal/Val Site
Link R ab. Lake Ewauna	H/D	H	H	G	G	G		Yes	No
Municipal and Industrial Use	D							Yes	No
Municipal and Industrial Discharge	D	D	D	D				Yes	No
Agricultural Diversion	D							Yes	No
Agricultural Discharge	D	H/D	H/D	G				Yes	No
Lake Ewauna[3]	D	H	H	G		G			Yes
Miller Island	D	H	H	G		G			Yes
Teeters Landing	D	H	H	G		G			Yes
Additional sites[4]	D	H	H	G		G			Yes
Keno Dam	D	H	H	G		G		Yes[5]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Other water quality constituents may be represented as well, e.g., specific conductance.

[3] USBR has 3 sites in Lake Ewauna that may be used to support model applications

[4] USBR has several additional sites between Lake Ewauna and Keno Dam that may be used for model application

[5] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

A.3.3 Keno Dam to JC Boyle Reservoir

The Klamath River between Keno Dam and JC Boyle Reservoir is a characterized by a steep gradient with moderate to high velocities. This relatively short river reach has no major tributaries but experiences an undetermined, but probably small spring flow accretion. There are no major withdrawals or discharges into the reach. Although Keno Dam releases are relatively constant (essentially operated as a “run-of-river” facility), short-term fluctuations in flow are evident at times. Such fluctuations are due mainly to the effects of diversions from and return flows to Lake Ewauna/Keno Reservoir in response to irrigation operations.

The reach is dominated by upstream water quality. Further, the reach is relatively short, with transit time being well under one day. Although the diurnal range of temperature and dissolved oxygen is somewhat moderated by releases from Keno Reservoir, by the time water reaches the end of this reach there is a diurnal signal is observable. Overall, little is known about the water quality response of this reach.

A.3.3.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

A.3.3.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Validation Data

Calibration and validation of the model will be completed using data from the site above JC Boyle Reservoir. Boundary conditions and calibration/validation data are summarized in Table 4.

Table 4 Keno Dam to JC Boyle Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
Keno Dam	H	H	H	G	G	G		Yes	No
Accretions	D/W	D/G	G	G	G*	G*		Yes	No
KR above JC Boyle	H	H	H	G				Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

A.3.3.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each): to characterize short-term variability in the reach and for model calibration and validation
    - continuously monitoring probes (physical parameters - hourly) at the top and bottom of reach
    - grab samples 2 times once day for three days at the top and bottom of reach to coincide with the continuously monitoring probe deployment
- field reconnaissance to identify potential spring flow accretion location, quantity and quality

A.3.4 JC Boyle Reservoir

The J.C. Boyle reservoir reach includes the portion of the mainstem Klamath River from J.C. Boyle dam (RM 224.7) to the upper end of the J.C. Boyle reservoir (RM 228) near the mouth of Spencer Creek. The reservoir is relatively shallow and typically experiences a short residence time and is prone to weak stratification.

A.3.4.1 Modeling Approach

This reach can be modeled in two ways. It can be represented in WQRRS as a weakly stratified to mixed reservoir system. It also can be modeled as a slow deep river using the river models RMA-2 (flow) and RMA-11 (water quality). Both approaches will be explored to potentially investigate both longitudinal and vertical characteristics of the water body. (Ultimately CE-QUAL-W2 was the selected model for this application. This is an update: Change from original framework.)

A.3.4.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- Bathymetric survey of reach (PacifiCorp)
- UTM or Lat/Long description of reach (USGS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), (USGS)

Initial Conditions

- initial reservoir stage
- initial water quality profile
- initial organic sediment mass
- for river models, initial condition will be developed using the models

Boundary Conditions and Validation Data

For WQRRS calibration and validation will utilize data from the vertical profile site JC Boyle Dam. If the river models are implemented, data from synoptic surveys (to be completed) will be necessary. Both models would be calibrated to effectively simulate outflow conditions as well. Boundary conditions and calibration/validation data are summarized in Table 5.

Table 5 JC Boyle Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae	Other[2]	Boundary Condition	Cal/Val Site
KR above JC Boyle	H	H	H	G	G	G		Yes[3]	No
JC Boyle Reservoir Profile/Synoptic	D	H/M (P)	M (P)	M (2 Depths)	M (2 Depths)	M (2 Depths)		No	Yes
JC Boyle Release (below Boyle)	H/D	H/D	G	G	G	G		Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Other water quality constituents may be represented as well, e.g., specific conductance.

[3] Shovel Creek and other accretions may be combined with Klamath River above JC Boyle

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly, M(P) refers to a monthly profile

G – Grab sample (frequency varies from sub-daily to monthly)

A.3.4.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each): to characterize short-term variability in the reach and for model calibration and validation
    - continuously monitoring probes (physical parameters) at the headwaters and in the reservoir release
    - monitor vertical profiles of temperature, dissolved oxygen, pH, specific conductance, and oxidation-reduction potential (ORP) at two intermediate points in the reservoir twice per day
    - grab samples 1 time per day for 3 days at the headwaters and in the reservoir release, as well as two intermediate points (coincident with the above noted profiles). These grab samples should occur at two depths in the reservoir, corresponding to roughly 1meter deep and 1 meter off the bottom.
    - algal species identification
- sediment sampling to determine sediment oxygen demand (SOD) and possibly nutrient release. One set of samples (cores) during the summer season
- collect samples to identify algal species
- field reconnaissance to quantify potential accretions and depletions to/from reservoir (e.g., Spencer Creek)

A.3.5 JC Boyle Bypass Reach

The JC Boyle bypass reach is 4.3 miles long, extending from JC Boyle Dam to the JC Boyle Powerhouse. Minimum FERC releases from JC Boyle dam are 100 cfs. Although

there are no major tributaries, there are significant spring flow accretions. The reach is steep and transit time appears to be on the order of hours. Spring flow accretion quantity and quality, as well as location are under represented in available data.

A.3.5.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

A.3.5.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Validation Data

Calibration and validation of the model will be completed using data from the site above JC Boyle penstock return. Boundary conditions and calibration/validation data are summarized in Table 6.

A.3.5.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each): to characterize short-term variability in the reach and for model calibration and validation
    - continuously monitoring probes (physical parameters - hourly) at the top and bottom of reach
    - grab samples 1 time per day for at the top and bottom of reach to coincide with the continuously monitoring probe deployment
- field reconnaissance to locate spring inflow locations and to collect representative water quality samples
- estimate spring inflow quantity in bypass reach

Table 6 JC Boyle Dam to penstock return (bypass reach) boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
JC Boyle Release to KR	H/D	H/D	G	G	G	G		Yes	No
Accretions	D	D/G	G	G	G	G		Yes	No
KR above Penstock Return	H/D	H	H	G	G	G		Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

A.3.6 JC Boyle Full Flow[4] Reach

The JC Boyle bypass reach is 16.4 miles long, extending from JC Boyle penstock return to the Copco Reservoir. During peaking periods flow rates vary on a subdaily basis between about 350 cfs (inflow from the bypass reach) to approximately 3000 cfs. Several small tributaries occur in this reach, the largest of which is Shovel Creek. The reach is steep and experiences a highly dynamic flow regime. The transit time is typically less than a day.

A.3.6.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

A.3.6.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)
- Brazie Ranch (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)

[4] This is now referred to as the Peaking Reach

- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Validation Data

Calibration and validation of the model will be completed using data from the site at Klamath River above Shovel Creek and an intermediate location between Shovel Creek and the penstock return (to be determined). Boundary conditions and calibration/validation data are summarized in Table 7.

Table 7 JC Boyle Dam penstock return to Copco Reservoir (full flow reach) boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
KR above Penstock Return	H/D	H	H	G	G	G		Yes	No
Penstock Return	H	H	H	G	G	G		Yes	No
Intermediate Location TBD		H	H	G	G	G		No	Yes
KR ab Shovel Ck	H	H	H	G	G	G		Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

A.3.6.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each):
  - continuously monitoring probes (physical parameters - hourly) at top, middle, and bottom of reach
  - grab samples 2 times per day at top, middle, and bottom of reach to coincide with the continuously monitoring probe deployment locations. Ideally, samples to be collected prior to peaking and after full flows occur.
  - monitor Shovel Creek and any other identified accretions that are deemed significant for temperature (logger) and one grab sample per day

- field reconnaissance to characterize river reach (cross section and slope), identify potential accretions (location and quantity), examine benthic algae conditions, and to locate intermediate sampling point for calibration and validation
- field studies to examine benthic algae conditions for model representation
- additional full meteorological station (Copco Village)

A.3.7 Copco Reservoir

Copco Reservoir is 5.4 miles long with a storage capacity of 46,867 acre-feet[5]. The reservoir has a residence time that ranges from two weeks to a month at typical summer flows and is subject to thermal stratification. Reservoir inflow, other than the Klamath River, is restricted to minor tributaries and spring flows.

A.3.7.1 Modeling Approach

The reservoir will be modeled with WQRRS. (Ultimately, CE-QUAL-W2 was the selected model for this application. This is an update: Change from original framework.)

A.3.7.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)
- Brazie Ranch (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)

Geometry

- Bathymetric survey of reach (PacifiCorp)
- UTM or Lat/Long description of reach (USGS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), (USGS)

Initial Conditions

- initial reservoir stage
- initial water quality profile
- initial organic sediment mass
- for river models, initial condition will be developed using the models

Boundary Conditions and Validation Data

For WQRRS calibration and validation will utilize data from the vertical profile site near Copco Dam. The model will be calibrated to effectively simulate outflow conditions as well. Boundary conditions and calibration/validation data are summarized in Table 8.

A.3.7.3 Additional Field Studies

- synoptic water quality study (3 times – one day each): to characterize longitudinal variability in reservoir
    - monitor vertical profiles of temperature, dissolved oxygen, pH, specific conductance, and oxidation-reduction potential (ORP) at a minimum of three points in the reservoir.

[5] Updated Copco Reservoir bathymetric surveys completed in 2001 identified that actual reservoir storage is approximately 40,000 acre-feet.

  - grab samples at above locations. The grab samples should occur at two or three depths in the reservoir, depending on total reservoir depth and thermal profile
  - algal species identification (sample each day at all three sites)
- sediment sampling to determine sediment oxygen demand (SOD) and nutrient release. One set of samples (cores) during the summer season.
- collect samples to identify algal species (monthly at dam site)
- field reconnaissance to quantify potential accretions and depletions to/from reservoir (e.g., springs)
- additional full meteorological station (Copco Village)

Table 8 Copco Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae	Other[2]	Boundary Condition	Cal/Val Site
KR ab Shovel Ck	H/D	H/D	H/D	G	G	G	Synoptic	Yes	No
Copco Reservoir Profile	H/D	H/M (P)	M(P)	M (3 Depths)	M (3 Depths)	M (3 Depths)	Sediment Algae species	No	Yes
Copco Release (below Copco)	H/D	H/D	G	G	G	G		Yes[3]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Other water quality constituents may be represented as well, e.g., specific conductance.

[3] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

A.3.8 Iron Gate Reservoir

Iron Gate Reservoir is 7 miles long with a storage capacity of approximately 58,000 acre-feet. Iron Gate Reservoir acts as a reregulating reservoir for Copco Reservoir hydropower releases. The reservoir has a residence time that ranges from three weeks to over a month at typical summer flows and is subject to thermal stratification. Reservoir inflow, other than the Klamath River, is restricted to minor tributaries and spring flows.

A.3.8.1 Modeling Approach

The reservoir will be modeled with WQRRS. (Ultimately, CE-QUAL-W2 was the selected model for this application. This is an update: Change from original framework.)

A.3.8.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)
- Brazie Ranch (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)

Geometry

- Bathymetric survey of reach (PacifiCorp)
- UTM or Lat/Long description of reach (USGS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), (USGS)

Initial Conditions

- initial reservoir stage
- initial water quality profile
- initial organic sediment mass
- for river models, initial condition will be developed using the models

Boundary Conditions and Validation Data

For WQRRS calibration and validation will utilize data from the vertical profile site near Iron Gate Dam. The model will be calibrated to effectively simulate outflow conditions as well. Boundary conditions and calibration/validation data are summarized in Table 9.

Table 9 Iron Gate Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae	Other[2]	Boundary Condition	Cal/Val Site
Copco Release (below Copco)	H/D	H/D	G	G	G	G		Yes	Yes
Iron Gate Reservoir Profile	H/D	H/M (P)	M (P)	M (3 Depths)	M (3 Depths)	M (3 Depths)	Sediment Algae	No	Yes
Iron Gate Release to KR (below IG)	H/D	H/D	G	G	G	G		Yes[3]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Other water quality constituents may be represented as well, e.g., specific conductance.

[3] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

A.3.8.3 Additional Field Studies

- synoptic water quality study (3 times – one day each): to characterize longitudinal variability in reservoir
  - monitor vertical profiles of temperature, dissolved oxygen, pH, specific conductance, and oxidation-reduction potential (ORP) at a minimum of three points in the reservoir.

    - grab samples at above locations. The grab samples should occur at two or three depths in the reservoir depending on total depth and thermal structure
    - algal species identification
- sediment sampling to determine sediment oxygen demand (SOD) and nutrient release. One set of samples (cores) during the summer season.
- collect samples to identify algal species
- more completely represent fish hatchery operations
- additional full meteorological station (Iron Gate Dam or Copco Village)

A.3.9 Klamath River below Iron Gate Dam

The Klamath River below Iron Gate Dam is regulated by upstream reservoir operations. Major tributaries downstream of the dam include the Shasta and Scott River. The reach is moderate to steep and experiences stable flow regime. The transit time between Iron Gate Dam (RM 190) and Seiad Valley (RM 129) during summer flow conditions ranges from one to two days.

A.3.9.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

A.3.9.2 Data Requirements

Meteorological Conditions

- Brazie Ranch (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Validation Data

Calibration and validation of the model will be completed using data from the site at Klamath River above Shasta River and near Seiad Valley, and possibly an additional intermediate location (to be determined). Boundary conditions and calibration/validation data are summarized in Table 10.

A.3.9.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each):): to characterize short-term variability in the reach and for model calibration and validation
    - continuously monitoring probes (physical parameters - hourly) at top and bottom of reach, as well as up to two intermediate locations (above Shasta River and one site to be determined)

  - grab samples one time per day at top, middle, and bottom of reach to coincide with the continuously monitoring probe deployment
  - monitor Shasta River and any other identified tributaries and accretions that are deemed significant for temperature (logger) and one grab sample per day
- field studies to examine benthic algae conditions for model representation
- additional full meteorological station (Iron Gate Dam)

Table 10 Below Iron Gate Dam to Seiad Valley boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
Iron Gate Release to KR (below IG)	H/D	H/D	H	G	G			Yes	No
KR above Shasta River		H	H	G	G			No	Yes
Shasta River inflow	H/D	H/D	H/D	G	G			Yes	No
Scott River inflow	H/D	H/D	H/D	G	G			Yes	No
Seiad Valley	H/D	H	H	G	G			Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

B Model Descriptions

B.1 CE-QUAL-W2

CE-QUAL-W2 (v3.1) is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. The model has been applied to rivers, lakes, reservoirs, and estuaries.

The model predicts water surface elevations, velocities, and temperatures. Temperature is included in the hydrodynamic calculations because of its effect on water density. The water quality algorithms incorporate 21 constituents in addition to temperature including nutrient/phytoplankton/dissolved oxygen (DO) interactions during anoxic conditions. Any combination of constituents can be simulated. Selective relationships pertinent to this application are shown in Figure 1. The effects of salinity or total dissolved solids/salinity on density and thus hydrodynamics are included only if they are simulated in the water quality module. The water quality algorithm is modular, allowing constituents to be easily added as additional subroutines. Selective withdrawal, the representations of internal curtains and weirs, and other features of this model allow the assessment of a wide range of configurations.

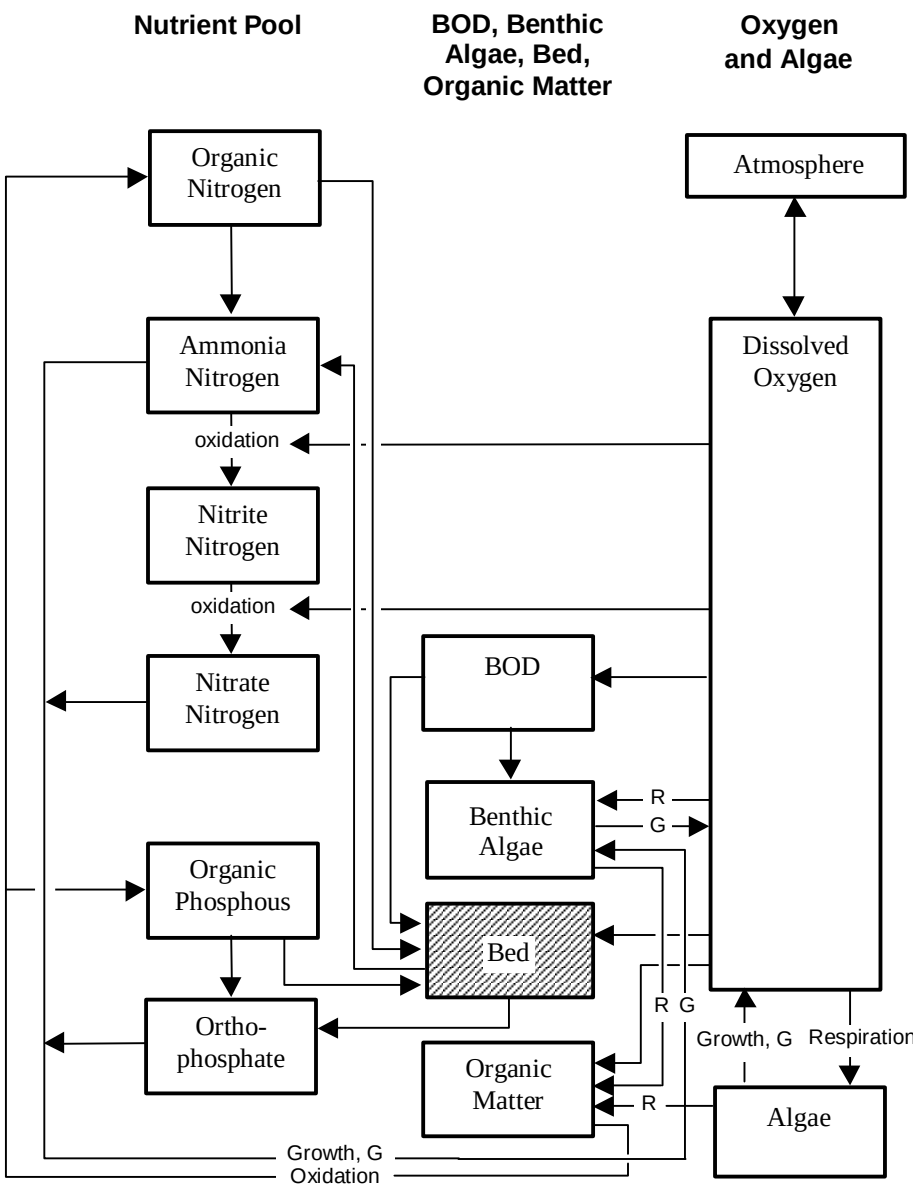


Figure 1. Selected water quality relationships for CE-QUAL-W2

B.2 RMA Models: Hydrodynamics and Water Quality

As with a handful of other numerical models, RMA-2 solves the full flow equations known as the St. Venant Equations, also called the shallow water equations. These equations utilize all terms of the conservation of momentum formulation and provide the most complete description of dynamic flow conditions. Several features of this model that make it a particularly useful tool for the Klamath River include:

- the model is a finite element model and the space-time criteria (e.g., Peclet number) for stability in the numerical solution of the governing equations is a necessary consideration
- the model has an option to represent steep river systems without utilizing unrealistic bed roughness parameters. This steep river system formulation is

critical in representing proper transit times, which is paramount to modeling water quality

- the model has been widely applied (it is one of the most used full hydrodynamic model in the United States) to a variety of river and estuary systems in the United States as well as internationally. The model author is available for support.

RMA-11 solves the advection-diffusion equation to determine the fate and transport of up to 16 constituents. Selected process pertinent to this application are illustrated in Figure 2. The water quality algorithm is modular allowing constituents to be added. Other features include:

- the model interfaces directly with the geometry and output of RMA-2
- all standard water quality routines are from QUAL2E. These routines have been tested and reviewed for completeness and correctness
- Additional processes have been added to the model to simulate attached algae

The RMA-2 and RMA-11 Combination

Fundamental to effectively modeling water quality is the proper representation of the flow regime (hydrodynamics). The two models RMA-2 and RMA-11 provide a complete hydrodynamic model with a comprehensive water quality model, creating a powerful tool for assessing flow and water quality response in complex river systems. Although this model resides in the private sector, the source code is supplied with the executable when purchased. That is, these are open codes (as opposed to many proprietary codes where the source code is unavailable to the user). Further, many of the model applications have occurred in the public sector (government agencies, universities, etc.) and the RMA-2 code has undergone intensive peer review.

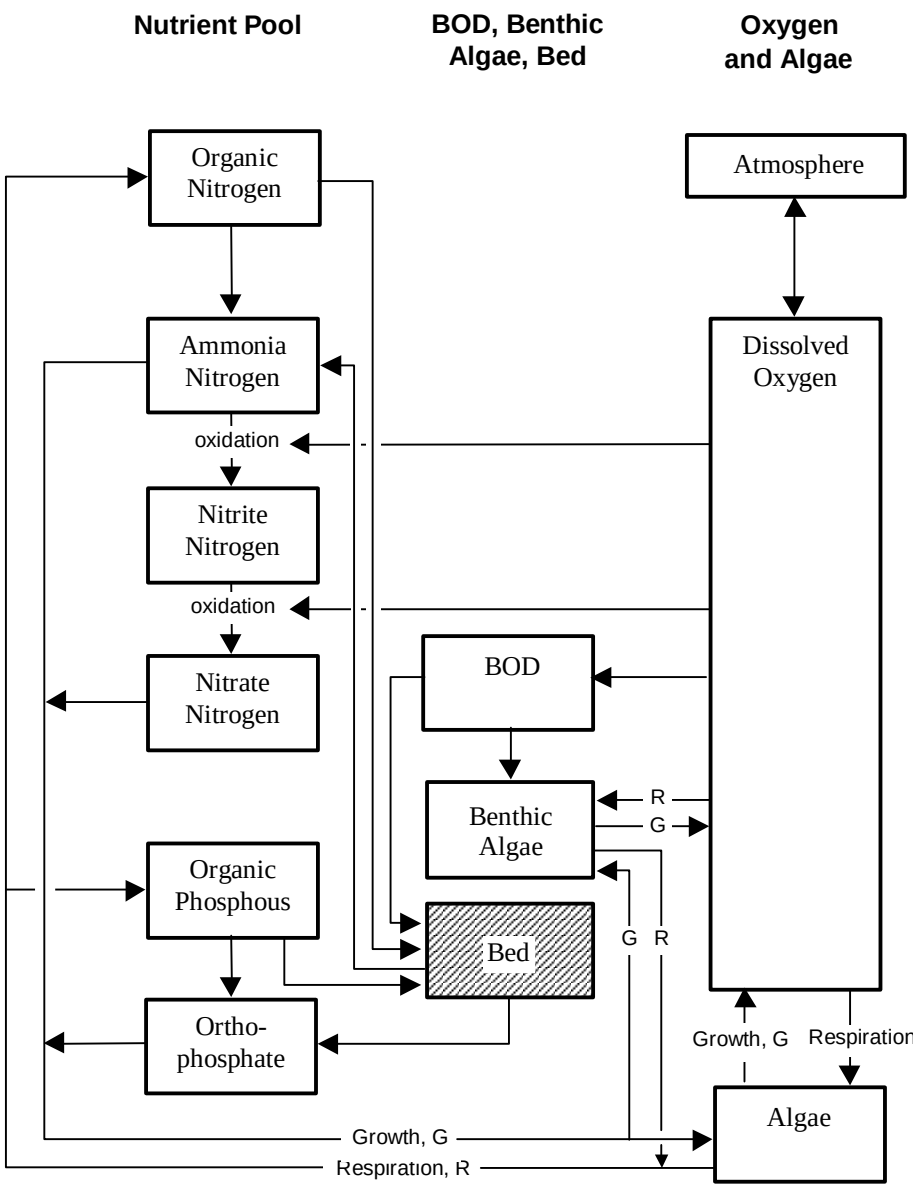


Figure 2. Selected water quality relationships for RMA-11

B.3 WQRRS (Reservoir Module)[6]

The model WQRRS is an Army Corps of Engineers river and reservoir system model, but the river and reservoir modules can be modeled separately. For this application the reservoir module is applied. Some of the attributes that are unique to WQRRS include the fact that is essentially an ecological model, representing not only water quality but also trophic levels from primary production, zooplankton predation, up to fish. Although all these processes are not deemed necessary for this application, because of its more comprehensive treatment of primary production it allows more flexibility, (e.g., benthic

[6] The WQRRS model was replaced with CE-QUAL-W2 at JC Boyle, Iron Gate, and Copco Reservoirs.

algae and phytoplankton, two species of phytoplankton, grazing by zooplankton). Further, the model readily allows for the simulation of selective withdrawal. The model has a few modifications/updates that may be pertinent to the Klamath River mainstem reservoirs, including

1) sediment nutrient release dynamics for ammonia and phosphorous
2) the ability of the analyst to examine the impacts of hypolimnetic oxygenation
3) seasonal evaporation coefficients

B.4 Interfacing the Models

Modeling the Klamath River reaches and reservoirs would require use of different models for reservoir and river reaches. The process of interfacing or linking the models is a matter of writing separate computer programs to process the output from one model (e.g., river model) such that it forms the input to the subsequent model (e.g., reservoir model). A necessary, but straightforward task. The end result is a model framework that can be used to examine individual reaches, or larger sections of the river and reservoir system.

B.5 Model Contact Information

B.5.1 CEQUAL-W2

U.S. Army Corps of Engineers, Waterways Experiment Station
Environmental Laboratory
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180
Contact: Thomas M. Cole(tcole@lasher.wes.army.mil)

B.5.2 RMA-2/RMA-11

Resource Management Associates PTY LTD
9 Dumaresq Street
Gordon
NSW 2071
Contact: Dr. Ian King (I.King@UNSW.EDU.AU)

B.5.3 WQRRS: Water Quality for River-Reservoir Systems

US Army Corps of Engineers – Hydrologic Engineering Center
609 2nd Street
Davis, CA 95616
Contact: none

C River Geometry

C.1 River Location Description

The x-y coordinates describing the river location were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill. The coordinates provided were Eastings and Northings in the UTM Zone 10 NAD 83 projection (meters) rather than in degrees/minutes/seconds. The USGS hydro coverage did not cover the reservoirs in the upper basin, these were digitized by CH2M Hill. A centerline was used to depict the line of the river through the reservoirs. The dataset provided by CH2M Hill had and a length of 257.08 river miles (from Link Dam to the mouth) and coordinates that were irregularly spaced. This data set was processed using a program called “Make River” that uses linear interpolation to produce an evenly spaced set of coordinates, and consequently shortens the river slightly. The coordinates were processed to 150-meter intervals, with a new river length 253.88 miles. This corresponded more closely with the most commonly used river mile index developed by the USGS. Once completed, this geometry was used to define the individual reaches as well as the description of the “without project” scenario.

D Flow Data

D.1 Tributaries from Iron Gate Dam to Turwar

Accretions from Iron Gate Dam to Turwar were defined and quantified according to the methodology identified by USGS (1995, 1997). In sum, the river was divided into multiple segments (reaches) based on available gages with full coverage between 1961 and 1922. USGS used monthly averages to determine accretions and depletions for each reach based on the differences in gage readings. These accretions and depletions were then assigned to individual tributaries based on estimated basin area (individual sub-basin contributions were obtained from personal communication with Mr. M. Flug). Not all tributaries to the Klamath River were included.

For this exercise, 7-day average values were used to identify accretions and depletions for identified tributaries. The same tributaries identified by USGS (1997) were used herein. The methodology is outlined below.

Total Accretion from Iron Gate Dam to Seiad Valley. Accretion value is equal to the flow at gage 11520500 (Klamath River nr. Seiad Valley) minus the sum of the flows at gages 11516530 (KR below Iron Gate Dam), 11517500 (Shasta River nr. Yreka), 11519500 (Scott River nr Fort Jones). This reach accretion is further sub-divided into shorter sub-reaches by according to the following criteria.

- <u>Klamath River from Iron Gate Dam to the confluence of the Shasta River</u>.
  Accretion equals 24.2% of the total area accretion.
  - This accretion is distributed between the following creeks as determined by watershed area:
    - Bogus Creek – 41%
    - Willow Creek – 22%
    - Cottonwood Creek – 37%
- <u>Klamath River from the confluence of the Shasta River to the confluence of the Scott River</u>.
  Accretion equals 38.2% of the total area accretion.
  - This accretion is distributed between the following creeks as determined by watershed area:
    - Humbug Creek – 28%
    - Beaver Creek – 32%
    - Horse Creek – 40%
- <u>Scott River from Ft. Jones to the confluence of the Klamath River</u>.
  Accretion equals 29.0% of the total area accretion.
- <u>Klamath River from the confluence of the Scott River to Seiad valley</u>.
  Accretion equals 8.6% of the total area accretion. This accretion is applied at Grider Creek.

Total Accretion from Klamath River from Seiad Valley to Orleans. Accretion equals the flow at gage 11523000 (Klamath River at Orleans) minus the sum of the

flows at gages 11520500 (Klamath River nr Seiad Valley), 11522500 (Salmon River at Somes Bar, Ca), and 11521500 (Indian Cr nr Happy Camp).

This accretion is distributed between the following creeks as determined by watershed area:

Thompson Creek – 16.6%
Elk Creek – 16.6%
Clear Creek – 21.4%
Ukonom Creek – 12.9%
Dillon Creek – 32.5%

Total Accretion from Klamath River from Orleans to the Mouth. Accretion equals gage 15530500 (KR nr Klamath (Turwar), CA) minus gage 15523000 (KR at Orleans) and 11530000 (Trinity River at Hoopa).

Klamath River from Orleans to the confluence of the Trinity River.
Accretion equals 29.3% of the total area accretion.

This accretion is distributed between the following creeks as determined by watershed area:

Camp Creek – 33.3%
Red Cap Creek – 33.3%
Bluff Creek – 33.3%

Trinity River from Hoopa to the confluence with the Klamath River.
Accretion equals 12.3% of the total area accretion.

Klamath River from the confluence of the Trinity River to the mouth.
Accretion equals 58.4% of total area accretion.

This accretion is distributed between the following creeks as determined by watershed area:

Pine Creek – 33.3%
Tectah Creek – 33.3%
Blue Creek – 33.3%

E Meteorological Data

The required hourly information for the meteorological input file consists of: air temperature (^oC), dew point temperature (^oC), wind speed (m/s), wind direction (radians), cloud cover (scale 0-10) and solar radiation (W/m^2). The Agrimet station located in Klamath Falls, Oregon, (KFLO) provided all of these parameters except for cloud cover. Wind speed and wind direction had to be converted to the units consistent with model requirements. The station provided hourly cumulative solar radiation. The difference between the cumulative solar radiation at each hour was determined and converted to the necessary units. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. This ratio was then converted to the appropriate scale for input into the model. It should be noted that this scale, from 0-10 is different from the scale required for RMA modeling, which is a scale from 0-1. Both sets of cloud cover were calculated from the same solar radiation data. Atmospheric pressure was unavailable, and was calculated based on elevation and a constant sea level pressure of 1013 mb.

Klamath Falls data was used throughout the modeling domain, i.e., from Link Dam (RM 255) to the mouth (RM 0) because it was the most complete and consistently avaiable record. However, it is clear that atmospheric conditions vary appreciably throughout the study reach due to elevation, orographic features, proximity to the Pacific Ocean, and the shear size of the study area. Meteorological observations within the basin are limited and non-uniformly distributed. Further, available parameters vary among stations. To overcome some of the challenges with representing meteorological conditions system-wide, PacifiCorp installed two additional weather stations (at Iron Gate Dam and Copco Village) to gather additional information within the project area. These stations, coupled with the station at Klamath Falls, the station maintained by the Yurok Tribe at Weitchpec, and observation locations in the Shasta Valley (National Weather Service at Montague and California Department of Forestry at Brazie Ranch) were examined to determine meteorological variability throughout the basin and, to the extent feasible, adjust parameters to more fully represent local conditions.

Klamath Falls (KFLO) meteorological data was used directly for the following reaches

- Link River
- Lake Ewauna to Keno Dam
- Klamath River from Keno Dam to JC Boyel Reservoir
- JC Boyle Reservoir
- JC Boyle Dam to Copco Reservoir

The only variations herein included modifying atmospheric pressure for elevation. Adjustment to meteorological parameters for Copco and Iron Gate Reservoirs, as well as the Klamath River reach from Iron Gate Dam to the mouth are presented below.

E.1 Copco and Iron Gate Reservoirs

Because Copco and Iron Gate Reservoir are roughly 1500 feet and 1700 feet, respectively, lower than Klamath Falls, the air temperature was adjusted to accommodate for the change in elevation. A lapse rate of 3.0 °C, based on data from Klamath Falls and a meteorological station at Iron Gate Dam. Air temperature was adjusted according to the following formula, based on Linacre (1992).

$$T_1 = T_2 + 0.003h \qquad (1)$$

Where: T1 = temperature at site 1
T2 = temperature at site 2
h = $E_2 - E_1$, meters
E_1 = Elevation of site 1
E_2 = Elevation of site 2

For the purposes of this study an average elevation of Copco and Iron Gate Reservoirs was applied (2450 ft (746.77 m)). Field data did not suggest any additional relationships between the Klamath Falls and Iron Gate Reservoir site. Thus, the remaining meteorological parameters from the KFLO station were not modified.

E.2 Meteorological Conditions below Iron Gate Dam

A review of available meteorological data at multiple locations in the Klamath River basin suggests variable meteorological conditions throughout the study area. Meteorological data are available in various forms, formats, frequencies, and for selected parameters at the several meteorological stations in the basin. Six stations were identified for meteorological data comparison and assessment for the 2002 field season (Table 1).

Table 11 Inventory of full meteorological stations located within the project area.

Station Name	Agency	Installation Date	Parameters	Elevation (ft)	Lat/Long
Klamath Falls	U.S. Bureau of Reclamation	3/31/99-present	S,W,Ta,P, RH,DP	4100	42°01' 53"N 121°45' 18"W
Copco Reservoir	PacifiCorp	6/7/02-present	S,W,Ta,P, RH,DP	2625 (approx)	n/a
Iron Gate Reservoir	PacifiCorp	6/7/02-present	S,W,Ta,P, RH,DP	2350 (approx)	n/a
Brazie Ranch	California Dept. of Forestry	1995/2000-present	S,W,Ta,RH	3020	41.6870N 122.6000W
Montague	National Weather Service	1930-present*	W,Ta,RH, DP,P	2518.4	41°44'N 122°33'W
Weitchpec	Yurok Tribe	2/11/02-present	S,W,Ta,RH,DP, P	300 (approx)	

* Data not archived until 2001. Sub-daily data not available prior to April 2001.
S – Solar Radiation
W – Wind Speed
Ta – Air temperature
P – Atmospheric pressure
RH – Relative humidity
DP – Dew point temperature

As illustrated in Table 1, meteorological monitoring is not consistent and the records are not particularly long. To include as many years as possible for analysis, Klamath Falls (KFLO) was used as the base data set, providing 3 full years of meteorological data. This data set was then compared with available records for 2002 to determine if there were clear relationships between Klamath Falls and the middle and lower Klamath basin regions. Common parameters used for comparison included air temperature (dry bulb), dew point temperature, and wind speed.

E.2.1 Air Temperature

Monthly mean air temperature was compared at each site from May through December (Figure 1). Lapse rates from Linacre (1992) were on the order of 6°C per 1000 meters of elevation change. Based on the available data, this rate of change appeared excessive. A lapse rate of 3°C per 1000 meters of elevation change was selected as a maximum.

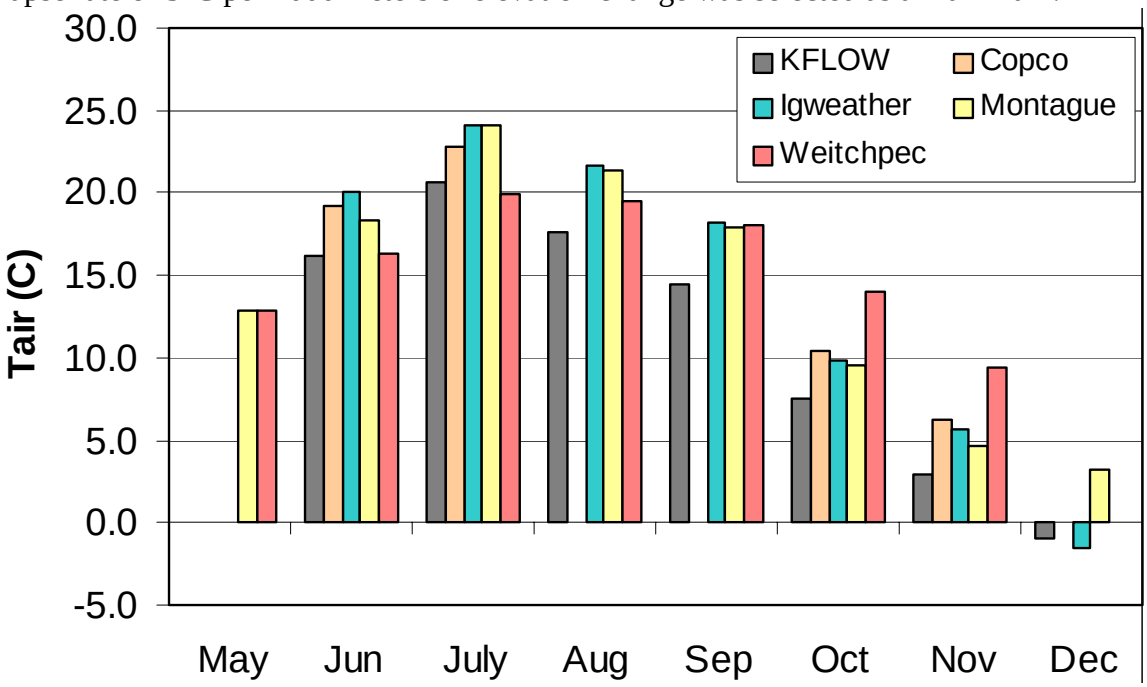


Figure 1 Air temperature at five locations in the Klamath Basin

The lapse rate for air temperature varied seasonally. The higher elevations around Klamath Falls (elevation >4000 ft) experience cold winters and relatively mild summer air temperatures. The coastal area experiences cool winters, with few days below freezing, and mild summers, similar to those found around Klamath Falls, followed by warm fall conditions. Finally the middle Klamath Basin experiences cold winters, hot summer, and warm fall conditions. The corrections based on the identified lapse rates are shown in Table 2.

Table 12 Air temperature corrections, based on month for Klamath River temperature modeling

Month	Correction: Klamath Falls (°C)	Correction: Iron Gate to Orleans (°C)	Correction: Orleans to Turwar (°C)
January	0.0	0.0	3.5
February	0.0	0.0	3.5
March	0.0	0.0	2.5
April	0.0	2.5	1.5
May	0.0	2.5	0.5
June	0.0	2.5	0.0
July	0.0	2.5	0.0
August	0.0	2.5	0.5
September	0.0	2.5	1.5
October	0.0	2.5	2.5
November	0.0	2.5	3.5
December	0.0	0.0	3.5
Positive corrections are added to the KFLO data to arrive at local conditions			

E.2.2 Dew Point

Monthly mean dew point temperature was compared at each site from May through December (Figure 2). Although most locations were quite similar, Weitchpec showed a marked deviation.

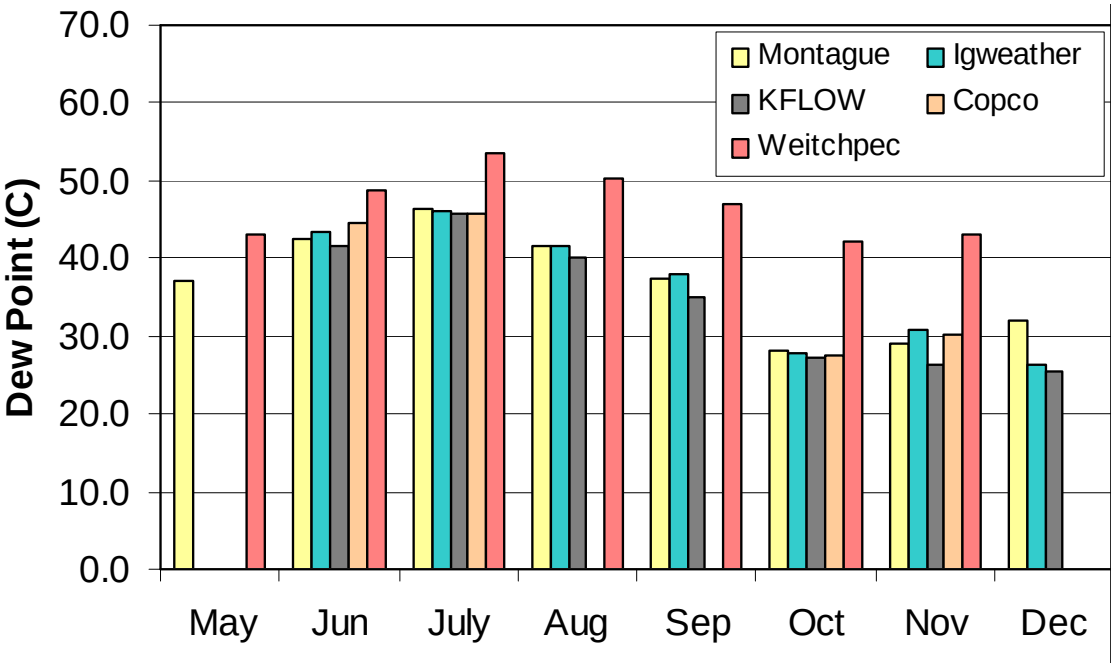


Figure 2 Dew point temperature at five locations in the Klamath Basin

A lapse rate of 6.9°C per 1000 meters of elevation change was selected as a maximum for dew point temperature. This lapse rate was only applied to the lower river region –

below Orleans. Further the correction was applied seasonally as shown in Table 3. Dew Point temperatures were used to determine wet bulb temperatures for use in the model.

Table 13 Dew point temperature corrections, based on month for Klamath River temperature modeling

Month	Correction: Klamath Falls (°C)	Correction: Copco and Iron Gate Res. (°C)	Correction: Iron Gate to Orleans (°C)	Correction: Orleans to Turwar (°C)
January	0.0	0.0	0.0	8.0
February	0.0	0.0	0.0	8.0
March	0.0	0.0	0.0	8.0
April	0.0	0.0	0.0	8.0
May	0.0	0.0	0.0	5.5
June	0.0	0.0	0.0	4.0
July	0.0	0.0	0.0	4.0
August	0.0	0.0	0.0	5.5
September	0.0	0.0	0.0	5.5
October	0.0	0.0	0.0	8.0
November	0.0	0.0	0.0	8.0
December	0.0	0.0	0.0	8.0
Positive corrections are added to the KFLO data to arrive at local conditions				

E.2.3 Wind Speed

Monthly mean wind speed was compared at each site from May through December (Figure 3).

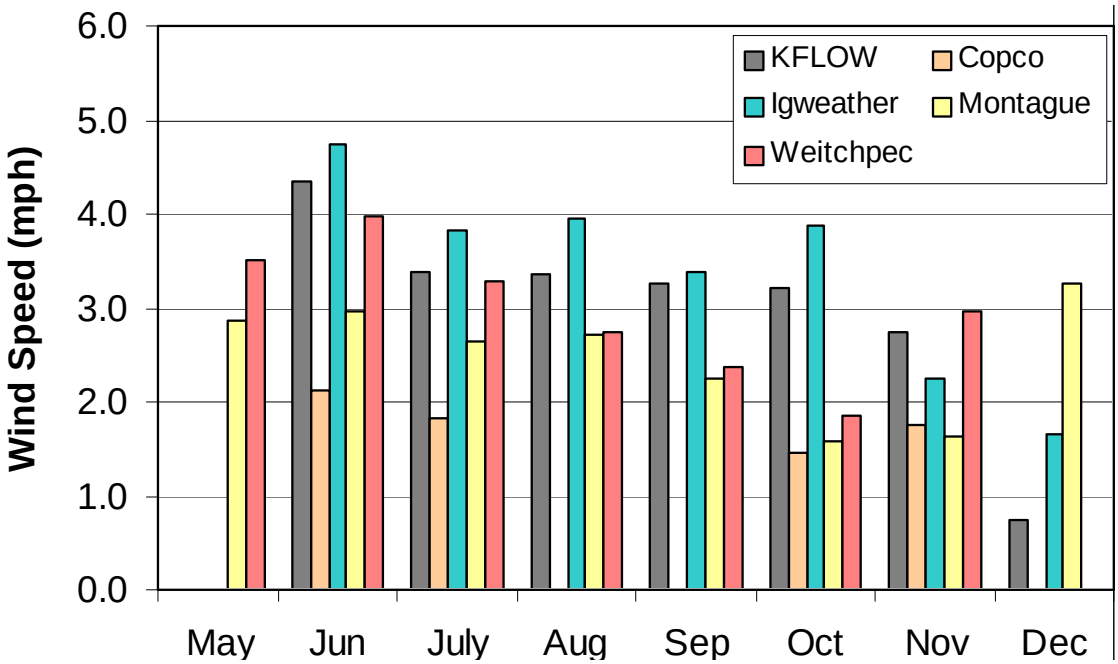


Figure 3 Wind speed at five locations in the Klamath Basin

Although seasonal variations are apparent in the mean monthly data, there was no clear trend (with the exception of Copco Reservoir, which due to a short record was not adjusted) or methods to make adjustments to wind. All sites utilized the KFLO wind data.

E.2.4 Atmospheric Pressure

Atmospheric pressure was corrected for elevation or calculated based on elevation.

E.2.5 Solar Radiation

Solar Radiation from Klamath Falls was used at all locations.

E.2.6 Summary

Based on air temperature the basin was divided into three meteorological "regions" (Figure 4). The upper basin extends from Link Dam to Copco Reservoir and utilizes Klamath Falls meteorological data. The middle region extends from Iron Gate Dam to Orleans The lower region, from Orleans to Turwar. Each reach is summarized below, data are summarized in Table 4.

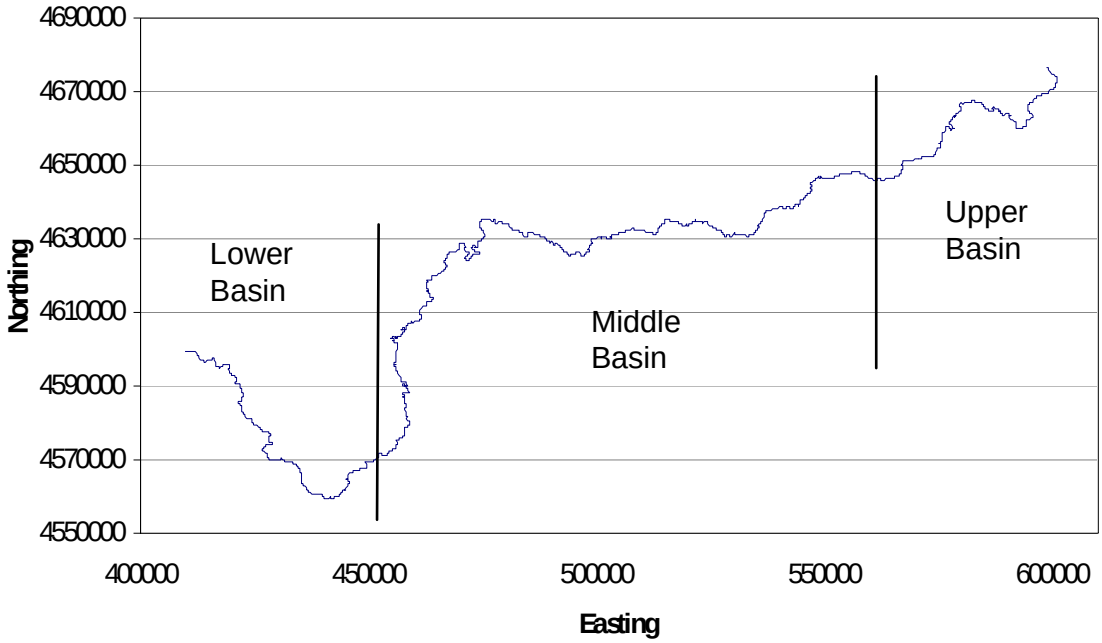


Figure 4 Meterological regions in the study area.

<u>Iron Gate Dam to Orleans</u>

The Klamath River from Iron Gate Dam to Orleans was modeled with RMA-11 for water temperature. The meteorological data set used for these models was based on KFLO data with the air temperature and atmospheric pressure corrected for elevation difference based on an elevation of 1320 at Seiad Valley. No modification was made to dew point temperatures, wind speed, or solar radiation. Dew point was converted to wet bulb temperatures for use in RMA-11.

Orleans to Turwar

The Klamath River from Orleans to Turwar was modeled with RMA-11 for water temperature. The meteorological data set used for these models was based on KFLO data with the air temperature, dew point, and atmospheric pressure corrected for elevation difference based on an elevation of 300 ft near the Trinity River. No modification was made to wind speed, or solar radiation. Dew point was converted to wet bulb temperatures for use in RMA-11.

Table 14 Meteorological Data used in model simulations

Location	Representative Elevation	Solar	Tair	Dew Point	Wind Speed	Barometric Pressure
Upper Basin	Klamath Falls	KFLO	KFLO	KFLO	KFLO	f(elevation)
Middle Basin*	Seiad Valley and Copco/Iron Gate*	KFLO	KFLO Corrected[1]	KFLO	KFLO	f(elevation)
Lower Basin	Weitchpec	KFLO	KFLO Corrected[2]	KFLO Corrected[3]	KFLO	f(elevation)

[1] Lapse Rate of 3.0°C per 1000 m of elevation change: April 1-Dec. 1

[2] Lapse Rate of 3.0°C per 1000 m of elevation change: seasonally

[3] Lapse Rate of 6.9°C per 1000 m of elevation change: seasonally

* For Existing Condition and Steady Flow scenarios, CE-QUAL-W2 representations of Copco and Iron Gate Reservoir use lapse rates and atmospheric pressure calculated on the average elevation of these two reservoirs. For the Without Project Scenario, KFLO data is used, without modification, from Link Dam to Iron Gate Dam. For all simulations between Iron Gate Dam and Orleans, Seiad Valley is used as the elevation for lapse rate and atmospheric pressure calculations.

F Water Quality Data

The 2002 field work was divided into two types of sample collection: monthly sampling and synoptic surveys. E&S Environmental performed the monthly sampling and both E&S and Watercourse Engineering, Inc. performed the synoptic surveys. There were nine monthly sampling sessions and three synoptic surveys performed during the 2002 collection. Field personnel collected four hundred twenty one sets of water samples from twenty two sites along the Klamath River from March 26 through November 13, 2002. The water sample sets were sent to Basic Laboratory in Redding, CA to be analyzed for total alkalinity, total Kjedhal nitrogen, ammonia, nitrate/nitrite, total phosphorus, ortho-phosphate, and biological oxygen demand. These parameters will be used to characterize the water quality in the main stem of the Klamath River, to identify water quality parameters of concern within selected river reaches, and to estimate input parameters for water quality models. Watercourse Engineering, Inc, in Napa, CA is responsible for ensuring the reliability of the data. In order to ensure data reliability, field personnel incorporated external quality assurance samples (QA samples) with the production samples as per the Quality Assurance Project Plan (QAPP) adopted by PacifiCorp and the U.S. Bureau of Reclamation (USBR).

The 2002 field data are attached in the following table.

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
3/26/2002	1012		Klamath R below JC Boyle Dam	65	0.9	0.14	0.27	0.51	0.11	<3	7.52	11.54	128	8.02
3/26/2002	1057		Klamath R Bypass Reach above Powerhouse	68	0.2	0.09	0.23	0.33	0.12	<3	9.29	11.89	108	8.21
3/26/2002	1113		JC Boyle Powerhouse Release	65	1.0	0.11	0.24	0.31	0.10	3	7.79	11.75	128	7.89
3/26/2002	1206		Spencer Creek	38	1.0	0.07	<0.05	0.15	0.05	<3	4.21	11.26	42	7.80
3/26/2002	1237		Klamath R above JC Boyle Reservoir	65	1.0	0.13	0.18	0.48	0.12	<3	8.86	10.32	126	7.92
3/26/2002	1355	1	JC Boyle Reservoir at Dam	61	1.0	0.11	0.21	0.30	0.10	<3	8.21	10.16	127	7.80
3/26/2002	1407	8	JC Boyle Reservoir at Dam	60	1.2	0.12	0.20	0.37	0.11	3	7.20	9.83	129	7.75
3/26/2002	1443		JC Boyle Reservoir upper	62	1.2	0.09	0.25	0.37	0.10	4	9.11	10.54	127	7.84
3/26/2002	1543		Klamath R below Keno Dam	64	1.0	0.12	0.12	0.50	0.10	3	8.19	10.85	126	7.90
3/27/2002	1051		Klamath R above Shovel Creek	64	0.8	<0.05	0.32	0.67	0.17	<3	7.78	11.36	119	8.04
3/27/2002	1103		Shovel Creek	43	<0.2	<0.05	<0.05	0.46	0.27	<3	5.93	11.25	60	8.05
3/27/2002	1213	1	Copco Reservoir at Dam	69	0.7	<0.05	0.23	0.70	0.24	<3	8.98	11.82	127	8.08
3/27/2002	1233	18	Copco Reservoir at Dam		0.8	0.06	0.31	0.70	0.13		6.16	9.81	121	7.77
3/27/2002	1237	25	Copco Reservoir at Dam	69	0.9	0.11	0.31	0.30	0.40	<3	6.03	9.57	120	7.68
3/27/2002	1321		Fall Creek	74	<0.2	0.05	0.07	0.25	0.25	<3	9.93	10.73	96	8.25
3/27/2002	1358		Klamath R above Irongate Reservoir	69	0.6	0.06	0.26	0.41	0.37	3	7.97	10.69	123	7.89
3/27/2002	1415		Jenny Creek	47	0.2	<0.05	<0.05	0.30	0.24	<3	7.67	12.59	62	7.99
3/27/2002	1452	1	Irongate Reservoir above Dam	70	0.8	<0.05	0.23	0.39	0.32	<3	8.97	13.58	123	8.17
3/27/2002	1509	14	Irongate Reservoir above Dam	70	0.8	0.08	0.39	0.50	0.38	<3	6.80	11.04	120	7.76
3/27/2002	1516	30	Irongate Reservoir above Dam	71	0.6	0.11	0.43	0.45	0.34	<3	6.45	10.82	118	7.70
3/27/2002	1607		Klamath R below Irongate Dam	70	0.7	0.07	0.23	0.38	0.36	3	8.65	12.37	123	8.10
3/27/2002	1654		Shasta R	161	0.4	0.06	<0.05	0.87	0.68	7	14.44		409	8.87
4/16/2002	915		Klamath R below JC Boyle Dam	54	0.9	0.11	0.13	0.18	0.16	<3	12.04	9.85	108	7.91
4/16/2002	1104		Klamath R Bypass Reach above Powerhouse	61	0.2	<0.05	0.15	0.53	0.20	<3	10.60	10.67	99	8.33
4/16/2002	1113		JC Boyle Powerhouse Release	53	0.8	0.14	0.14	0.24	0.17	<3	12.22	9.35	108	7.85
4/16/2002	1140		Spencer Creek	23	<0.2	<0.05	<0.05	0.20	0.09	<3	4.71	11.35	28	7.89
4/16/2002	1220		Klamath R below Keno Dam	72	1.0	0.14	0.13	0.42	<0.03	4	11.94	9.74	175	7.75
4/16/2002	1255		Klamath R above JC Boyle Reservoir	69	0.9	0.07	0.31	0.36	0.19	<3	12.17	10.10	177	8.06
4/16/2002	1443	1	JC Boyle Reservoir at Dam	54	0.7	0.10	0.13	0.27	0.16	<3	12.28	8.58	108	7.90
4/16/2002	1452	8	JC Boyle Reservoir upper	57	0.9	0.12	0.18	0.41	0.20	<3	11.88	8.62	112	7.79

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
4/16/2002	1528		JC Boyle Reservoir at Dam	66	0.8	<0.05	0.26	0.32	0.19	<3	11.21	9.55	160	7.86
4/16/2002	1604		Klamath R above Shovel Creek	60	0.8	0.06	0.25	0.41	0.20	<3	11.35	10.40	133	8.10
4/16/2002	1609		Shovel Creek	32	0.2	0.06	<0.05	0.25	0.17	<3	4.75	11.89	38	8.08
4/16/2002	1815		Shasta R	264	0.5	0.06	<0.05	0.41	0.32	4	11.52	10.85	382	8.79
4/17/2002	1045	1	Copco Reservoir at Dam	65	0.7	0.07	0.20	0.31	0.17	<3	13.15	9.14	137	8.15
4/17/2002	1104	15	Copco Reservoir at Dam	64	0.8	0.16	0.23	0.35	0.15	<3	9.33	7.60	124	7.74
4/17/2002	1110	25	Copco Reservoir at Dam	69	1.0	0.27	0.28	0.49	0.24	<3	7.12	5.93	124	7.48
4/17/2002	1200		Klamath R above Irongate Reservoir	65	0.8	<0.05	0.21	0.27	0.15	<3	12.33	9.45	132	7.82
4/17/2002	1210		Fall Creek	72	<0.2	<0.05	0.05	0.21	0.11	<3	8.75	11.34	95	8.15
4/17/2002	1230		Jenny Creek	44	<0.2	<0.05	<0.05	0.22	0.09	<3	5.35	12.24	56	8.10
4/17/2002	1342	1	Irongate Reservoir above Dam	60	0.7	0.07	0.13	0.39	0.09	<3	12.57	9.97	122	8.02
4/17/2002	1358	12	Irongate Reservoir above Dam	62	0.6	0.09	0.20	0.19	0.12	<3	9.85	8.64	119	7.79
4/17/2002	1412	30	Irongate Reservoir above Dam	66	0.7	<0.05	0.60	0.36	0.15	<3	6.45	7.60	118	7.52
4/17/2002	1515		Klamath R below Irongate Dam	60	0.5	0.05	0.14	0.20	0.12	<3	12.48	9.95	124	7.86
5/20/2002	1500		Klamath R above Copco		0.8	0.05	0.18	0.21	0.14		14.23b	9.8b	230b	8.81b
5/20/2002	1600		Klamath River at State Line		1.1	0.05	0.11	0.26	0.15		14.25b	8.91b	254b	8.4b
5/21/2002	900		Klamath R above Copco		0.6	0.08	0.12	0.16	0.17		12.23	9.34	254	8.17
5/21/2002	1000		Klamath River at State Line		0.6	0.09	0.17	0.53	0.18		12.44	9.45	250	8.31
5/21/2002	1028		Klamath Lake above Link Dam		0.8	0.21	<0.05	0.49	0.13		12.20	9.20	137	8.20
5/21/2002	1045		Mouth of Link R		0.8	0.29	<0.05	0.41	0.12		12.50	9.70	105	8.20
5/21/2002	1125		Shovel Creek		<0.2	0.07	<0.05	0.65	0.15					
5/21/2002	1141		Klamath R below Keno Dam		0.9	0.17	<0.05	0.63	0.14		13.00	9.40	166	8.60
5/21/2002	1209		Klamath R above JC Boyle Reservoir		<0.2	0.16	0.10	0.43	0.16		13.60	9.30	155	8.50
5/21/2002	1234		Spencer Creek		<0.2	0.10	<0.05	0.21	0.09		9.20	10.20	71	8.60
5/21/2002	1303		Klamath R Bypass Reach above Powerhouse		0.3	0.13	0.13	0.33	0.21		12.20	10.00	151	8.70
5/21/2002	1306		JC Boyle Powerhouse Release		0.9	0.24	0.10	0.45	0.17		13.90	8.80	190	8.40
5/21/2002	1330		Klamath River at State Line		0.7	0.29	0.15	0.30	0.18		13.51	9.17	246	8.54
5/21/2002	1350		Klamath R below JC Boyle Dam		0.8	0.18	0.12	0.43	0.16		13.80	9.00	209	8.40
5/21/2002	1415		Klamath R above Copco		0.6	0.15	0.11	0.47	0.20		13.48a	10.54a	228a	8.88a
5/21/2002	1455	1	JC Boyle Reservoir at Dam		0.9	0.22	0.11	0.48	0.16		14.00	8.70	229	8.20

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
5/21/2002	1500	8	JC Boyle Reservoir at Dam		0.8	0.29	0.11	0.37	0.16		13.20	8.60	185	7.80
5/22/2002	810		Klamath River at State Line		0.8	0.08	0.14	0.24	0.13		11.54t	8.52t	240t	8.13t
5/22/2002	850		Shovel Creek	36	0.2	0.06	<0.05	0.19	0.10	<3				
5/22/2002	920		Klamath R above Copco		0.7	0.12	0.09	0.26	0.14		11.74b	10.22b	231b	8.55b
5/22/2002	1043	1	JC Boyle Reservoir at Dam	60	0.7	0.08	0.09	0.20	0.13	<3	13.60	11.84	174	7.70
5/22/2002	1045		Klamath R above Shovel Creek	64	0.7	0.08	0.11	0.18	0.14	<3				
5/22/2002	1048	8	JC Boyle Reservoir at Dam	58	0.8	0.11	0.09	0.20	0.13	<3	12.80	11.26	158	7.60
5/22/2002	1143		Klamath R above Irongate Reservoir	67	0.6	0.08	<0.05	0.13	0.11	<3	14.62	8.99	151	8.24
5/22/2002	1205		Klamath R below JC Boyle Dam	60	0.9	0.09	0.11	0.25	0.14	<3	13.30	10.10	168	8.60
5/22/2002	1213		Fall Creek	75	<0.2	<0.05	0.06	0.44	0.11	<3	10.24	10.72	103	8.15
5/22/2002	1233		Jenny Creek	60	0.2	0.05	<0.05	0.10	0.09	<3	10.75	10.80	93	8.23
5/22/2002	1238		Klamath R Bypass Reach above Powerhouse	69	0.3	0.06	0.14	0.20	0.15	<3	12.50	11.00	143	9.40
5/22/2002	1247		JC Boyle Powerhouse Release	60	0.8	0.08	0.09	0.24	0.13	<3	13.30	10.00	166	9.00
5/22/2002	1303		Klamath R below Irongate Dam	65	0.6	0.06	<0.05	0.19	0.10	<3	14.67	10.55	139	8.53
5/22/2002	1318		Spencer Creek	40	0.1	<0.05	<0.05	0.08	0.06	<3	11.90	10.60	70	9.70
5/22/2002	1344		Klamath R above JC Boyle Reservoir	56	0.8	0.06	0.09	0.24	0.45	<3	14.70	11.10	155	9.40
5/22/2002	1350		Klamath River at State Line		0.7	0.09	0.09	0.19	0.13		13.76t	9.1t	228t	8.68t
5/22/2002	1415		Klamath R below Keno Dam	60	0.9	0.06	<0.05	0.28	0.14	<3	13.10	10.70	161	8.70
5/22/2002	1425		Shasta R	292	0.7	0.06	<0.05	0.48	0.31	<3	16.66	11.97	483	8.83
5/22/2002	1445		Mouth of Link R	45	0.8	0.06	<0.05	0.17	0.10	<3	13.40	10.60	103	9.20
5/22/2002	1455		Klamath R above Copco		0.6	0.09	0.08	0.25	0.15		13.95t	10.71t	218t	9.01t
5/22/2002	1500		Klamath R above Shasta	68	0.7	0.06	<0.05	0.16	0.10	<3	17.03	11.22	151	8.81
5/22/2002	1507		Klamath Lake above Link Dam	43	0.7	<0.05	<0.05	0.12	0.08	<3	13.60	10.50	102	9.10
5/23/2002	325	25	Copco Reservoir at Dam	64	1.0	0.33	0.24	0.38	0.25	4	9.51	1.10	130	7.16
5/23/2002	557	1	Copco Reservoir at Dam	66	0.7	<0.05	<0.05	0.21	0.09	<3	14.88	9.60	151	8.64
5/23/2002	612	12	Copco Reservoir at Dam	65	0.5	0.07	0.08	0.22	0.11	<3	13.57	7.48	146	7.93
5/23/2002	656	1	JC Boyle Reservoir at Dam		0.8	0.07	0.09	0.27	0.14		13.40	12.40	156	8.00
5/23/2002	702	8	JC Boyle Reservoir at Dam		0.7	0.05	0.10	0.16	0.07		13.10	11.10	154	7.70
5/23/2002	745		Klamath River at State Line		0.7	0.06	0.11	0.22	0.12		11.57b	8.36b	225b	8.08b
5/23/2002	752	1	Irongate Reservoir above Dam	66	0.6	<0.05	<0.05	0.44	0.08	<3	15.01	10.39	142	8.79

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
5/23/2002	807	12	Irongate Reservoir above Dam	65	0.4	<0.05	0.15	0.27	0.15	<3	13.57	7.48	146	7.93
5/23/2002	815	30	Irongate Reservoir above Dam	32	0.7	<0.05	0.34	0.24	0.15	<3	9.47	0.78	130	7.13
5/23/2002	822		Klamath R below JC Boyle Dam		0.8	<0.05	<0.05	0.21	0.08		13.20	9.30	156	8.10
5/23/2002	830		Shovel Creek		0.3	0.05	<0.05	0.24	0.09					
5/23/2002	856		Klamath R Bypass Reach above Powerhouse		0.7	<0.05	0.10	0.25	0.13		10.90	10.80	139	9.10
5/23/2002	900		JC Boyle Powerhouse Release		0.3	<0.05	0.14	0.35	0.14		13.10	10.20	154	8.80
5/23/2002	900		Klamath R above Copco		0.9	0.06	0.06	0.21	0.12		11.41	10.09	219	8.44
5/23/2002	1058		Spencer Creek		0.9	0.10	0.08	0.23	0.13		9.40	10.70	71	9.40
5/23/2002	1128		Klamath R above JC Boyle Reservoir		0.2	<0.05	<0.05	0.16	0.06		14.00	9.90	229	9.80
5/23/2002	1205		Klamath R below Keno Dam		0.9	<0.05	0.11	0.24	0.16		13.00	10.10	248	9.80
5/23/2002	1249		Mouth of Link R		1.1	<0.05	<0.05	0.30	0.17		13.40	10.30	103	9.40
5/23/2002	1304		Klamath Lake above Link Dam		0.7	<0.05	<0.05	0.22	0.09		13.10	9.80	101	9.60
6/18/2002	1015		Klamath R below JC Boyle Dam	88	1.1	0.15	0.24	0.38	0.25	<3	19.09	8.12	225	8.34
6/18/2002	1113		Klamath R Bypass Reach above Powerhouse	74	0.8	0.12	0.23	0.24	0.16	<3	13.80	9.78	139	8.23
6/18/2002	1119		JC Boyle Powerhouse Release	97	1.8	0.20	0.26	0.35	0.24	<3	18.97	7.53	227	8.12
6/18/2002	1154		Spencer Creek	58	0.2	0.03	<0.05	0.14	0.08	4	17.16	8.67	98	8.11
6/18/2002	1219		Klamath R above JC Boyle Reservoir	93	1.3	0.07	0.27	0.36	0.24	4	18.88	8.80	233	8.66
6/18/2002	1255		Klamath R below Keno Dam	92	1.6	0.15	<0.05	0.38	0.21	6	18.33	8.76	228	8.87
6/18/2002	1427	1	JC Boyle Reservoir at Dam	88	1.0	0.08	0.17	0.35	0.23	4	20.56	9.19	227	8.78
6/18/2002	1436	8	JC Boyle Reservoir at Dam	92	1.3	0.17	0.27	0.36	0.24	3	18.46	6.76	234	8.10
6/19/2002	1043		Klamath R above Shovel Creek	88	1.2	0.11	0.24	0.32	0.22	<3	16.66	10.18	197	8.46
6/19/2002	1207	1	Copco Reservoir at Dam	77	1.1	0.12	<0.05	0.37	0.17	5	20.11	9.12	182	8.58
6/19/2002	1219	9	Copco Reservoir at Dam	75	1.0	0.18	0.07	0.30	0.14	2	18.13	7.19	174	8.22
6/19/2002	1231	25	Copco Reservoir at Dam	71	1.1	0.24	0.43	0.36	0.29	<3	11.09	0.27	135	7.20
6/19/2002	1340		Klamath R above Irongate Reservoir	78	1.0	0.11	0.08	0.34	0.18	<3	19.41	9.16	177	8.43
6/19/2002	1352		Fall Creek	76	0.5	0.10	0.09	0.21	0.07	<3	12.71	10.19	95	8.15
6/19/2002	1406		Jenny Creek	82	0.1	0.10	<0.05	0.14	0.03	<3	16.72	9.44	143	8.40
6/19/2002	1501	1	Irongate Reservoir above Dam	77	1.0	0.10	<0.05	0.32	0.15	3	22.21	9.70	190	8.58
6/19/2002	1507	15	Irongate Reservoir above Dam	72	1.0	0.10	0.06	0.19	0.14	4	18.28	7.52	172	8.16
6/19/2002	1530	30	Irongate Reservoir above Dam	70	1.0	0.13	0.69	0.26	0.18	<3				

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
6/19/2002	1645		Klamath R below Irongate Dam	68	1.1	0.10	<0.05	0.21	0.13	3	20.13	9.41	184	8.23
6/19/2002	1822		Klamath R above Shasta	78	1.0	0.04	<0.05	0.24	0.13	<3	22.22	10.25	186	9.11
6/19/2002	1845		Shasta R	284	1.0	0.04	<0.05	0.47	0.32	3	23.72	7.98	556	8.76
7/15/2002	1445		Klamath R above Copco		0.5	0.05	0.37	0.18	0.20		22.20	7.20	113	8.37
7/15/2002	1630		Klamath River at State Line		0.8	0.13	0.65	0.23	0.23		21.44	6.46	111	8.26
7/16/2002	815		Klamath River at State Line		<0.2	0.04	0.49	0.16	0.20		18.29	6.84	110	7.62
7/16/2002	900		Klamath R above Shovel Creek	62	0.6	0.05	0.62	0.26	0.23	3	19.80	7.19	114	8.06
7/16/2002	1032	1	Copco Reservoir at Dam	73	1.2	0.04	<0.05	0.21	0.18	8	23.33	11.61	181	9.16
7/16/2002	1040		Klamath R above Copco		0.6	0.05	0.65	0.17	0.24		20.96	7.56	117	8.25
7/16/2002	1056	13	Copco Reservoir at Dam	80	0.4	0.09	0.33	0.71	0.29	3	17.80	1.89	2	7.60
7/16/2002	1056	25	Copco Reservoir at Dam	72	0.7	0.42	0.07	0.46	0.45	5	11.60	0.11	141	7.12
7/16/2002	1102	1	JC Boyle Reservoir at Dam	58	1.0	0.12	0.72	0.29	0.27	3				
7/16/2002	1110	8	JC Boyle Reservoir at Dam	58	1.2	0.23	0.75	0.28	0.27	4				
7/16/2002	1136		Klamath R above Irongate Reservoir	71	0.7	0.06	0.14	0.19	0.22	4	21.76	7.60	182	8.53
7/16/2002	1138		Klamath R below JC Boyle Dam	58	1.1	0.27	0.76	0.27	0.28	5	23.90		132	
7/16/2002	1201		Fall Creek	74	0.2	<0.05	0.06	0.11	0.10	4	12.51	10.57	111	8.18
7/16/2002	1230		Klamath River at State Line		0.3	0.05	0.38	0.14	0.18		18.05	7.45	106	8.26
7/16/2002	1233		Jenny Creek	90	<0.2	<0.05	<0.05	<0.05	0.09	2	20.80	8.99	187	8.25
7/16/2002	1257		Klamath R Bypass Reach above Powerhouse	64	0.2	0.03	0.40	0.15	0.17	<3	16.40		139	
7/16/2002	1304		JC Boyle Powerhouse Release	58	1.1	0.21	0.78	0.27	0.27	3	23.90		130	
7/16/2002	1315		Shovel Creek	58	<0.2	0.09	0.08	0.09	0.12	<3	17.04	7.91	71	7.89
7/16/2002	1321	1	Irongate Reservoir above Dam	79	0.5	<0.05	<0.05	0.12	0.14	4	26.22	10.53	217	9.04
7/16/2002	1338	12	Irongate Reservoir above Dam	66	0.3	0.11	0.17	0.13	0.13	3	15.14	3.79	151	7.54
7/16/2002	1352	30	Irongate Reservoir above Dam	66	0.4	<0.05	0.61	0.14	0.19	<3	7.05	1.84	125	7.24
7/16/2002	1405		Spencer Creek	64	<0.2	<0.05	<0.05	<0.05	0.07	<3	22.90		114	
7/16/2002	1415		Klamath R above Copco		0.5	0.07	0.37	0.21	0.21		21.00	6.86	110	8.49
7/16/2002	1431		Klamath R above JC Boyle Reservoir	56	1.0	0.11	0.91	0.25	0.25	3				
7/16/2002	1510		Klamath R below Keno Dam	60	2.3	0.48	0.05	0.31	0.18	5	24.10			
7/16/2002	1513		Klamath R below Irongate Dam	77	0.6	0.06	0.10	0.18	0.18	3	22.16	9.13	196	8.38
7/16/2002	1550		Klamath R above Shasta	75	0.4	0.06	0.07	0.15	0.18	4	24.92	10.71	207	8.81

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
7/16/2002	1619		Shasta R	246	0.5	0.08	<0.05	0.30	0.38	3	28.57	8.49	578	8.77
7/17/2002	815		Klamath River at State Line		0.5	0.07	0.47	0.19	0.18		18.08	7.50	110	7.64
7/17/2002	930	1	JC Boyle Reservoir at Dam		1.4	0.15	0.69	0.42			24.20	5.90		
7/17/2002	934	9	JC Boyle Reservoir at Dam		1.3	0.24	0.75	0.37	0.24		23.00	3.90		
7/17/2002	945		Klamath R above Copco		0.8	0.11	0.66	0.23	0.20		20.63	7.90	120	7.98
7/17/2002	1004		Klamath R below JC Boyle Dam		1.3	0.15	0.74	0.53	0.23		23.50			
7/17/2002	1109		Klamath R Bypass Reach above Powerhouse		0.4	0.14	0.40	0.29	0.14		16.30	8.70		
7/17/2002	1112		JC Boyle Powerhouse Release		1.3	0.18	0.76	0.51	0.27		23.10	6.10		
7/17/2002	1201		Klamath R above JC Boyle Reservoir		1.2	<0.05	0.98	0.50	0.21		24.20			
7/17/2002	1230		Klamath R below Keno Dam		1.4	0.68	0.05	0.42	0.16		23.80	6.60		
7/17/2002	1250		Klamath River at State Line		0.5	0.07	0.37	0.13	0.15		17.95	7.89	105	8.42
7/17/2002	1415		Klamath R above Copco		0.5	0.11	0.39	0.17	0.16		21.07	8.09	110	8.63
7/17/2002	1500		Klamath Lake above Link Dam		2.0	0.25	0.06	0.62	0.11		24.00	5.70		
7/17/2002	1515		Mouth of Link R		2.0	0.23	0.11	0.55	0.10		24.80	6.40		
7/18/2002	625	1	JC Boyle Reservoir at Dam		1.6	0.12	0.67	0.30	0.21		24.20	6.70		
7/18/2002	628	9	JC Boyle Reservoir at Dam		1.6	0.26	0.75	0.30	0.24		22.70	4.30		
7/18/2002	715		Klamath R below JC Boyle Dam		1.5	0.21	0.76	0.28	0.24		22.80			
7/18/2002	755		JC Boyle Powerhouse Release		1.7	0.28	0.76	0.33	0.23		21.80	5.30		
7/18/2002	800		Klamath River at State Line		0.6	0.11	0.51	0.57	0.17		18.62	6.84	104	7.67
7/18/2002	805		Klamath R Bypass Reach above Powerhouse		0.5	0.05	0.37	0.16	0.13		14.50	8.70		
7/18/2002	915		Klamath R above Copco		0.8	0.12	0.70	0.54	0.20		20.57	7.35	119	8.06
7/18/2002	930		Klamath R above JC Boyle Reservoir		1.8	0.11	1.05	0.30	0.23		21.70	7.20		
7/18/2002	1017		Klamath R below Keno Dam		<0.2	0.60	0.08	0.27	0.19		23.20	6.30		
7/18/2002	1100		Mouth of Link R		2.0	0.28	0.18	0.18	0.11			6.20		
7/18/2002	1127		Klamath Lake above Link Dam		2.1	0.24	0.10	0.18	0.09		24.70	5.00		
8/13/02	915		Klamath R below JC Boyle Dam	72	1.7	0.27	0.82	0.30	0.30	3	20.09	7.85	184	7.94
8/13/02	1018		Klamath R Bypass Reach above Powerhouse	65	0.5	0.10	0.36	0.15	0.19	3	13.92	9.74	127	8.26
8/13/02	1024		JC Boyle Powerhouse Release	70	1.6	0.22	0.73	0.29	0.29	4	19.34	7.35	179	7.86
8/13/02	1122		Spencer Creek	66	0.1	0.04	<0.05	0.05	0.06	<3	16.90	8.66	108	8.21
8/13/02	1148		Klamath R above JC Boyle Reservoir	72	1.8	0.09	0.71	0.28	0.29	5	21.01	8.36	199	8.48

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
8/13/02	1221		Klamath R below Keno Dam	75	2.1	0.64	0.13	0.28	0.24	5	20.56	7.46	203	8.15
8/13/02	1316	1	JC Boyle Reservoir at Dam	72	1.7	0.39	0.66	0.30	0.29	5	22.19	6.64	196	7.91
8/13/02	1331	8	JC Boyle Reservoir at Dam	73	1.7	0.45	0.76	0.25	0.30	5	18.85	4.80	183	7.66
8/14/2002	1025		Klamath R above Shovel Creek	66	0.6	0.10	0.49	0.11	0.20	<3	18.00	10.12	150	8.38
8/14/2002	1037		Shovel Creek	61	0.1	0.07	<0.05	0.06	0.12	<3	14.86	9.88	98	8.10
8/14/2002	1151	1	Copco Reservoir at Dam	71	0.9	0.14	0.35	0.14	0.18	4	21.84	9.25	163	8.60
8/14/2002	1209	17	Copco Reservoir at Dam	74	0.2	0.33	0.05	0.29	0.58	3	16.62	1.16	159	7.58
8/14/2002	1216	25	Copco Reservoir at Dam	70	1.2	1.04	<0.05	0.53	0.18	7	11.90	0.09	149	7.23
8/14/2002	1306		Klamath R above Irongate Reservoir	70	0.7	0.21	0.38	0.17	0.22	3	20.34	6.97	159	8.10
8/14/2002	1321		Fall Creek	73	0.2	0.08	0.07	0.03	0.08	7	13.33	10.56	113	8.04
8/14/2002	1339		Jenny Creek	70	0.3	0.08	<0.05	<0.05	0.07	<3	20.68	8.95	182	8.63
8/14/2002	1427	1	Irongate Reservoir above Dam	70	2.1	0.12	<0.05	0.17	0.11	14	25.09	16.85	190	9.70
8/14/2002	1442	12	Irongate Reservoir above Dam	70	0.7	0.11	0.45	0.17	0.25	<3	19.05	0.53	172	7.60
8/14/2002	1457	30	Irongate Reservoir above Dam	70	0.6	0.09	0.69	0.11	0.19	<3	7.14	0.10	125	7.25
8/14/2002	1557		Klamath R below Irongate Dam	72	1.2	0.14	0.15	0.16	0.15	8	22.42	10.50	177	9.16
8/14/2002	1642		Klamath R above Shasta	75	0.9	0.13	0.22	0.12	0.18	5	23.79	10.39	158	8.80
8/14/2002	1701		Shasta R	302	0.7	0.11	<0.05	0.28	0.41	4	27.62	9.32	667	8.91
9/9/2002	1400		Klamath River at State Line		0.4	0.09	0.16	0.14	0.42		14.90	9.45	176	8.14
9/9/2002	1515		Klamath R above Copco		0.5	0.08	0.16	0.12	0.41		13.72	9.01	178	7.88
9/10/2002	815		Klamath River at State Line		0.6	0.07	0.18	0.03	0.27		13.28	7.81	191	7.58
9/10/2002	910		Klamath R above Shovel Creek	70	0.9	0.08	0.13	0.16	0.14	2	14.00	8.47	224	7.78
9/10/2002	915	1	Copco Reservoir at Dam	78	0.7	0.07	0.26	0.23	0.19	5	18.51	7.66	202	8.50
9/10/2002	925	25	Copco Reservoir at Dam	84	1.4	0.95	<0.05	0.69	0.59	8	12.42	0.10	201	7.38
9/10/2002	930	14	Copco Reservoir at Dam	80	0.8	0.32	0.26	0.27	0.23	6	16.85	2.22	208	7.79
9/10/2002	950		Klamath R Bypass Reach above Powerhouse	80	<0.2	0.05	0.16	0.12	0.09	<3	12.20	9.65	137	8.21
9/10/2002	1005		JC Boyle Powerhouse Release	94	1.2	0.12	0.16	0.27	0.15	3	14.60	8.64	203	8.38
9/10/2002	1020		Klamath R above Irongate Reservoir	80	0.8	0.11	0.31	0.25	0.18	6	18.10	7.18	108	8.05
9/10/2002	1035		Klamath R above Copco		0.9	0.09	0.14	0.13	0.29		15.00	8.58	246	7.86
9/10/2002	1035		Klamath R below JC Boyle Dam	100	1.7	0.14	0.14	0.28	0.19	<3	16.80	8.78	248	8.48
9/10/2002	1045		Fall Creek	74	<0.2	0.09	0.07	0.03	<0.03	2	10.10	11.39	143	8.31

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
9/10/2002	1100		Jenny Creek	92	0.1	0.08	<0.05	0.08	<0.03	<3	13.04	10.60	192	8.51
9/10/2002	1135		Spencer Creek	62	0.3	0.04	<0.05	0.08	<0.03	<3	10.60	10.16	77	8.04
9/10/2002	1158	1	Irongate Reservoir above Dam	74	1.1	0.08	0.13	0.16	0.16	3	20.51	10.32	180	9.10
9/10/2002	1159		Klamath R above JC Boyle Reservoir	102	2.1	0.13	0.13	0.23	0.19	3	18.10	8.33	256	8.78
9/10/2002	1220		Klamath River at State Line		0.5	0.06	0.15	0.15	0.26		13.56	7.74	176	8.03
9/10/2002	1225	30	Irongate Reservoir above Dam	72	0.6	0.20	0.43	0.14	<0.03	3	7.34	0.06	193	7.36
9/10/2002	1230	16	Irongate Reservoir above Dam	90	0.4	0.08	0.19	0.21	0.15	6	14.97	0.15	188	7.51
9/10/2002	1234		Klamath R below Keno Dam	104	2.0	0.21	<0.05	0.29	0.17	5	17.40	8.97	250	8.98
9/10/2002	1300		Shovel Creek	64	0.1	0.07	0.05	0.07	0.26	<3	13.75	8.75	80	7.56
9/10/2002	1340		Klamath R below Irongate Dam	74	0.7	0.08	0.24	0.17	0.12	3	19.34	8.69	181	8.36
9/10/2002	1352	1	JC Boyle Reservoir at Dam	104	2.2	0.29	0.05	0.29	0.20	5	19.10	11.45	264	8.99
9/10/2002	1358	7	JC Boyle Reservoir at Dam	104	2.1	0.21	0.12	0.27	0.19	3	16.30	6.66	244	8.37
9/10/2002	1400		Klamath R above Shasta	76	0.6	0.19	0.23	0.17	0.13	<3	20.10	11.14	181	8.44
9/10/2002	1430		Klamath R above Copco		0.6	0.10	0.14	0.17	0.27		15.48	8.52	181	8.58
9/10/2002	1445		Shasta R	260	0.4	<0.05	0.05	0.26	0.19	4	19.62	10.37	567	8.75
9/11/2002	800		Klamath River at State Line		0.9	0.09	0.17	0.15	0.14		14.49	6.58	251	7.24
9/11/2002	838		Klamath R above JC Boyle Reservoir		1.5	0.22	0.24	0.27	0.19		15.20	8.08	234	8.14
9/11/2002	906		Klamath R below JC Boyle Dam		1.5	0.31	0.10	0.26	0.21		16.60	8.33	249	8.58
9/11/2002	945		Klamath R above Copco		1.1	0.09	0.11	0.17	0.13		15.00	7.61	281	7.95
9/11/2002	950	1	JC Boyle Reservoir at Dam		1.6	0.50	0.05	0.30	0.18		17.20	10.23	252	8.93
9/11/2002	958	7	JC Boyle Reservoir at Dam		1.6	0.43	0.09	0.22	0.18		16.40	6.21	248	8.33
9/11/2002	1113		Klamath R Bypass Reach above Powerhouse		0.4	0.08	0.15	0.12	0.08		13.00	9.76	142	8.34
9/11/2002	1120		JC Boyle Powerhouse Release		1.1	0.41	0.10	0.20	0.18		16.10	10.20	216	8.73
9/11/2002	1158		Klamath R below Keno Dam		2.0	0.22	<0.05	0.26	0.18		17.40	8.58	240	9.03
9/11/2002	1200		Klamath River at State Line		0.4	0.07	0.16	0.09	0.10		14.68	7.79	190	7.86
9/11/2002	1232		Mouth of Link R		1.8	0.23	0.06	0.17	0.12		18.20	8.89	92	9.55
9/11/2002	1250		Klamath Lake above Link Dam		1.9	0.23	<0.05	0.18	0.15		17.50	11.03	90	9.49
9/11/2002	1345		Klamath R above Copco		0.8	0.26	0.11	0.17	0.14		17.28	8.72	260	8.69
9/12/2002	800		Klamath River at State Line		0.4	0.13	0.13	0.14	0.21		13.34	6.55	181	8.09
9/12/2002	817	1	JC Boyle Reservoir at Dam		1.5	0.29	<0.05	0.21	0.18		17.40	11.85	252	7.58

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
9/12/2002	822	8	JC Boyle Reservoir at Dam		1.5	0.26	0.08	0.19	0.17		16.40	5.98	251	8.31
9/12/2002	852		Klamath R below JC Boyle Dam		1.6	0.24	0.08	0.23	0.18		16.80	8.32	251	8.64
9/12/2002	915		Klamath R above Copco		0.5	0.09	0.11	0.12	0.21		14.47	8.57	184	8.13
9/12/2002	1020		Klamath R Bypass Reach above Powerhouse		0.3	0.05	0.15	0.08	0.08		12.60	9.78	140	8.27
9/12/2002	1030		JC Boyle Powerhouse Release		0.9	0.21	0.10	0.23	0.18		16.20	8.41	235	8.53
9/12/2002	1122		Klamath R above JC Boyle Reservoir		1.5	0.11	0.19	0.17	0.20		17.40	8.38	236	8.42
9/12/2002	1154		Klamath R below Keno Dam		1.6	0.14	<0.05	0.23	0.21		17.70	8.49	235	9.03
9/12/2002	1226		Mouth of Link R		2.2	0.17	0.08	0.14	0.14		19.40	8.66	96	9.52
9/12/2002	1245		Klamath Lake above Link Dam		2.1	0.17	0.05	0.11	0.13		18.60	11.74	93	9.54
10/8/2002	1027	1	JC Boyle Reservoir at Dam	80	2.1	0.27	0.54	0.22	0.08	6	13.70	8.72	222	7.11
10/8/2002	1030	8	JC Boyle Reservoir at Dam	77	1.6	0.40	0.53	0.21	0.10	5	12.70	7.35	195	7.11
10/8/2002	1150		Klamath R Bypass Reach above Powerhouse	73	1.1	0.15	0.65	0.11	0.09	<3	13.00	8.24	162	7.40
10/8/2002	1244		Klamath R below JC Boyle Dam	75	1.7	0.34	0.57	0.19	0.09	5	13.80	7.90	182	7.40
10/8/2002	1350		Spencer Creek	61	<0.2	<0.05	<0.05	<0.05	<0.03	5	10.10	8.64	115	7.50
10/8/2002	1446		Klamath R above JC Boyle Reservoir	72	1.7	0.26	0.59	0.15	0.09	4	14.80	7.14	165	7.40
10/8/2002	1629		Klamath R below Keno Dam	72	2.5	0.37	0.13	0.03	0.05	7	14.40	7.99	131	7.70
10/9/2002	925		Klamath R above Shovel Creek	73	0.8	0.07	0.76	0.11	0.10	5	11.70	9.04	163	7.50
10/9/2002	1000		Shovel Creek	82	0.1	0.03	0.08	0.06	0.05	<3	8.60	9.73	118	7.40
10/9/2002	1112		Klamath R below Irongate Dam	81	0.5	0.08	0.17	0.18	0.16	<3	16.10	6.94	204	7.50
10/9/2002	1215	1	Irongate Reservoir above Dam	100	0.6	0.07	0.09	0.16	0.12	<3	17.20	12.20	184	8.40
10/9/2002	1225	8	Irongate Reservoir above Dam	<10	0.7	0.13	0.23	0.20	0.17	3	15.70	6.31	183	8.30
10/9/2002	1235	30	Irongate Reservoir above Dam	72	0.5	0.20	0.43	0.17	0.18	<3	7.90	0.17	157	8.40
10/9/2002	1411		Klamath R above Irongate Reservoir	83	0.8	0.14	0.25	0.23	0.20	<3	14.90	5.98	204	7.40
10/9/2002	1424		Fall Creek	74	0.2	0.10	0.09	0.06	0.04	<3	11.10	8.64	138	7.50
10/9/2002	1505	1	Copco Reservoir at Dam	84	0.8	0.08	0.26	0.16	0.17	3	16.50	9.66	186	8.57
10/9/2002	1510	10	Copco Reservoir at Dam	80	0.7	0.10	0.26	0.15	0.12	<3	14.60	6.82	180	8.46
10/9/2002	1515	26	Copco Reservoir at Dam	84	1.5	1.01	<0.05	0.58	0.62	5	12.90	0.32	176	8.53
10/9/2002	1615		Jenny Creek	99	0.1	0.06	<0.05	<0.05	0.04	4	13.10	8.52	194	7.70
10/9/2002	1820		Shasta R	214	0.3	0.21	0.11	0.19	0.18	<3	15.60	7.20	435	7.60
10/9/2002	1845		Klamath R above Shasta	80	0.5	0.09	0.21	0.15	0.16	3	17.30	8.16	202	7.70

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
11/12/2002	820		Klamath R below Keno Dam	62	1.5	0.55	0.22	0.14	0.12	4	5.35	11.94	144	7.75
11/12/2002	845		Klamath R above JC Boyle Reservoir	58	1.2	0.20	0.73	0.17	0.11	<3	5.33	12.07	143	7.84
11/12/2002	912		Spencer Creek	55	0.2	0.03	<0.05	0.04	<0.03	<3	3.07	12.73	105	7.73
11/12/2002	948		Klamath R Bypass Reach above Powerhouse	63	0.4	0.07	0.43	0.09	0.07	<3	9.01	11.89	144	8.07
11/12/2002	1002		JC Boyle Powerhouse Release	58	1.2	0.29	0.65	0.13	0.08	<3	6.28	11.35	144	7.68
11/12/2002	1052		Klamath R below JC Boyle Dam	55	1.0	0.30	0.72	0.16	0.12	<3	5.78	12.49	144	7.76
11/12/2002	1237	1	JC Boyle Reservoir at Dam	54	1.3	0.31	0.69	0.14	0.10	3	5.95	11.00	144	7.72
11/12/2002	1242	8	JC Boyle Reservoir at Dam	58	1.3	0.32	0.64	0.19	0.11	<3	5.64	11.11	144	7.68
11/13/2002	811		Klamath R above Shovel Creek	60	0.7	0.08	0.78	0.11	0.11	6	6.73	11.34	146	7.87
11/13/2002	815		Shovel Creek	63	<0.2	0.04	<0.05	0.07	0.06	<3	6.69	11.22	124	7.86
11/13/2002	1036	1	Copco Reservoir at Dam	74	0.8	0.15	0.48	0.14	0.12	5	8.53	10.06	181	7.83
11/13/2002	1041	10	Copco Reservoir at Dam	75	0.9	0.16	0.48	0.21	0.12	<3	8.27	9.95	181	7.83
11/13/2002	1046	28	Copco Reservoir at Dam	71	0.9	0.21	0.52	0.15	0.13	<3	7.65	9.14	175	7.68
11/13/2002	1200		Klamath R above Irongate Reservoir	75	0.7	0.20	0.51	0.15	0.15	3	8.35	10.78	180	7.77
11/13/2002	1221		Fall Creek	76	<0.2	0.03	<0.05	0.05	0.05	5	8.91	11.74	145	8.15
11/13/2002	1245		Jenny Creek	91	0.1	0.05	<0.05	0.03	0.02	<3	7.18	12.18	205	8.27
11/13/2002	1342	1	Irongate Reservoir above Dam	78	0.7	0.15	0.60	0.16	0.16	<3	10.68	8.04	197	7.72
11/13/2002	1347	10	Irongate Reservoir above Dam	78	1.0	0.17	0.29	0.15	0.16	<3	9.89	8.04	198	7.70
11/13/2002	1352	30	Irongate Reservoir above Dam	76	0.6	0.22	0.34	0.20	0.17	<3	8.85	5.38	191	7.45
11/13/2002	1540		Klamath R below Irongate Dam	78	0.7	0.16	0.30	0.18	0.16	<3	9.95	10.18	197	7.68
11/13/2002	1617		Klamath R above Shasta	82	0.7	0.10	0.33	0.20	0.17	<3	10.56	12.05	198	8.44
11/13/2002	1638		Shasta R	219	0.3	0.06	0.25	0.25	0.28	<3	9.80	11.24	485	8.51

FLAG = *: No flow from JC Boyle PH at time of sample
t = sonde measurement from the top of hour
b = sonde measurement from the bottom of hour was used
a = the average of the top and bottom of hour sonde measurement is presented

G Data Processing for Calibration/Validation

G.1 Computation of Dissolved Oxygen Saturation

Dissolved oxygen saturation concentration is a function of water temperature, atmospheric pressure, and concentration of dissolved solids. The APHA (1985) formulation, namely

$$\ln (O_{sn}) = -139.34411 + (1.575701 \times 10^{5}/T) - (6.642308 \times 10^{7}/T^{2}) + (1.243800 \times 10^{10}/T^{3}) - (8.621949 \times 10^{11}/T^{4})$$

where

O_{sn} = saturation dissolved oxygen at 1 atmosphere (mg l^{-1})

T = water temperature (K)

To correct for atmospheric pressure at elevations less than roughly 4000 feet

$$O_s = O_{sn} P$$

Where

O_s = equilibrium dissolved oxygen concentration at non-standard pressure (mg $^{l-1}$)

P = atmospheric pressure (atm)

To correct for atmospheric pressure at elevations greater than roughly 4000 feet

$$O_s = O_{sn} P [(1-(P_{wv}/P)](1- \phi P) / [(1-P_{wv}) (1-\phi)]$$

where

P_{wv} = partial pressure of water vapor (atm) computed from,

$\ln (P_{wv}) = 11.8571 - 3840.70/(T_{a'}) - 216961/(T_{a'})^2$

where $T_{a'}$ is air temperature (K), and

$\phi = 0.000975 - 1.425 \times 10^{-5} (T_a) + 6.436 \times 10^{-8}(T_a)^2$

where T_a is air temperature (°C)

and other parameters are previously defined.

The former representation, for elevations less than approximately 4000 feet, was used in these analyses. Salinity (dissolved solids) can be incorporated in the above formulation, but was not addressed in this analysis.

Daily atmospheric pressure was corrected for elevation using assumed a constant sea level value of 1013 mb as per

$$P = 1013 - 3.436(E/100) - 0.0029(E/100)^2 + 0.0001(E/100)^3$$

Where E is elevation in feet and P is barometric pressure in millibars (U.C. Cooperative Extension, ___).

G.2 Correction for Biofouling Effects on Dissolved Oxygen Observations

Dissolved oxygen data for the calibration period was available from USBR (2003). The data clearly show that biofouling affected field observations (Figure 1). Probes were changes

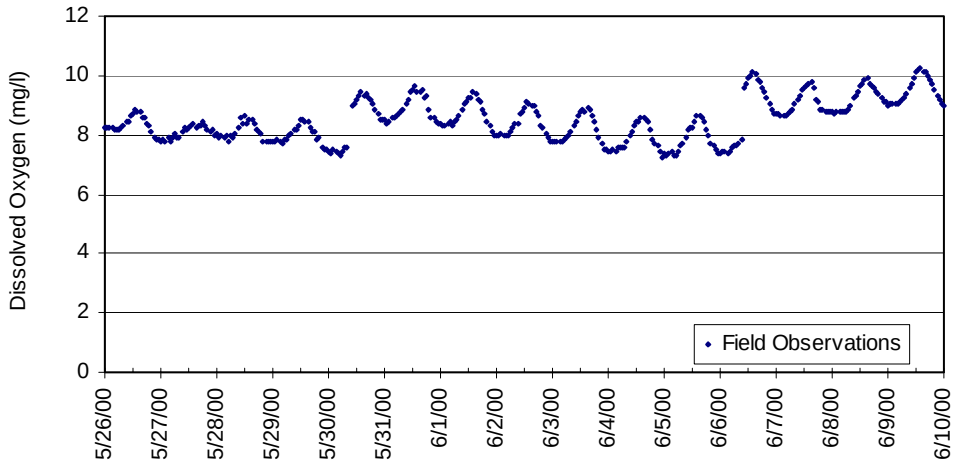


Figure 1. Observed dissolved oxygen at Seiad Valley, May-June 2000

To adjust the observed dissolved oxygen trace it was assumed that upon deployment the "fresh" probes are reading correctly. Using the difference form the last reading on the retrieved probe and the first reading deployed probe the traces were adjusted to provide a reasonable estimate of actual conditions. This method, which distributes the error over the entire period assumes that biolfouling affects probes uniformly from the hour of deployment to the hour of retrieval. Figure 2 shows the final results for the week of May 30 through June 6, 2000. Figure 3 shows the results for August 1-14, 2000.

Similar conditions occurred at the Klamath River at Youngs Bar and were addressed in the same fashion (Figures 4 and 5).

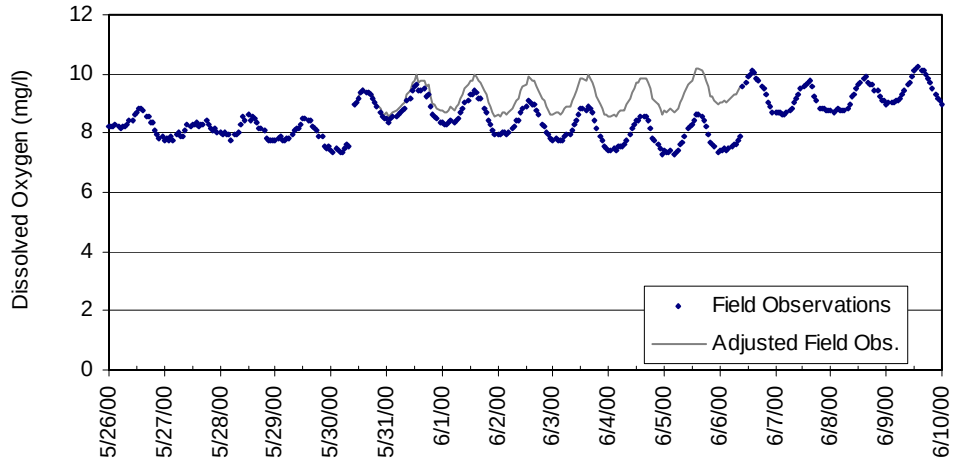


Figure 2. Observed and adjusted dissolved oxygen at Seiad Valley, May-June 2000

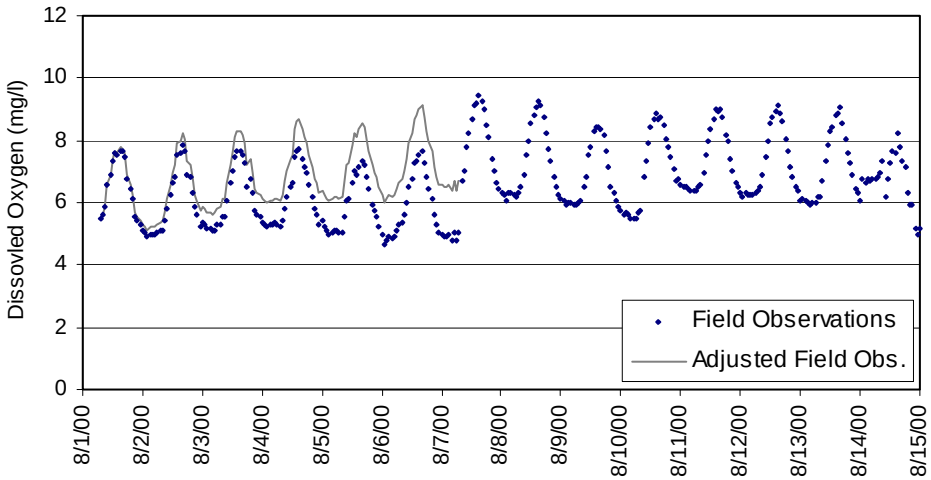


Figure 3. Observed and adjusted dissolved oxygen at Seiad Valley, August 2000

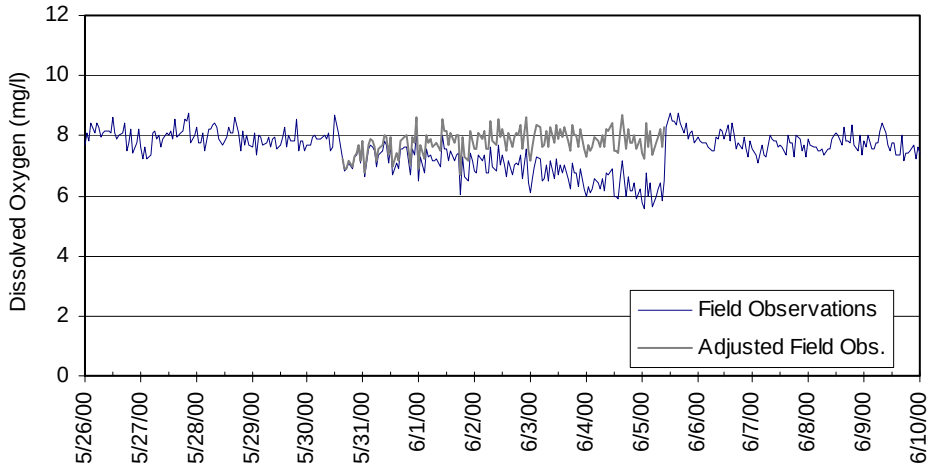


Figure 4. Observed dissolved oxygen at Youngs Bar, May-June 2000

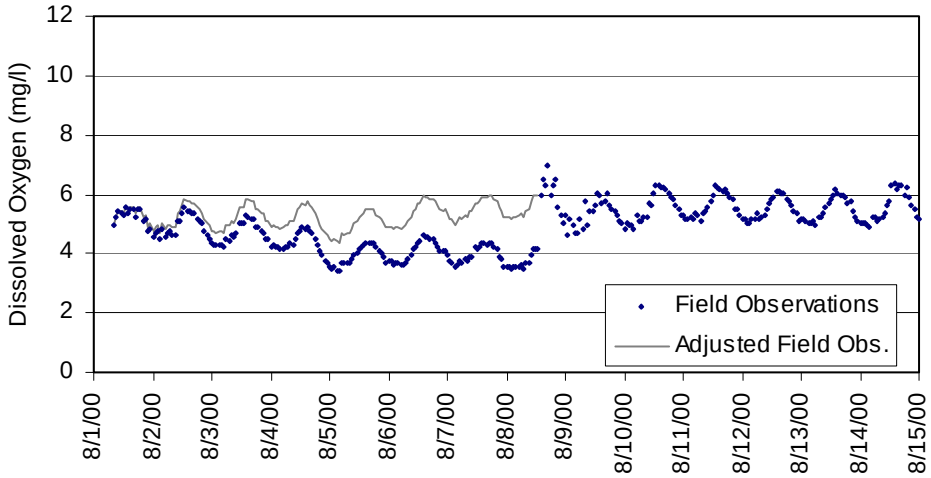


Figure 5. Observed and adjusted dissolved oxygen at Youngs Bar, August 2000

H 2001 Lake Ewauna/Keno Reach Boundary Conditions – Graphical and Tabular Presentation

The data to support the 2001 application of CE-QUAL-W2 to the Lake Ewauna/Keno Reservoir reach was not completed in a time to be included in the main documentation. The reader is referred to the main documentation, section 2.3.2 for the definitions of the various boundary conditions. Certain data are the same for 2001 and for 2000 and are not replicated herein.

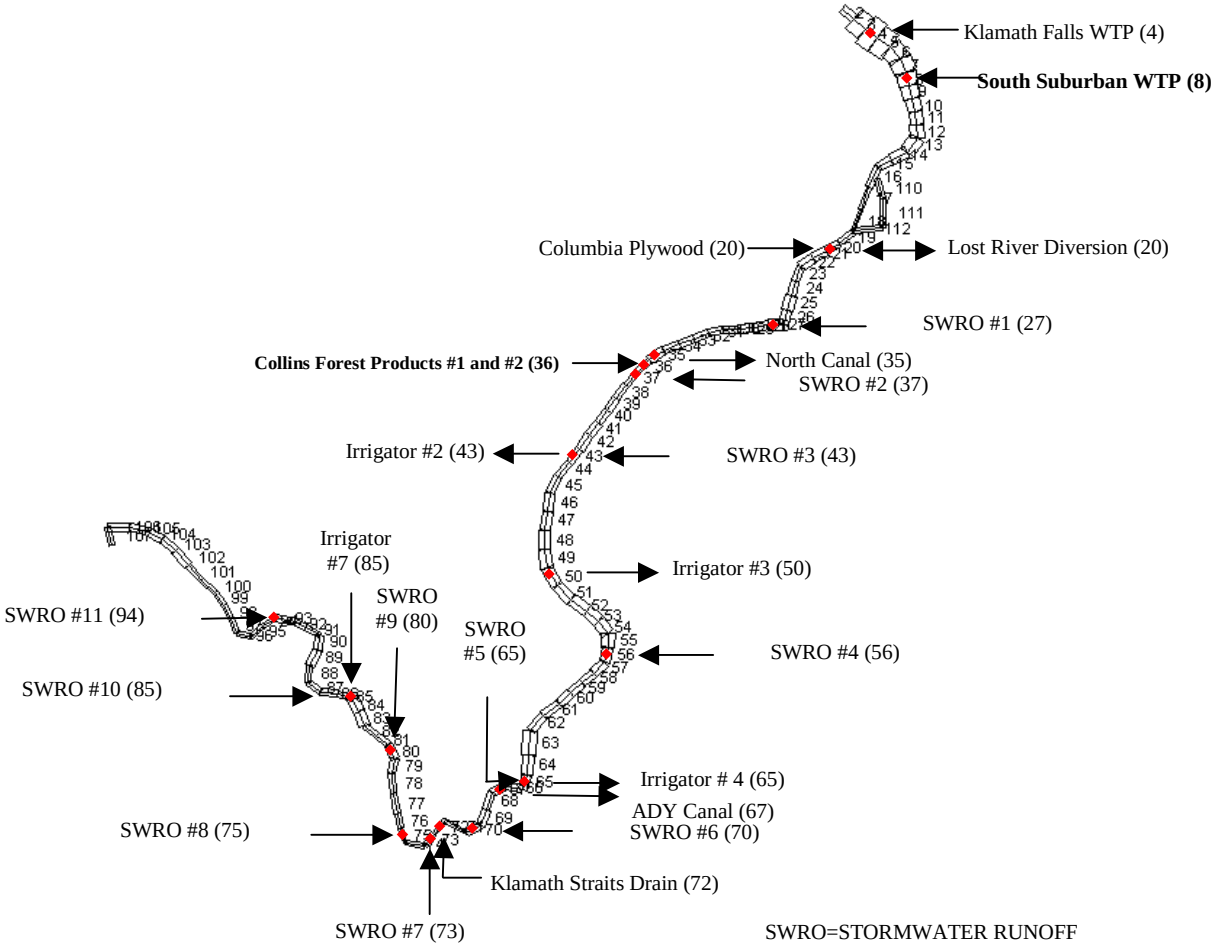


Figure 1. Map of Lake Ewauna to Keno Dam CE-QUAL-W2 presentation, identifying inputs and withdrawals

Link River Inflow

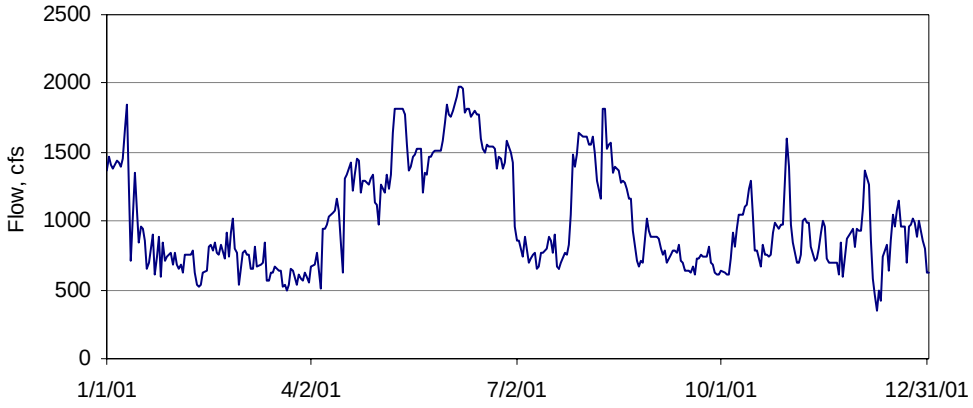
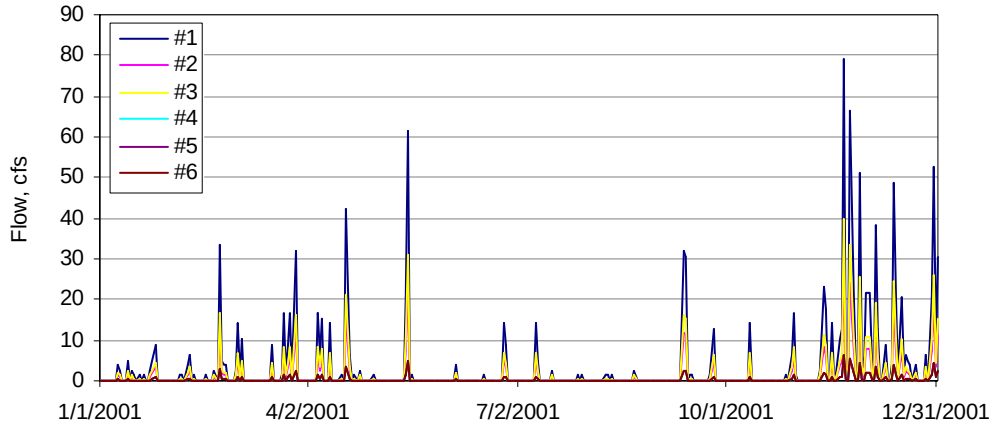


Figure 2. Lake Ewauna inflow at Link River for Lake Ewauna to Keno Dam reach model, 2001

Tributary Inflows



(a)

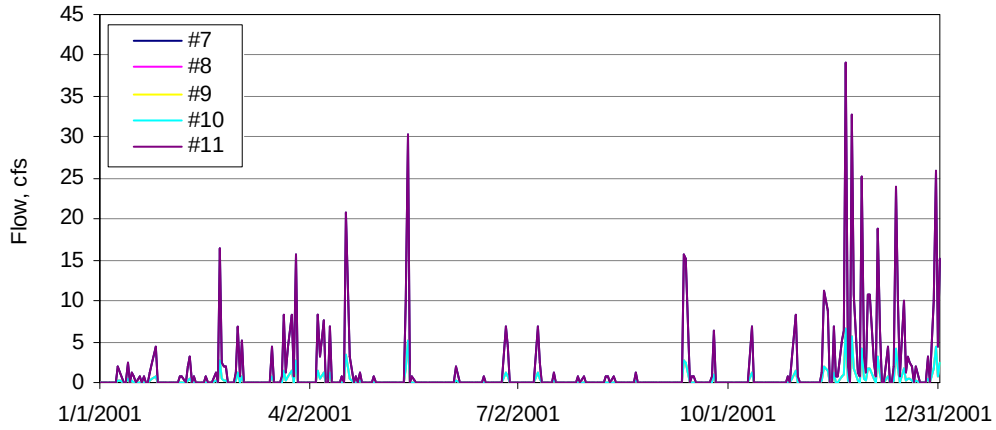


Figure 3. Storm water runoff flow for Lake Ewauna to Keno Dam reach model: (a) Runoff input locations #1 through #6, (b) Runoff input locations #7 through #11

Columbia Plywood

Table 15. Columbia Plywood inflow temperatures for Lake Ewauna to Keno Dam reach model, 2001

Julian Day	Inflow Temperature, C
1	13.61
15	13.33
46	13.89
74	14.44
105	16.11
135	17.22
166	18.89
196	21.11
227	20.56
258	18.33
288	15.56
319	13.33
349	13.89
366	13.61

Klamath Falls Water Treatment Plant

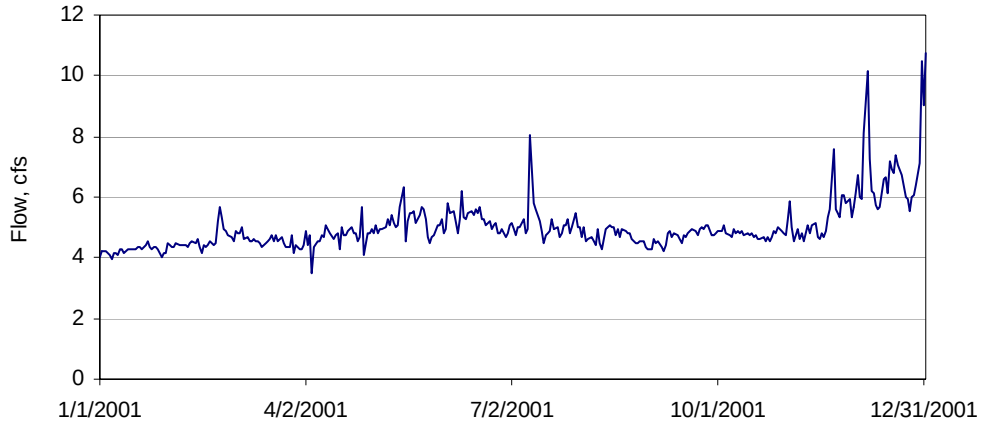


Figure 4. Klamath Falls Wastewater Treatment Plant for Lake Ewauna to Keno Dam reach model, 2001

South Suburban Sanitation District

Table 2. South Suburban Sanitation District flow for Lake Ewauan to Keno Dam reach model, 2001

Julian Day	Flow, cfs
1	3.11
15	2.98
46	2.69
75	3.00
106	2.68
136	0.86
167	0.96
197	1.03
228	1.58
259	2.18
289	2.06
320	2.46
350	4.92
366	5.09

Collins Forest Products

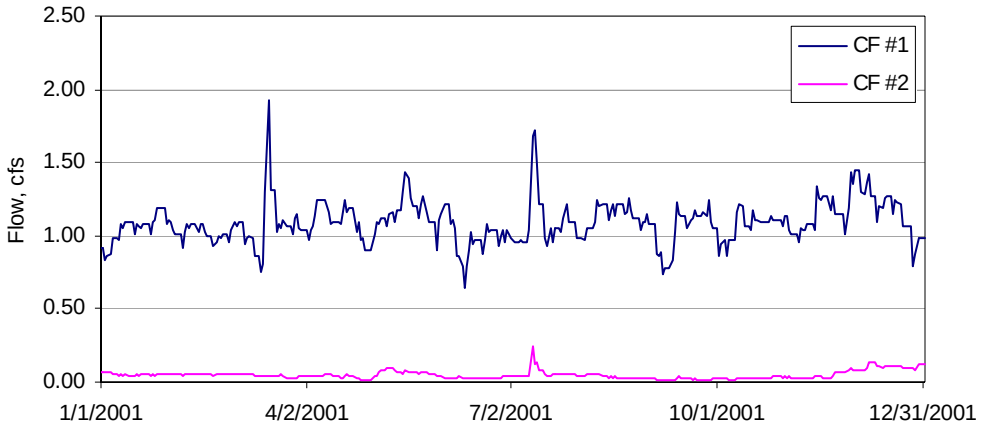


Figure 5. Collins Forest Product flows #1 and #2 for Lake Ewauna to Keno Dam reach model

Lost River Diversion Channel

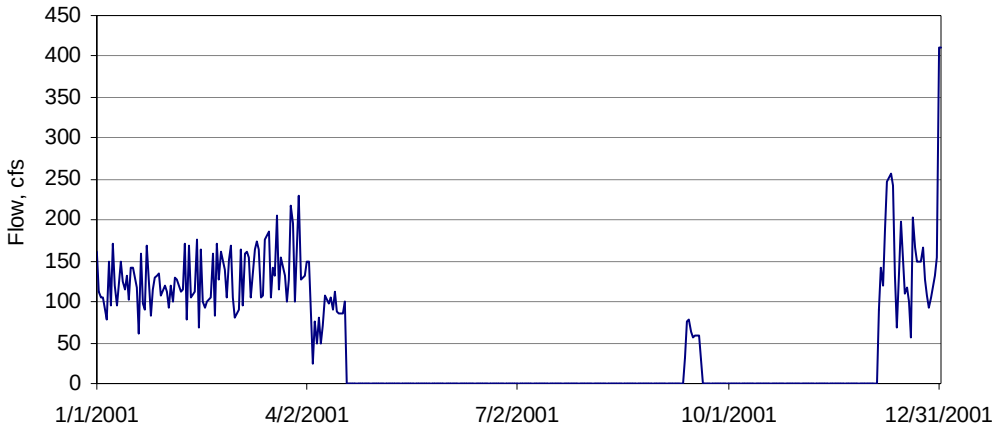


Figure 6. Lost River Diversion Channel inflows to Lake Ewauna for Lake Ewauna to Keno Dam reach model

Klamath Straits Drain

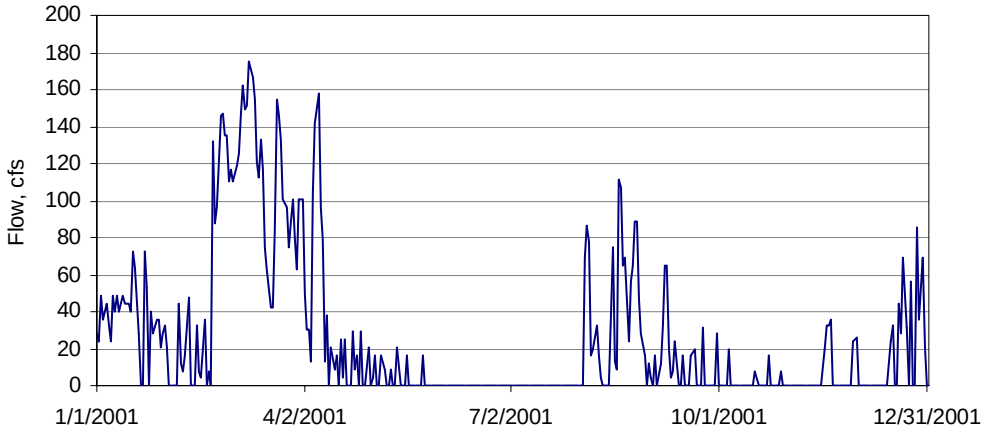


Figure 7. Klamath Straits Drain flow for Lake Ewauna to Keno Dam reach model

Withdrawals

Klamath Reclamation Project Diversions

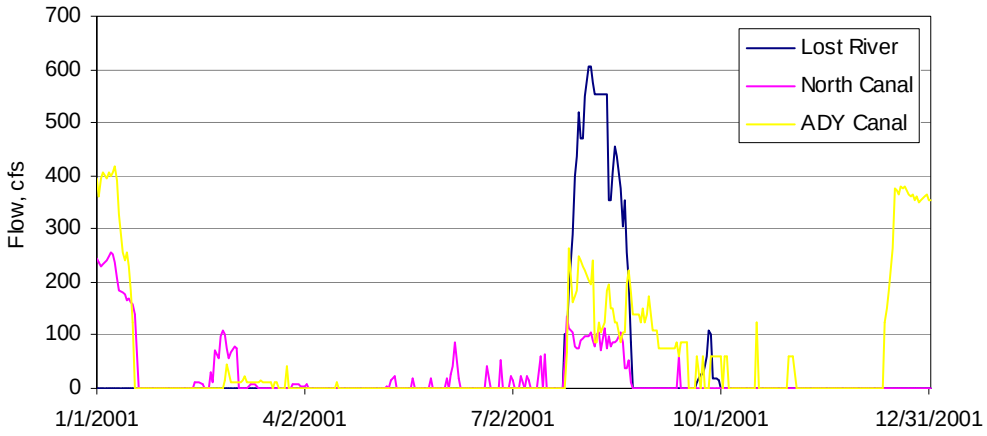


Figure 8. Klamath reclamation project diversions for Lake Ewauna to Keno Dam reach model, 2001

Non-Reclamation Irrigation Diversions

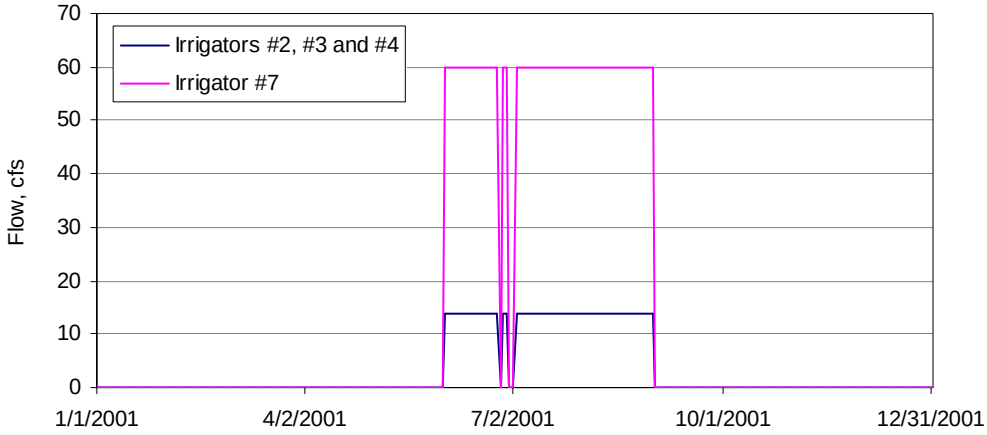


Figure 9. Irrigator withdrawals for Lake Ewauna to Keno Dam reach model, 2001

Keno Dam Outflow

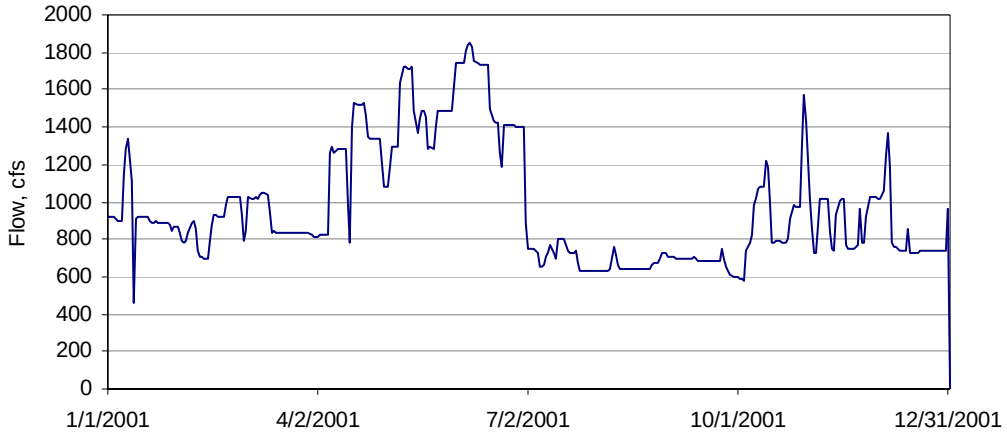


Figure 10. Keno Dam outflow for Lake Ewauna to Keno Dam reach model, 2001

Accretion/Depletion

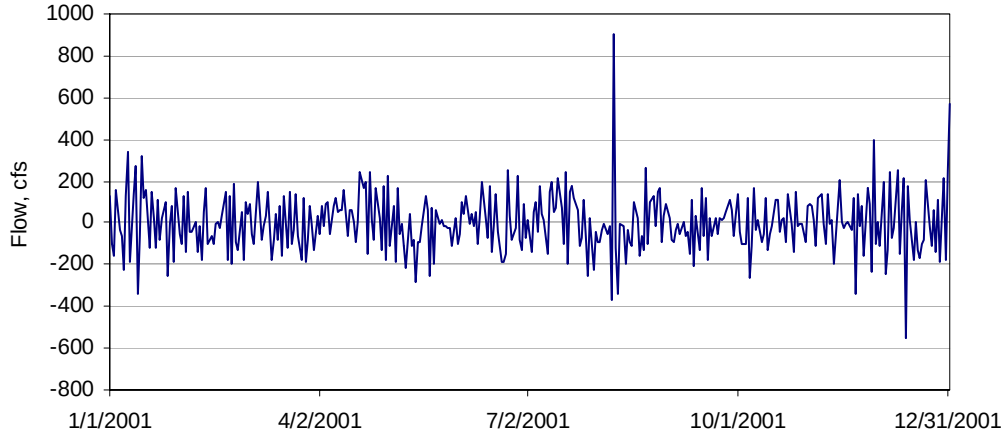


Figure 11. Accretion / depletion flow (distributed tributary) for Lake Ewauna to Keno Dam reach model, 2001

Tributary Temperatures

Klamath Falls Wastewater Treatment Plant Inflow Temperatures

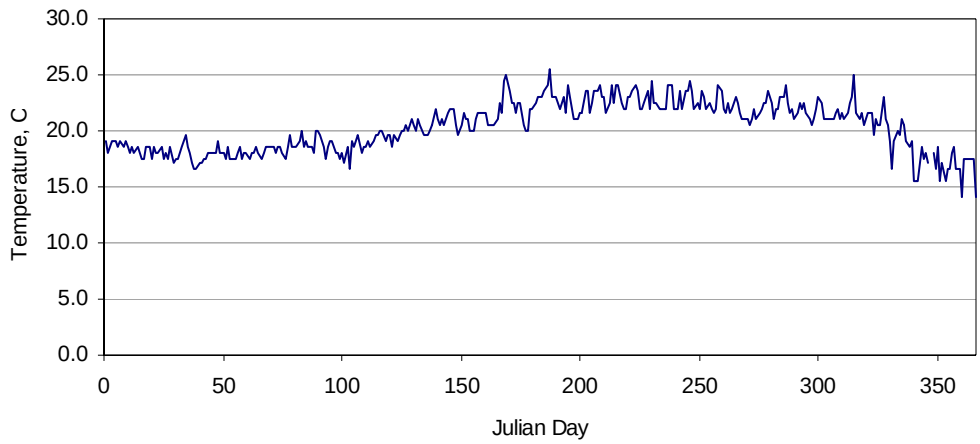


Figure 12. Klamath Falls Wastewater Treatment Plant inflow temperatures for Lake Ewauna to Keno Dam reach model

South Suburban Inflow Temperatures

Table 3. South Suburban Sanitation District inflow temperatures for Lake Ewauna to Keno Dam reach model implementation

Julian Day	Inflow Temperature, C
1	3.5
15	2.7
46	2.6
75	7.4
106	10.0
136	14.7
167	17.0
197	20.3
228	20.6
259	17.1
289	11.3
320	5.3
350	1.0
366	2.2

Lost River Inflow Temperatures

Table 4. Lost River Diversion inflow temperatures for Lake Ewauna to Keno Dam reach model

Julian Day	Inflow Temperature, C
1	3.62
4	3.62
17	1.74
37	5.95
52	5.20
66	7.98
192	26.21
205	25.19
221	26.75
235	18.28
247	20.48
275	19.42
289	12.62
303	9.22
317	7.14
366	7.14

Collins Forest Products Inflow Temperatures

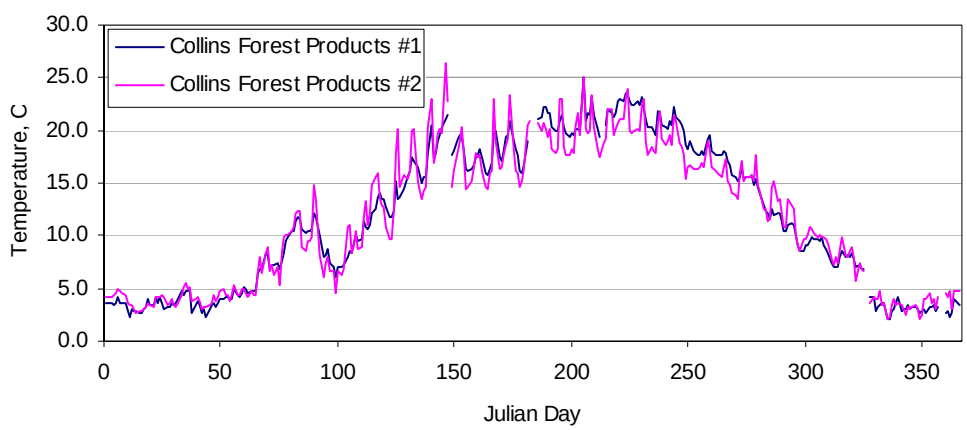


Figure 13. Collins Forest Products #1 and #2 inflow temperature for Lake Ewauna to Keno Dam reach model

Klamath Straits Drain Inflow Temperatures

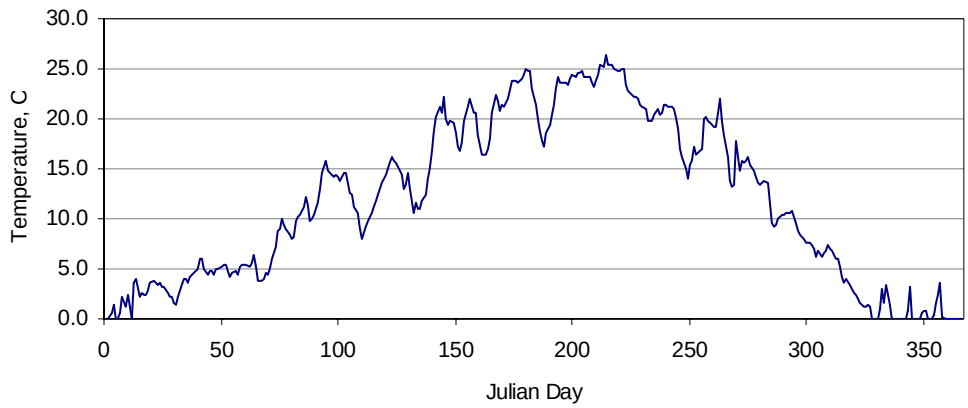


Figure 14. Klamath Straits Drain inflow temperatures for Lake Ewauna to Keno Dam reach model

Tributary Water Quality

Klamath Falls Wastewater Treatment Plant

Table 5. KFWTP inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	4.0	3.0	6.0	1.5	0.0	0.0	0.0	14.0	0.0	3.9	14.0	50.0
15	200.0	0.0	9.3	3.0	6.0	1.5	0.0	0.0	0.0	9.1	0.0	4.5	14.0	50.0
46	200.0	0.0	14.4	3.0	6.0	1.5	0.0	0.0	0.0	9.6	0.0	4.6	14.0	50.0
74	200.0	0.0	25.6	3.0	6.0	1.5	0.0	0.0	0.0	30.5	0.0	4.2	14.0	50.0
105	200.0	0.0	13.5	3.0	6.0	1.5	0.0	0.0	0.0	12.3	0.0	4.6	14.0	50.0
135	200.0	0.0	5.5	3.0	6.0	1.5	0.0	0.0	0.0	3.9	0.0	4.5	14.0	50.0
166	200.0	0.0	6.1	3.0	6.0	1.5	0.0	0.0	0.0	3.4	0.0	4.4	14.0	50.0
196	200.0	0.0	3.5	3.0	6.0	1.5	0.0	0.0	0.0	3.0	0.0	4.1	14.0	50.0
227	200.0	0.0	5.7	3.0	6.0	1.5	0.0	0.0	0.0	3.5	0.0	3.8	14.0	50.0
258	200.0	0.0	2.4	3.0	6.0	1.5	0.0	0.0	0.0	3.5	0.0	3.8	14.0	50.0
288	200.0	0.0	3.1	3.0	6.0	1.5	0.0	0.0	0.0	7.1	0.0	4.3	14.0	50.0
319	200.0	0.0	3.4	3.0	6.0	1.5	0.0	0.0	0.0	3.1	0.0	4.5	14.0	50.0
349	200.0	0.0	2.3	3.0	6.0	1.5	0.0	0.0	0.0	3.4	0.0	4.1	14.0	50.0
366	200.0	0.0	3.0	3.0	6.0	1.5	0.0	0.0	0.0	2.0	0.0	5.0	14.0	50.0

South Side Sanitation District

Table 6. SSSD inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	42.5	0.0	9.4	0.0	0.0	0.0	0.0	28.6	0.0	15.0	0.0	61.2
15	200.0	0.0	73.8	0.0	11.5	0.0	0.0	0.0	0.0	26.6	0.0	14.0	0.0	41.1
46	200.0	0.0	80.9	0.0	21.0	0.0	0.0	0.0	0.0	28.6	0.0	12.5	0.0	37.2
75	200.0	0.0	50.9	0.0	18.0	0.0	0.0	0.0	0.0	30.7	0.0	7.9	0.0	21.7
106	200.0	0.0	26.8	0.0	25.0	0.0	0.0	0.0	0.0	28.0	0.0	3.8	0.0	8.6
136	200.0	0.0	30.5	2.8	15.0	0.2	0.0	0.0	0.0	30.3	0.0	4.7	0.0	11.5
167	200.0	0.0	45.2	1.9	5.5	2.0	0.0	0.0	0.0	30.4	0.0	4.8	0.0	8.6
197	200.0	0.0	37.8	2.5	2.8	1.3	0.0	0.0	0.0	28.9	0.0	4.5	0.0	10.6
228	200.0	0.0	46.5	2.7	6.3	0.3	0.0	0.0	0.0	25.9	0.0	5.4	0.0	41.5
259	200.0	0.0	70.0	2.2	8.8	1.7	0.0	0.0	0.0	42.9	0.0	6.0	0.0	74.2
289	200.0	0.0	38.8	2.2	3.3	0.6	0.0	0.0	0.0	33.9	0.0	7.9	0.0	75.6
320	200.0	0.0	30.9	0.0	6.5	0.0	0.0	0.0	0.0	35.6	0.0	10.3	0.0	37.1
350	200.0	0.0	30.6	0.0	4.5	0.0	0.0	0.0	0.0	30.7	0.0	13.8	0.0	67.6
366	200.0	0.0	42.5	0.0	9.4	0.0	0.0	0.0	0.0	28.6	0.0	12.1	0.0	30.6

Lost River Diversion Channel

Table 7. Wilson Reservoir 2001 Data

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	2.0	0.9	9.7	23.0	140.0
4	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	2.0	1.0	11.5	23.0	120.0
17	175.0	0.0	10.0	0.1	0.1	0.4	0.0	0.0	0.0	2.0	0.4	13.2	23.0	140.0
37	175.0	0.0	10.0	0.1	0.1	0.3	0.0	0.0	0.0	2.0	0.4	12.1	23.0	140.0
52	175.0	0.0	10.0	0.1	0.2	0.4	0.0	0.0	0.0	2.0	0.4	10.1	23.0	130.0
66	175.0	0.0	10.0	0.1	0.1	0.1	0.0	0.0	0.0	2.0	0.7	10.3	23.0	140.0
192	175.0	0.0	10.0	0.4	0.0	0.2	0.0	0.0	0.0	5.4	1.7	6.7	23.0	132.0
205	175.0	0.0	10.0	0.2	0.0	0.1	0.0	0.0	0.0	5.7	1.0	5.9	23.0	135.0
221	175.0	0.0	10.0	0.3	0.1	0.0	0.0	0.0	0.0	6.2	1.2	8.0	23.0	139.0
235	175.0	0.0	10.0	0.3	0.1	0.3	0.0	0.0	0.0	6.6	1.2	3.8	23.0	132.0
247	175.0	0.0	10.0	0.2	0.0	0.0	0.0	0.0	0.0	6.9	0.8	4.2	23.0	142.0
275	175.0	0.0	10.0	0.1	0.1	0.0	0.0	0.0	0.0	7.7	0.7	7.9	23.0	153.0
289	175.0	0.0	10.0	0.2	0.0	0.0	0.0	0.0	0.0	7.6	0.5	8.9	23.0	164.0
303	175.0	0.0	10.0	0.1	0.1	0.0	0.0	0.0	0.0	6.6	0.1	9.2	23.0	146.0
317	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	5.6	0.3	9.7	23.0	156.0
366	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	2.0	0.9	9.7	23.0	150.0

Columbia Plywood

Table 8. Columbia Plywood inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	25.0	0.0	16.0	0.15	0.15	0.24	0.0	5.0	0.0	8.0	0.0	7.0	15.8	52.0
366	25.0	0.0	16.0	0.15	0.15	0.24	0.0	5.0	0.0	8.0	0.0	7.0	15.8	52.0

Collins Forest Products

Table 9. Collins Forest Products #1 inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	11.6	0.2	0.2	0.2	0.0	0.0	0.0	29.8	0.0	3.5	12.2	50.0
15	200.0	0.0	12.5	0.2	0.2	0.2	0.0	0.0	0.0	34.3	0.0	3.5	12.2	50.0
46	200.0	0.0	14.6	0.2	0.2	0.2	0.0	0.0	0.0	51.4	0.0	3.5	12.2	50.0
75	200.0	0.0	19.9	0.2	0.2	0.2	0.0	0.0	0.0	38.8	0.0	3.5	12.2	50.0
106	200.0	0.0	12.1	0.2	0.2	0.2	0.0	0.0	0.0	32.1	0.0	3.5	12.2	50.0
136	200.0	0.0	6.6	0.2	0.2	0.2	0.0	0.0	0.0	18.7	0.0	3.5	12.2	50.0
167	200.0	0.0	8.0	0.2	0.2	0.2	0.0	0.0	0.0	11.1	0.0	3.5	12.2	50.0
197	200.0	0.0	6.2	0.2	0.2	0.2	0.0	0.0	0.0	10.6	0.0	3.5	12.2	50.0
228	200.0	0.0	2.3	0.2	0.2	0.2	0.0	0.0	0.0	7.2	0.0	3.5	12.2	50.0
259	200.0	0.0	2.6	0.2	0.2	0.2	0.0	0.0	0.0	9.5	0.0	3.5	12.2	50.0
289	200.0	0.0	18.4	0.2	0.2	0.2	0.0	0.0	0.0	18.8	0.0	3.5	12.2	50.0
320	200.0	0.0	28.6	0.2	0.2	0.2	0.0	0.0	0.0	27.8	0.0	3.5	12.2	50.0
350	200.0	0.0	34.9	0.2	0.2	0.2	0.0	0.0	0.0	28.5	0.0	3.5	12.2	50.0
366	200.0	0.0	11.6	0.2	0.2	0.2	0.0	0.0	0.0	29.8	0.0	3.5	12.2	50.0

Table 10. Collins Forest Products #2 concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	20.7	3.0	3.0	0.5	0.0	0.0	0.0	15.0	0.0	3.5	11.9	50.0
15	200.0	0.0	32.5	3.0	3.0	0.5	0.0	0.0	0.0	12.6	0.0	3.5	11.9	50.0
46	200.0	0.0	42.5	3.0	3.0	0.5	0.0	0.0	0.0	17.1	0.0	3.5	11.9	50.0
75	200.0	0.0	38.0	3.0	3.0	0.5	0.0	0.0	0.0	18.1	0.0	3.5	11.9	50.0
106	200.0	0.0	35.8	3.0	3.0	0.5	0.0	0.0	0.0	23.6	0.0	3.5	11.9	50.0
136	200.0	0.0	24.3	3.0	3.0	0.5	0.0	0.0	0.0	14.1	0.0	3.5	11.9	50.0
167	200.0	0.0	5.3	3.0	3.0	0.5	0.0	0.0	0.0	5.9	0.0	3.5	11.9	50.0
197	200.0	0.0	7.6	3.0	3.0	0.5	0.0	0.0	0.0	7.6	0.0	3.5	11.9	50.0
228	200.0	0.0	3.2	3.0	3.0	0.5	0.0	0.0	0.0	6.3	0.0	3.5	11.9	50.0
259	200.0	0.0	2.9	3.0	3.0	0.5	0.0	0.0	0.0	8.0	0.0	3.5	11.9	50.0
289	200.0	0.0	2.1	3.0	3.0	0.5	0.0	0.0	0.0	5.1	0.0	3.5	11.9	50.0
320	200.0	0.0	10.9	3.0	3.0	0.5	0.0	0.0	0.0	8.0	0.0	3.5	11.9	50.0
350	200.0	0.0	31.1	3.0	3.0	0.5	0.0	0.0	0.0	16.1	0.0	3.5	11.9	50.0
366	200.0	0.0	20.7	3.0	3.0	0.5	0.0	0.0	0.0	15.0	0.0	3.5	11.9	50.0

Klamath Straits Drain

Table 16. KSD inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	354.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
15	374.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
46	316.0	0.0	24.0	0.2	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
75	365.0	0.0	24.0	0.2	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
106	409.0	0.0	24.0	0.4	0.3	0.5	0.0	10.0	0.0	5.0	1.0	4.7	37.0	150.0
136	423.0	0.0	24.0	0.5	0.5	0.5	0.0	13.0	0.0	5.0	1.0	6.8	37.0	150.0
167	319.0	0.0	24.0	0.5	0.5	0.5	0.0	15.0	0.0	5.0	1.0	3.5	37.0	150.0
197	266.0	0.0	24.0	0.5	0.5	1.0	0.0	15.0	0.0	5.0	1.0	2.4	37.0	150.0
228	252.0	0.0	24.0	0.3	0.5	1.3	0.0	13.0	0.0	5.0	1.0	1.9	37.0	150.0
259	296.0	0.0	24.0	0.2	1.0	2.0	0.0	10.0	0.0	5.0	1.0	2.8	37.0	150.0
289	376.0	0.0	24.0	0.2	1.5	0.3	0.0	10.0	0.0	5.0	1.0	3.3	37.0	150.0
320	294.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.1	37.0	150.0
350	334.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
366	354.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0

Distributed Tributary

Table 12. Distributed tributary concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	25.0	0.0	0.0	0.1	0.05	1.0	0.0	0.0	0.0	1.0	0.0	3.0	20.2	80.0
274	25.0	0.0	0.6	0.1	0.05	1.0	0.0	0.0	0.0	1.0	0.0	3.0	20.2	80.0
366	25.0	0.0	0.6	0.1	0.05	1.0	0.0	0.0	0.0	1.0	0.0	3.0	20.2	80.0

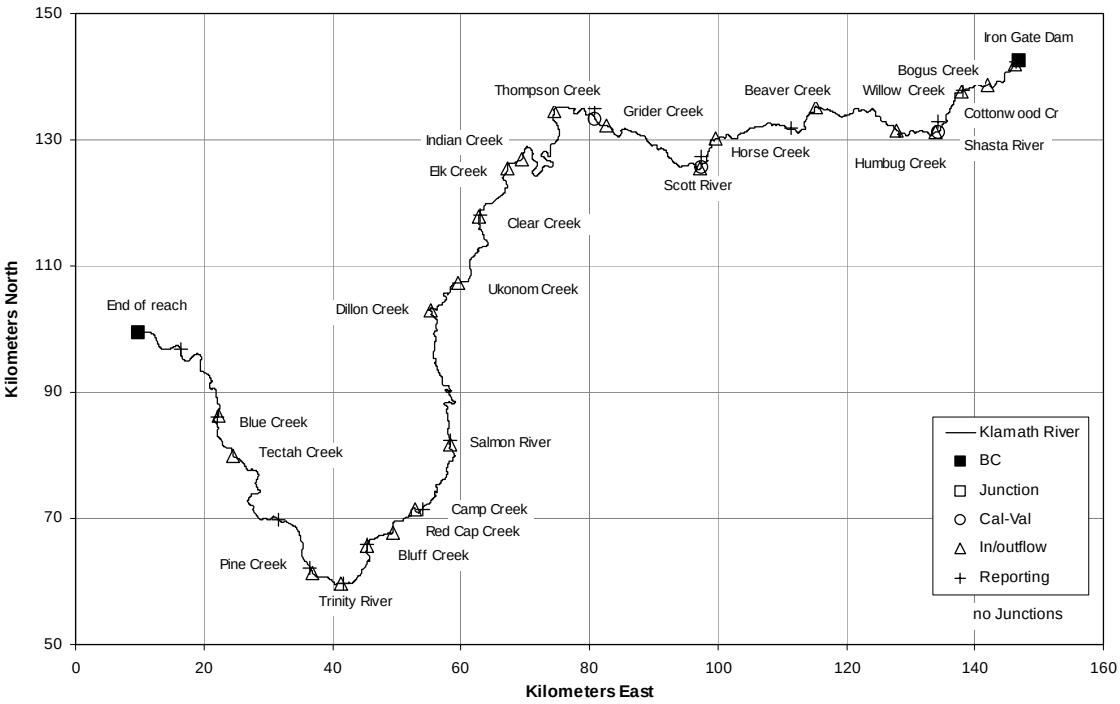
"Tracer" is a conservative constituent that does not decay or react with time or space. Can be used to check conservation of mass within the model framework.

Stormwater Runoff

Table 13. Storm water runoff concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	25.0	0.0	5.0	0.05	0.05	0.1	0.0	3.0	0.0	0.7	0.0	9.0	15.9	52.0
366	25.0	0.0	5.0	0.05	0.05	0.1	0.0	3.0	0.0	0.7	0.0	9.0	15.9	52.0

Klamath River Modeling Framework to Support the PacifiCorp Federal Energy Regulatory Commission Hydropower Relicensing Application



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Unit Abbreviations

Acre-feet	ac-ft
Cubic feet per second	cfs
Day	d
Degree Celsius	°C
Degree Fahrenheit	°F
Degree Kelvin	K
Feet	ft
Fluid ounce	fl oz
Gallon	gal
Gram	g
Hectare	ha
Hour	hr
Inch	in
Joule	J
Kilogram	kg
Kilometer	km
Liter	L
Meter	m
Microgram	µg
Micromhos	µmhos
Mile	mi
Millibar	mb
Milliliter	ml
Microgram	µg
Milligram	mg
Millimeter	mm
Ounce	oz
Parts per billion	ppb
Parts per million	ppm
Parts per thousand	ppt
Pascal	Pa
Pounds per square inch	psi
Second	s
Watt	W
Yard	yd

Unit Conversions

Class	Multiply	By	To Obtain
Area	acre	4047.0	m^2
	acre	0.4047	ha (10 000 m^2)
	ft^2	0.0929	m^2
	yd^2	0.8361	m^2
	mi^2	2.590	km^2
Length	ft	0.3048	m
	in	25.4	mm
	mi	1.6093	km
	yd	0.9144	m
Volume	ft^3	0.0283	m^3
	gal	3.785	L
	fl oz	29.575	mL
	yd^3	0.7646	m^3
	acre-feet	1233.49	m^3
Mass	oz	28.35	g
	lb	0.4536	kg
Concentration	g/l	1.0	ppb
	g/l	1.0	mg/m^3
	g/l	0.001	mg/l
	mg/l	1.0	ppm
	mg/l	1.0	g/m^3
	mg/l	0.001	g/L
	g/l	1.0	ppt
	g/l	1.0	kg/m^3
Density	lb/ft^3	6894.7	kg/m^3
Velocity	ft/s	0.3048	m/s
	mi/hr	0.4470	m/s
	mi/hr	1.6093	km/h
Flow Rate	cfs	0.0283	cms
Temperature	°F	$T_{°C} = (T_{°F} – 32.0)/1.8$	°C

Temperature Conversion Table

Temperature		Temperature	
^oC	^oF	^oC	^oF
0.0	32.0	25.0	77.0
1.0	33.8	26.0	78.8
2.0	35.6	27.0	80.6
3.0	37.4	28.0	82.4
4.0	39.2	29.0	84.2
5.0	41.0	30.0	86.0
6.0	42.8	31.0	87.8
7.0	44.6	32.0	89.6
8.0	46.4	33.0	91.4
9.0	48.2	34.0	93.2
10.0	50.0	35.0	95.0
11.0	51.8	36.0	96.8
12.0	53.6	37.0	98.6
13.0	55.4	38.0	100.4
14.0	57.2	39.0	102.2
15.0	59.0	40.0	104.0
16.0	60.8	41.0	105.8
17.0	62.6	42.0	107.6
18.0	64.4	43.0	109.4
19.0	66.2	44.0	111.2
20.0	68.0	45.0	113.0
21.0	69.8	46.0	114.8
22.0	71.6	47.0	116.6
23.0	73.4	48.0	118.4
24.0	75.2	49.0	120.2

Julian Days (2000 Leap Year)

1-Jan-00	1	**1-Mar-00**	61	**1-May-00**	122	**1-Jul-00**	183	**1-Sep-00**	245	**1-Nov-00**	**306**
2-Jan-00	2	2-Mar-00	62	2-May-00	123	2-Jul-00	184	2-Sep-00	246	2-Nov-00	307
3-Jan-00	3	3-Mar-00	63	3-May-00	124	3-Jul-00	185	3-Sep-00	247	3-Nov-00	308
4-Jan-00	4	4-Mar-00	64	4-May-00	125	4-Jul-00	186	4-Sep-00	248	4-Nov-00	309
5-Jan-00	5	5-Mar-00	65	5-May-00	126	5-Jul-00	187	5-Sep-00	249	5-Nov-00	310
6-Jan-00	6	6-Mar-00	66	6-May-00	127	6-Jul-00	188	6-Sep-00	250	6-Nov-00	311
7-Jan-00	7	7-Mar-00	67	7-May-00	128	7-Jul-00	189	7-Sep-00	251	7-Nov-00	312
8-Jan-00	8	8-Mar-00	68	8-May-00	129	8-Jul-00	190	8-Sep-00	252	8-Nov-00	313
9-Jan-00	9	9-Mar-00	69	9-May-00	130	9-Jul-00	191	9-Sep-00	253	9-Nov-00	314
10-Jan-00	10	10-Mar-00	70	10-May-00	131	10-Jul-00	192	10-Sep-00	254	10-Nov-00	315
11-Jan-00	11	11-Mar-00	71	11-May-00	132	11-Jul-00	193	11-Sep-00	255	11-Nov-00	316
12-Jan-00	12	12-Mar-00	72	12-May-00	133	12-Jul-00	194	12-Sep-00	256	12-Nov-00	317
13-Jan-00	13	13-Mar-00	73	13-May-00	134	13-Jul-00	195	13-Sep-00	257	13-Nov-00	318
14-Jan-00	14	14-Mar-00	74	14-May-00	135	14-Jul-00	196	14-Sep-00	258	14-Nov-00	319
15-Jan-00	15	15-Mar-00	75	15-May-00	136	15-Jul-00	197	15-Sep-00	259	15-Nov-00	320
16-Jan-00	16	16-Mar-00	76	16-May-00	137	16-Jul-00	198	16-Sep-00	260	16-Nov-00	321
17-Jan-00	17	17-Mar-00	77	17-May-00	138	17-Jul-00	199	17-Sep-00	261	17-Nov-00	322
18-Jan-00	18	18-Mar-00	78	18-May-00	139	18-Jul-00	200	18-Sep-00	262	18-Nov-00	323
19-Jan-00	19	19-Mar-00	79	19-May-00	140	19-Jul-00	201	19-Sep-00	263	19-Nov-00	324
20-Jan-00	20	20-Mar-00	80	20-May-00	141	20-Jul-00	202	20-Sep-00	264	20-Nov-00	325
21-Jan-00	21	21-Mar-00	81	21-May-00	142	21-Jul-00	203	21-Sep-00	265	21-Nov-00	326
22-Jan-00	22	22-Mar-00	82	22-May-00	143	22-Jul-00	204	22-Sep-00	266	22-Nov-00	327
23-Jan-00	23	23-Mar-00	83	23-May-00	144	23-Jul-00	205	23-Sep-00	267	23-Nov-00	328
24-Jan-00	24	24-Mar-00	84	24-May-00	145	24-Jul-00	206	24-Sep-00	268	24-Nov-00	329
25-Jan-00	25	25-Mar-00	85	25-May-00	146	25-Jul-00	207	25-Sep-00	269	25-Nov-00	330
26-Jan-00	26	26-Mar-00	86	26-May-00	147	26-Jul-00	208	26-Sep-00	270	26-Nov-00	331
27-Jan-00	27	27-Mar-00	87	27-May-00	148	27-Jul-00	209	27-Sep-00	271	27-Nov-00	332
28-Jan-00	28	28-Mar-00	88	28-May-00	149	28-Jul-00	210	28-Sep-00	272	28-Nov-00	333
29-Jan-00	29	29-Mar-00	89	29-May-00	150	29-Jul-00	211	29-Sep-00	273	29-Nov-00	334
30-Jan-00	30	30-Mar-00	90	30-May-00	151	30-Jul-00	212	30-Sep-00	274	30-Nov-00	335
31-Jan-00	31	31-Mar-00	91	31-May-00	152	31-Jul-00	213	**1-Oct-00**	275	**1-Dec-00**	336
1-Feb-00	32	**1-Apr-00**	92	**1-Jun-00**	153	**1-Aug-00**	214	2-Oct-00	276	2-Dec-00	337
2-Feb-00	33	2-Apr-00	93	2-Jun-00	154	2-Aug-00	215	3-Oct-00	277	3-Dec-00	338
3-Feb-00	34	3-Apr-00	94	3-Jun-00	155	3-Aug-00	216	4-Oct-00	278	4-Dec-00	339
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5-Feb-00	36	5-Apr-00	96	5-Jun-00	157	5-Aug-00	218	6-Oct-00	280	6-Dec-00	341
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22-Feb-00	53	22-Apr-00	113	22-Jun-00	174	22-Aug-00	235	23-Oct-00	297	23-Dec-00	358
23-Feb-00	54	23-Apr-00	114	23-Jun-00	175	23-Aug-00	236	24-Oct-00	298	24-Dec-00	359
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27-Feb-00	58	27-Apr-00	118	27-Jun-00	179	27-Aug-00	240	28-Oct-00	302	28-Dec-00	363
28-Feb-00	59	28-Apr-00	119	28-Jun-00	180	28-Aug-00	241	29-Oct-00	303	29-Dec-00	364
29-Feb-00	60	29-Apr-00	120	29-Jun-00	181	29-Aug-00	242	30-Oct-00	304	30-Dec-00	365
		30-Apr-00	121	30-Jun-00	182	30-Aug-00	243	31-Oct-00	305	31-Dec-00	366
						31-Aug-00	244				

Julian Days (2001)

1-Jan-01	1	**1-Mar-01**	60	**1-May-01**	121	**1-Jul-01**	182	**1-Sep-01**	244	**1-Nov-01**	**305**
2-Jan-01	2	2-Mar-01	61	2-May-01	122	2-Jul-01	183	2-Sep-01	245	2-Nov-01	306
3-Jan-01	3	3-Mar-01	62	3-May-01	123	3-Jul-01	184	3-Sep-01	246	3-Nov-01	307
4-Jan-01	4	4-Mar-01	63	4-May-01	124	4-Jul-01	185	4-Sep-01	247	4-Nov-01	308
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6-Jan-01	6	6-Mar-01	65	6-May-01	126	6-Jul-01	187	6-Sep-01	249	6-Nov-01	310
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1-Feb-01	32	**1-Apr-01**	91	**1-Jun-01**	152	**1-Aug-01**	213	2-Oct-01	275	2-Dec-01	336
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28-Feb-01	59	28-Apr-01	118	28-Jun-01	179	28-Aug-01	240	29-Oct-01	302	29-Dec-01	363
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		30-Apr-01	120	30-Jun-01	181	30-Aug-01	242	31-Oct-01	304	31-Dec-01	365
						31-Aug-01	243				

1 Introduction

Watercourse Engineering, Inc. (Watercourse) has undertaken the design and implementation of a flow and water quality modeling framework for the Klamath River from Link Dam to Turwar to support studies for the Federal Energy Regulatory Commission Hydropower relicensing process. Link Dam is located at Klamath River Mile (RM) 255 and Turwar at RM 5. The original framework and supporting documentation are found in attached appendices. Outlined herein are three specific tasks:

1) Model Implementation
2) Calibration and Validation
3) Model Application

Model implementation is the process of gathering appropriate data (including geometry, flow, water quality, and meteorology) and formatting it for input into numerical models. Also included in this step is selection of default model parameters and general model testing. The end result of model implementation is a running, but uncalibrated model. Model calibration and validation is the stage wherein model parameters are modified to fit the model to field observations – calibration. The model is then tested on an independent set of data (validation) to illustrate that the model can replicate field conditions with parameter values determined in calibration. The final stage of implementation is model application, wherein the calibrated models are applied to selected management strategies or scenarios. Such scenarios may represent varied flow or water quality conditions and may include the addition or removal of project facilities to identify potential impacts and outcomes. Data sets for model implementation, calibration and application are described in the text.

This report is arranged as per the three specific modeling tasks outlined above, with supporting information presented in appendices. Appendices includes the modeling framework proposed with additions and changes included, as well as other supporting information.

2 Model Implementation

2.1 Model Selection

Flow and water quality conditions in the Klamath River basin vary dramatically along the approximately 250 river miles from Link Dam (RM 255), near Klamath Falls Oregon, to Turwar (RM 5), California. There are a wide range of natural and anthropogenic influences affecting water quality along this extended stretch of river: inflows to the system at Link Dam originate in hypereutrophic Upper Klamath Lake; there are four major reservoirs on the main stem Klamath River; diversions and return flows for agriculture, as well as municipal and industrial use, occur in the reach between Link Dam and Keno Dam; and the river receives considerable inflow from tributaries as it flows towards the Pacific Ocean..

A combination of discrete river models and reservoir models were selected to address these diverse system characteristics. Selected river models were produced by Resource Management Associates (RMA). Flow is represented with RMA-2, a finite element hydrodynamic model capable of modeling highly dynamic flow regimes in short space and time steps. Output from the model (including velocity, depth, and representative surface and bed areas) is passed to the water quality model RMA-11. RMA-11 is a finite element water quality model simulating the fate and transport of a wide range of physical, chemical, and biological constituents. These two linked river models are applied on hourly or sub-hourly time steps to capture the short-term response of state variables such as temperature and dissolved oxygen. For this application the RMA models are applied in one-dimension, representing variations along the longitudinal axis of the river while vertical and lateral details are averaged.

System reservoirs are represented by the two-dimensional, longitudinal/vertical hydrodynamic and water quality model CE-QUAL-W2. Because the model assumes lateral homogeneity, it is well suited for relatively long and narrow water bodies exhibiting longitudinal and vertical water quality gradients. The CE-QUAL-W2 model is capable of representing a wide range physical, chemical, and biological processes affecting water quality. The model can simulate selective withdrawal, sediment nutrient release dynamics, nitrogen inhibition under anoxic conditions, internal weirs and curtains, and other options useful in assessing a wide range of existing and possible future conditions of the system. To interface with the river model, time steps on the same scale as the river models are employed.

2.2 Model Implementation

The river and reservoir models were implemented for nine discrete river reaches. These reaches are presented in Table 1 and shown on a map of the river in Figure 1. Model implementation includes constructing appropriate system geometry, flow and water quality conditions (boundary conditions, initial conditions), calibration/validation datasets, meteorological data, and other model parameters.

- Geometry data include a description of the river location (i.e., latitude and longitude, UTM, or similar coordinate system), bed slope, and cross section data. For reservoirs, bathymetric information and facilities information (such as stage-volume relationships, intake structure configurations, elevations, locations of diversion structures, and return points) are required.
- Flow and water quality information include system inflow (main stem system headwater, tributaries, return flows, etc.), outflow (diversions), reservoir storage change, and facilities operations. Water quality data for all inflows, as well as in-river and reservoir conditions, are required.
- Meteorological data include standard parameters for heat budget calculation within the numerical models, e.g., air temperature, wet bulb temperature (or dew point temperature), solar radiation, cloud cover, wind speed, and/or barometric pressure.
- Other model parameters include selection of time step, spatial resolution, identified periods of analysis, and selection of default model constants and coefficients.

Table 1. River reaches and representation in the modeling framework

Reach	Existing Representation	Model(s)
Link River	River	RMA-2/RMA-11
Lake Ewauna-Keno Dam	Reservoir	CE-QUAL-W2
Keno Dam to J.C. Boyle Reservoir	River	RMA-2/RMA-11
J.C. Boyle Reservoir	Reservoir	CE-QUAL-W2
Bypass Reach[a]	River	RMA-2/RMA-11
Peaking Reach[a]	River	RMA-2/RMA-11
Copco Reservoir[b]	Reservoir	CE-QUAL-W2
Iron Gate Reservoir	Reservoir	CE-QUAL-W2
IG Dam to Turwar	River	RMA-2/RMA-11

[a] The Bypass and Peaking sections are modeled as a single reach
[b] Copco 2 is not represented in the framework

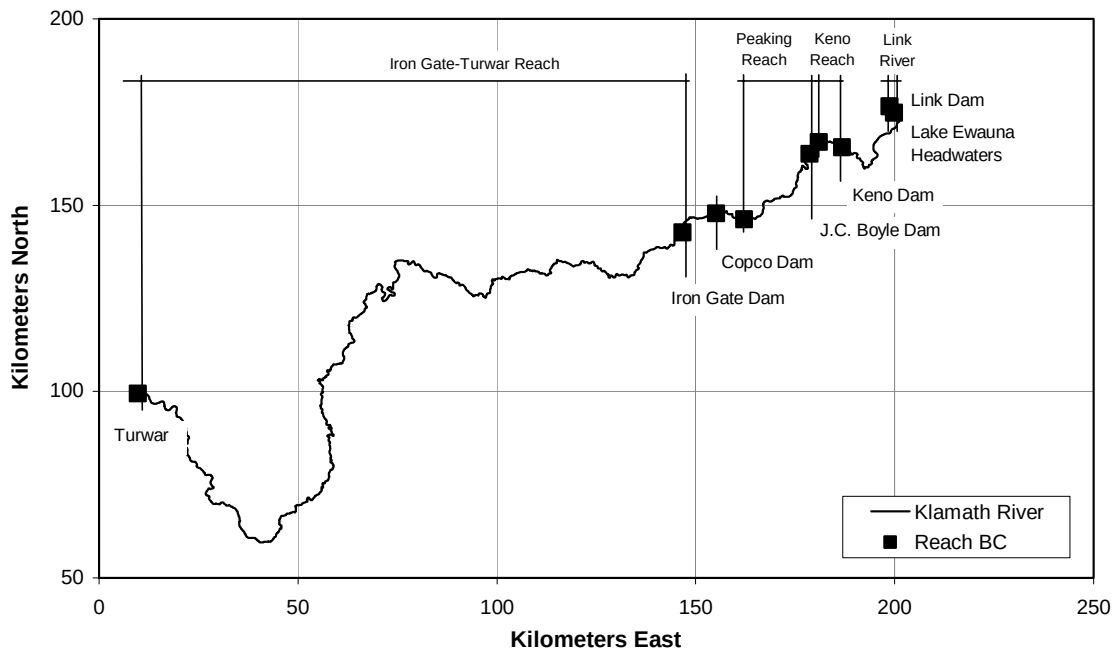


Figure 1. Designated river reaches and reservoirs

To create a system-wide simulation, the models are applied in series, starting with upper most reach – Link River – and passing output from one reach to the next. Thus output from the Link River (simulated with RMA models) forms the upstream boundary condition for the CE-QUAL-W2 representation of Lake Ewauna/Keno Reservoir. Similarly, output from CE-QUAL-W2 forms the headwater boundary condition for the river models representing the Keno River reach, the Klamath River from Keno Dam to J.C. Boyle Dam, and so on down the river. Flow conditions are generally not passed from reservoir to river reaches. Instead, historical flows (typically reported near the top of each river reach) are used as headwater boundary conditions for most river reaches. Further details of the flow records used in each reach are outlined later in this section.

Water quality is passed downstream between both reservoir and river reaches. But the river models (RMA) and the reservoir model (CE-QUAL-W2) do not represent all water quality parameters in the same fashion. The river models represent organic matter as organic nitrogen and organic phosphorous, while the reservoir model represents organic matter as refractory and labile dissolved and particulate organic matter. Stoichiometric equivalents are used to convert the appropriate information for passing from one model to the next. Details of these conversions are addressed in Model Application.

2.3 River-Reservoir Reaches

Model implementation for each reach is outlined in this section. Each reach is presented, in upsteam to downstream order, with a description of geometric data, flow and water quality conditions, and meteorological conditions.

2.3.1 Link River

The Link River reach starts at Link Dam and terminates at Lake Ewauna. There are two powerhouses which discharge into this reach. Geometry, flow, water quality, meteorological conditions, and other model parameters are outlined below. Flow is modeled with RMA-2 and water quality with RMA-11.

2.3.1.1 River Geometry

River Location

Coordinates describing river location and path were determined using a digitized version of 1:24,000 USGS topographic quadrangles provided by CH2MHill, as discussed in Appendix C. This information was translated into a network of nodes and elements for use by the numerical model. The Link River reach and important locations within the reach are shown in Figure 2 and presented in Table 2. All coordinates presented in this report are referenced to UTM 400000E 4500000N, NAD27 (typical).

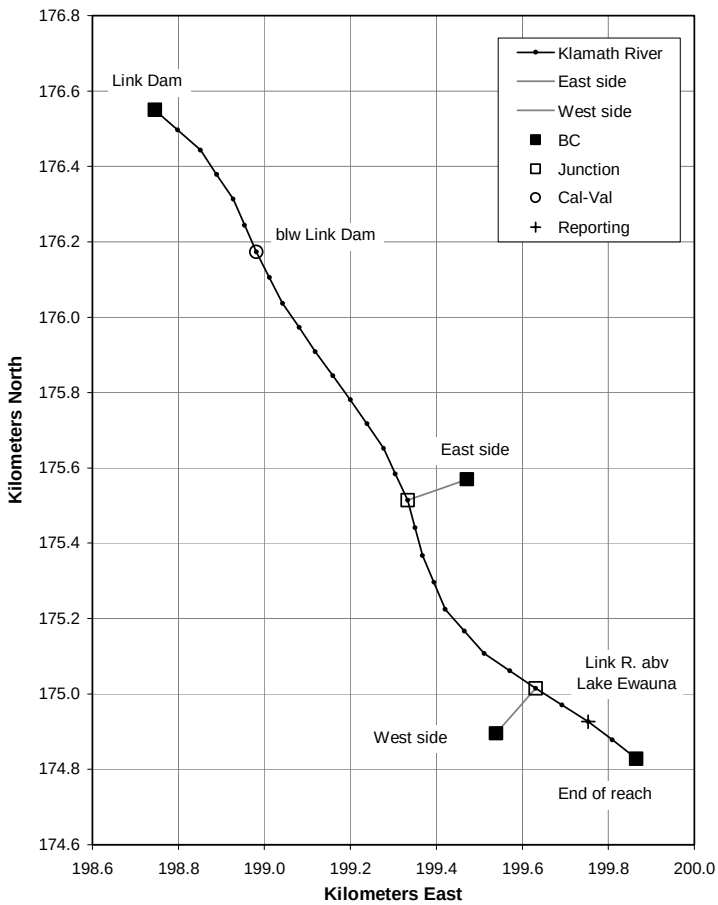


Figure 2. Map of Link River representation

Table 2. Geometry information for Link River

Location	Node	Element	x-coord	y-coord	Site type
Link Dam	1	1	198.8	176.6	BC
East Side	17	9	199.9	174.8	BC
West Side	25	13	199.5	175.6	BC
End Link R reach	29	14	199.5	174.9	BC
East Side	30	15	199.3	175.54	Junction, inflow
West Side	34	16	199.6	175.0	Junction, inflow
Link River above Lake Ewauna	27	-	199.8	174.9	Reporting Point

River Width

Link River widths were obtained from 1:7,500-scale aerial photos taken July 21, 1988.Daily average flow for that day was 920 cfs. Width measurements were taken at six locations within this relatively short river reach. Cross sections are represented by trapezoids with twenty-to-one side slopes on the main stem and one-to-one side slopes in the tributaries.

Bed Elevations/Slope

Bed slope for the reach was estimated from USGS topographic maps and estimated Lake Ewauna elevations. Upstream reach elevation was set at 4130.5 ft msl (1259 m) and the downstream reach elevation was set at 4084.6 ft msl (1245 m). Elevations were estimated from topographic contours to preserve the genral slope of the river. Because of uncertainty in these estimates, actual river bed elevations may differ. Link River reach geometry is summarized in Table 3.

Junctions and side flow

Tributaries and inflows can be represented in several fashions in RMA-2. When such inflows form a large percentage of the baseflow in the main stem, a junction is added to the model as a small branch. This type of inflow is placed at a single point in the model – a node. When inflows to the main stem are relatively modest, they are included in the model as element side flows. In this case the inflow is placed into simulated reach over the length of a single element. The Link River reach is simulated with two junctions and no element side flows.

Table 3. Link River Geometry Summary

Node spacing	75 meters
Number of nodes	29 nodes in length; 37 nodes total including junctions
Length	1.31 miles from RM 252.57-253.88
Elevations	Range: 1245-1259 meters
Widths	Constant widths: 5 meters main stem; 20 meters junction elements
Side slopes	20:1 main stem; 1:1 junctions
Data sources	UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps.
Notes	2 junctions: East side, West side; Nodes 30-33 at East side; 34-37 at West side

2.3.1.2 Flow Data

Inflows and Outflows

Water enters the Link River reach via releases from Link Dam. Two diversions are made from Upper Klamath Lake at Link Dam: one takes water along the west side of the river through a canal and short penstock to the West Side power house and the other takes water along the East Side of the River to the East Side power house. The East Side powerhouse returns to the river above the West Side powerhouse return. Between the East Side and West Side powerhouses lies the USGS Gage (11507500 Link River at Klamath Falls, OR). No outflows are represented in this reach.

Flow entering the reach at the upstream-most element (Link Dam) is termed the Link Bypass flow. East Side Turbine flows were calculated as the difference between the Link River USGS gage 11507500 and the Link Bypass flow. West Side Turbine flows are reported by PacifiCorp. East Side and West Side powerhouses are represented by junction elements in the model. There are no tributaries or accretions included as element side flows in the Link River reach.

Downstream Boundary Condition

The hydrodynamic downstream boundary condition for the Link River reach is determined by Lake Ewauna water surface elevation. This approach resulted in a variable stage downstream boundary condition, replicating backwater conditions at the lower end of the reach. Elevations measured by PacifiCorp in the vicinity of Highway 97 are assumed to represent stage at the headwaters of Lake Ewauna. Because river elevations were approximated from topographic maps and stage measurements are accurate, elevation discrepancies arise where rivers meet reservoirs. This discrepancy was estimated to be around 3 meters at Lake Ewauna headwaters, so the downstream boundary conditions for the Link River reach was defined as Keno Reservoir elevations plus 3 meters (9.84 feet).

2.3.1.3 Water Quality Data

Water quality data for the Link River reach was derived from multiple sources. Little data exists at Link Dam prior to 2001. Grab samples collected at Fremont Bridge from

1994 to 2001 and provided by the Klamath Tribes were used to describe seasonal water quality conditions at the upstream boundary of the reach. The East Side and West Side Turbines were assumed to have the same water source as the flows at Link Dam (the upstream boundary), so the same water quality was used for all three water sources in the Link River reach.. Data sources for Link River water quality boundary conditions are outlined in Table 4.

Table 4. Data sources for boundary conditions to the Link River reach

Data	Source	Type
Water quality parameters[1]	Klamath Tribes	Seasonal estimates
Temperature	U.S. Bureau of Reclamation	Hourly, seasonal estimates
Dissolved Oxygen	U.S. Bureau of Reclamation	Hourly, seasonal estimates

[1] Water quality parameters include pH, conductivity, total phosphorus, orthophosphates, total nitrogen, nitrate + nitrite, ammonia, chlorophyll-a and phaeophytin.

Temperature

Water temperatures reported from USBR monitoring of A-Canal during 2000-2001 were used to construct a composite of hourly inflow temperatures for the Link River. Calendar year 2000 temperatures were available from Julian Day (JD) 133 though JD 333. Calendar year 2001 temperatures were used from JD 26 through JD 133. Temperatures from JD 1 through 26 and from JD 333 through 367 were estimated by assuming that the temperature on JD 1 and JD 367 was 2 ºC and linearly interpolating. The East Side and West Side Turbines were assumed to have the same water source as the flows at Link Dam, so the same temperatures were used for all three water sources in the Link River reach.

Constituent Concentrations

Dissolved Oxygen: Limited field data are available to describe Link Dam dissolved oxygen. Hourly dissolved oxygen saturation concentrations were calculated from USBR water quality probe temperatures for A-Canal during 2000-2001. In a method analogous to that used for temperature, calculated dissolved oxygen concentrations were used to construct a composite of hourly inflow for the Link River reach. Calendar year 2000 dissolved oxygen saturation values were available from JD 133 though JD 333. Calendar year 2001 temperatures were used from JD 26 through JD 133. Dissolved oxygen concentrations from JD 1 through 26 and from JD 333 through 367 were estimated as the saturation values of the inflow temperatures. The East Side and West Side Turbines have the same water source as the flows at Link Dam, therefore the same dissolved oxygen were used for all three water sources in the Link River reach.

BOD: There was no biochemical oxygen demand data available for 2000. BOD levels were estimated based on available data from the 2002 sampling program completed by USBR. Samples were collected at two-week intervals from late April through September, 2002. BOD concentrations for Link Dam prior to April were assumed to be 2.0 mg/l. The USBR sampling effort suggests that BOD levels remain elevated through

the end of September. BOD was assumed to be 10 mg/l on October 15th, 3 mg/l on November 15th, and 2 mg/l after December 15th.

Nutrients and Algae: Water quality boundary conditions for the Link River were calculated from Upper Klamath Lake grab sample data collected by the Klamath Tribes from 1994-2001 at the Fremont Bridge (Kann, 2001). The Fremont Bridge location in Upper Klamath Lake was selected because of the proximity to the Link Dam.

Between 1994 and 2001 there were approximately 60 grab samples with nutrient concentrations (at multiple depths). Because there were insufficient samples in 2000 to identify a boundary condition for the Link River reach, a composite of all data were used to create monthly average concentrations that represented general seasonal conditions.

Comparison of field data suggested that conditions in the Fremont Bridge area were generally well mixed (i.e., minimal vertical variation for the selected water quality constituents). Thus all samples were used in the determination of monthly average concentrations. Data were sorted by Julian day and averaged. Monthly averages were calculated from the daily data. The first and last days of the year were given concentrations that were the average of the January and December monthly average concentrations. Organic nitrogen and phosphorus were calculated as the total forms minus the inorganic forms of each nutrient.

2.3.1.4 Meteorological Data

Required hourly information for a meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

Meteorological data for the Link River reach were derived from meteorological observations near Klamath Falls, OR. This meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure was calculated based on elevation (4100 ft (1250 m)) and assumed constant throughout the simulation period (870 mb). Wet bulb temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

All times within the modeling effort are Pacific Standard Time. Daylight Saving Time is not used.

2.3.2 Lake Ewauna to Keno Dam

The Lake Ewauna to Keno Dam reach extends from the headwaters of Lake Ewauna (RM 253) to Keno Dam (RM 233). The impoundment is generally a broad, shallow body of water. System width ranges from several hundred to over 1000 feet (over 300 meters), and a depths range to a maximum of roughly 20 feet (approximately 6 meters). There are

several discharges and withdrawals in this reach. Physical characteristics (e.g., geometry), flow, water quality, meteorological conditions, and other model parameters are outlined below. The reach is modeled with CE-QUAL-W2.

2.3.2.1 Reservoir Physical Data

The primary purpose of Keno Dam operations is to provide a regulated water surface for irrigation project diversions within this reservoir reach. A total of eighteen discharges and seven withdrawals were represented in the model.

Keno Dam Features

The Keno Dam spillway, with an invert elevation of 4070 feet, contains six Taintor gates. Three additional outlets include a sluice conduit, the fish attraction outlet, and the fish ladder exit to the reservoir. The details of these outlets are summarized in Table 5.

Table 5. Keno Dam outlet features

Outlet	Invert Elevation	Dimension	Operation
Sluice Conduit	4,073.0 ft	36 inch diameter	Manual gate
Fish Attraction Outlet	4,075.0 ft	30 inch diameter	Manual gate
Fish Ladder	4,078.5 ft	60 inch width	Stop logs
Spillway	4,070.0 ft	6 gates @ 40 ft width each	Remote control on three gates
Sources:	PacifiCorp (2002), PacifiCorp (2000)		

Reservoir Bathymetry for CE-QUAL-W2

The model was originally implemented with the bathymetry for the Lake Ewauna to Keno Dam section of the Klamath River derived from existing bathymetry created by Dr. Scott Wells (ODEQ, 1995). This representation was replaced using the results of a recent bathymetrc survey of the entire reservoir (MaxDepth Aquatics, Inc., 2004).

The number of segments, number of layers, segment lengths, layer widths per segment and water surface elevation from the Wells (ODEQ, 1995) work largely retained, but were supplemented by new segment orientations calculated from the x-y coordinates provided by CH2MHill. Orientation of individual river segments was updated because the original file orientations contained discrepancies when applied to the newer versions of CE-QUAL-W2. Model representation is shown in Figure 3.

In addition to segment and layer specifications, bottom roughness was represented by a Manning coefficient of 0.04 for each segment. The volume generated by model representation was consistent with the volume calculated from reservoir bathymetry available from PacifiCorp.

The CE-QUAL-W2 representation of Lake Ewauna to Keno reach has two branches. Branch 1 has 106 active segments, all 1000 ft (304.8 m) in length. Branch 2 has three active segments, each 800 ft (243.8 m) in length. There are fifteen active layers in Lake Ewauna all 2.00 ft (0.61 m) thick. Branch 2 starts at Branch 1, Segment 14, and ends at Branch 1, Segment 18. A total of eighteen discharges and seven withdrawals were

represented in the model (see Table 6). Branch 2 has no external inflows or outflows. The modeled and observed stage-volume curve is shown in Figure 4.

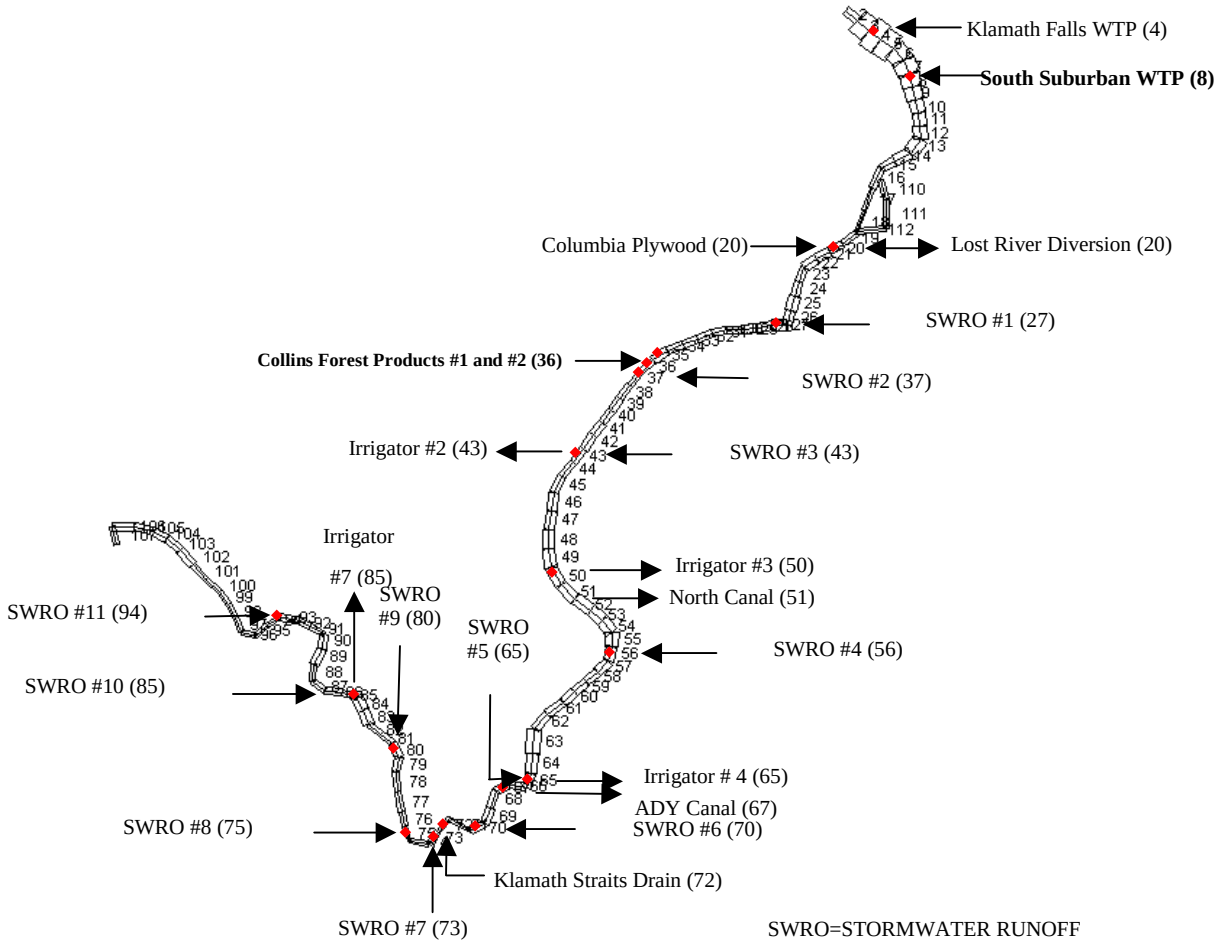


Figure 3. Map of Lake Ewauna to Keno Dam CE-QUAL-W2 representation, identifying inputs and withdrawals

Table 6. Modeled inflows and outflows in the Lake Ewauna to Keno Dam reach

Name	Type	River Bank [a]	Approximate RM [b]	Model Segment
Klamath Falls Wastewater Treatment Plant	Inflow	Left	253	4
South Suburban Sanitation District	Inflow	Left	252	8
Columbia Plywood	Inflow	Right	250	20
Lost River Diversion	Inflow / Outflow	Left	250	20
Collins Forest Products #1	Inflow	Right	247	36
Collins Forest Products #2	Inflow	Right	247	36
Klamath Straits Drain	Inflow	Left	240	72
Stormwater Runoff #1	Inflow	NA	249	27
Stormwater Runoff #2	Inflow	NA	247	37
Stormwater Runoff #3	Inflow	NA	246	43
Stormwater Runoff #4	Inflow	NA	243	56
Stormwater Runoff #5	Inflow	NA	242	65
Stormwater Runoff #6	Inflow	NA	241	70
Stormwater Runoff #7	Inflow	NA	240	73
Stormwater Runoff #8	Inflow	NA	240	75
Stormwater Runoff #9	Inflow	NA	239	80
Stormwater Runoff #10	Inflow	NA	238	85
Stormwater Runoff #11	Inflow	NA	236	94
North Canal	Outflow	Left	247	35
ADY Canal	Outflow	Left	241	67
Irrigator #1	Inflow / Outflow	NA	246	43
Irrigator #2	Inflow / Outflow	NA	244	50
Irrigator #3	Inflow / Outflow	NA	242	65
Irrigator #4	Inflow / Outflow	NA	238	85

[a] : The river bank is given for reference only. The model does not discriminate between river bank when simulating flows.

[b] : The river miles are approximate as each model segment is 1000 ft in length.

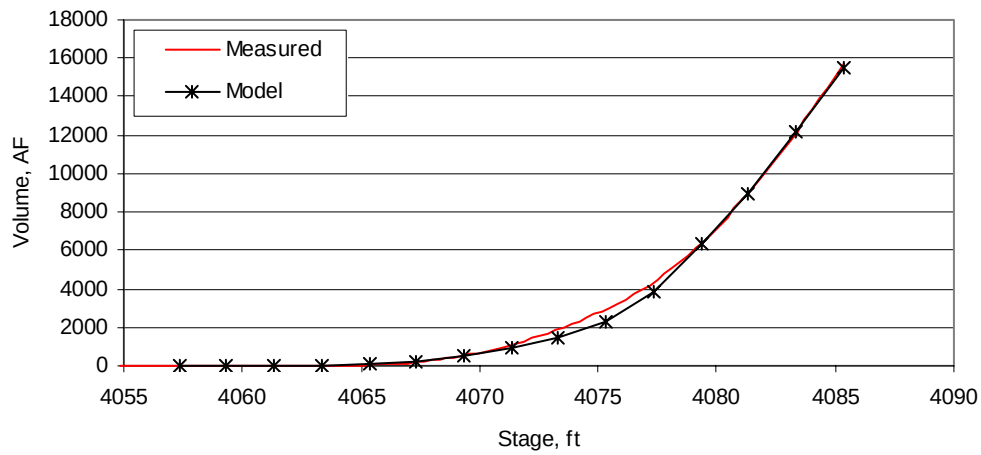


Figure 4. Comparison of measured and model representation of Lake Ewauna stage-volume (S-V) relationships

2.3.2.2 Flow Data

Flow data required for the model application includes the upstream boundary condition representing water flowing into Lake Ewauna from Link River. In addition there are a series of discrete withdrawals and inflows along the reach. Accretion/depletion flow, representing un-quantified losses and gains within the reach, is distributed evenly among the four irrigator locations. Typically flow data are recorded in cubic feet per second or million gallons per day – all flows were converted to cubic meters per second for model input. Each flow component is addressed below.

Link River Inflow

The USGS Gage at Link River is upstream of the Westside Powerhouse return. Thus, the branch inflow flow rates for the Lake Ewauna to Keno reach were determined by subtracting the PacifiCorp West Turbine Gage from the USGS Gage 11507500.

Tributary Inflows

Storm water Runoff

Storm water runoff flow from the Wells 1992 simulation (ODEQ, 1995) was compared to 1992 rainfall data recorded at the KFLO meteorological station. A relationship for the 1992 data was determined between total storm water runoff flow rate and daily precipitation using linear regression.

$$SWRO = 12.129 \times R \qquad (r^2=1)$$

Where: SWRO = Total stormwater runoff, cms

R = precipitation, inches

An average percent of total stormwater runoff flow for each of the eleven locations was determined for each rainfall event in 1992. Calendar year 2000

daily precipitation from KFLO and the relationships determined from the 1992 data were used to calculate each of the eleven storm water runoff flow rates for 2000. The placement of stormwater runoff flows is as per Wells (ODEQ, 1995).

Columbia Plywood

An average monthly flow for Columbia Plywood discharge was calculated from the maximum monthly flows recorded on the plant's monthly monitoring reports submitted to ODEQ. The average for calendar year 2000 was 0.01 cfs (0.0004 cms) and was applied throughout the year.

Klamath Falls Water Treatment Plant

Daily flows for the Klamath Falls Wastewater Treatment Plant were provided by daily flows recorded in monthly monitoring reports submitted to ODEQ. These flows are typically variable, ranging from 5-12 cfs, until May when variability diminishes significantly and flows average a little over 4 cfs. Daily flow from the Klamath Falls Wastewater Treatment Plant was input into the model after being converted to the appropriate units.

South Suburban Sanitation District

Daily flows from South Suburban Sanitation District were derived from flows recorded five times a week in the monthly monitoring reports the District submitted to the ODEQ. Because plant discharge varied little from day to day and were relatively small, input flows for 2000 were monthly averages based on measured data. These monthly averages range from a little over 2 cfs to just over 4 cfs.

Collins Forest Products #1 and #2

Daily inflows from Collins Forest Products discharge #1 and #2 were taken from monthly monitoring reports submitted to ODEQ. These flows average about 1.4 cfs and 0.1 cfs for discharge #1 and #2, respectively. Daily measured data was directly input into the model.

Lost River Diversion Channel

The daily inflows into Lake Ewauna from the Lost River Diversion Channel are gauged by USBR. These records were used to define both the Lost River discharge to, and withdrawal from, Lake Ewauna to Keno Reach (for diversion from Lake Ewauna to Keno reach see the withdrawal section below).

Klamath Straits Drain

Inflow to Lake Ewauna from the Klamath Straits Drain is gauged by USBR. Daily input flows range from a minimum of 0.0 to a maximum of nearly 350 cfs, depending on the season. High monthly variability occurs between February and September. Flows used in the simulations were taken directly from the recorded information.

Withdrawals

Klamath Reclamation Project Diversions

There are three withdrawals within Lake Ewauna for the Klamath Reclamation Project: the Lost River, North Canal and ADY Canal. All three withdrawals were daily flows, gauged by USBR. Lost River withdrawals range dramatically in summer months to a maximum withdrawal of over 600 cfs. North Canal withdrawals are less variable and peak in summer and winter months at about 150-200 cfs. ADY Canal withdrawals follow the same pattern as those at North Canal but are of greater magnitude, reaching maxima of 400-500 cfs.

Non-Reclamation Irrigation Diversions

Due to a lack of available records describing non-USBR irrigation, daily withdrawal rates from the Wells 1992 simulation (ODEQ, 1995) were applied for 2000. The irrigation season was assumed to extend from May 30, 2000 JD 152) to September 30, 2000 (JD 274). Withdrawals peaked at a steady 60 cfs for Irrigator #7 and at a steady 14 cfs for Irrigators #2, #3, and #4. Prior to and after the irrigation season flows were assumed to be zero for all four irrigation withdrawals.

Keno Dam Outflow

The hourly flow rate at Keno Dam was taken from data recorded at USGS Gage 11509500, Klamath River near Keno, Oregon. The flows, ranging from a maximum of over 4000 cfs in spring to a minimum of just under 500 cfs in summer.

Accretion / Depletion (Distributed Tributary) Inflow

Flow representing net un-gauged accretions and depletions from the system was determined using a water balance based on the aforementioned inflows and outflows and the change in storage recorded at Keno Dam (provided by PacifiCorp). This flow was represented in CE-QUAL-W2 by four point sources located at irrigator withdrawal points.

2.3.2.3 Water Quality Data

Water quality data for the main inflow to the Lake Ewauna to Keno Dam reach model implementation is described below. However, during calibration and application, Link River reach simulation output was used to provide all water quality data for the main inflow to the Lake Ewauna to Keno Dam reach.

Temperature

In CE-QUAL-W2, only model inflows are required to have assigned water quality data. All withdrawals from the system assume the temperature or water quality at the point of withdrawal. Inflow locations, data sources, and data and model resolution are summarized in Table 7, followed by descriptions of each data set.

Table 7. Temperature data for inflow locations, including data source, and data and model resolution

Location	Source	Data Resolution	Model Input Resolution
Link River	USBR	Hourly, other	Hourly, other [a]
Distributed tributary	Estimated	n/a	Annual
Stormwater	Estimated	n/a	Annual
Columbia Plywood	ODEQ	monthly	Monthly
KFWTP	ODEQ / estimated	Daily	Daily
South Suburban Sanitation District	ODEQ	Daily	Monthly
Collins Forest Products #1, 2	ODEQ	Daily	Daily
Lost River	USBR	Semi-monthly	Semi-monthly
Klamath Straits Drain	USBR	hourly	daily, other [a]

[a] : Hourly data was not available for all periods.

Link River Temperature

For model implementation, hourly temperatures from Link Dam (A-Canal) recorded by USBR were used as input temperatures. For calibration and application, simulated hourly temperatures from the Link River reach simulation were used as hourly input temperatures for the Lake Ewauna reach simulation.

Distributed Tributary Accretion/Depletion Temperature

Accretions and depletions to the Lake Ewauna reach were assumed to represent groundwater exchange within the reach. A constant inflow temperature of 12.0^{o}C was assumed for the entire 2000 simulation.

Tributary Temperatures

Storm water Runoff

Temperatures for storm water runoff in 2000 were assumed constant at 12.0^{o}C for the entire year, which is the same as the temperature assigned to storm water runoff in the 1992 Wells simulation (ODEQ, 1995).

Columbia Plywood

Monthly values provided in the Columbia Plywood monitoring reports to ODEQ were used as model input. These temperatures range from 13.3 °C in winter to 21.1 °C in summer.

Klamath Falls Wastewater Treatment Plant

Klamath Falls Wastewater Treatment Plant (KFWTP) was not required to report effluent temperature prior to July 2001. However, after 2001, daily effluent temperature was reported as well as daily blowdown temperature and daily combined effluent and blowdown temperature. Blowdown is the water used as coolant at the cogeneration plant. Blowdown temperatures were not available

prior to July 2001, because effluent was not being used at the cogeneration plant as cooling water. Using the existing data set, a linear regression relationship between the daily influent and effluent temperatures was determined based on data from July 2001 through February 2002. All temperatures in the relationship are in Fahrenheit.

$$T_{effluent} = 0.8952(T_{influent}) + 8.1293 \qquad (r^2 = 0.89)$$

This relationship was used to calculate the effluent temperatures for 2000 for the KFWTP, which were then converted to degrees Celsius. Resulting temperatures range from a low of about 15°C, to a high of about 23°C. A brief spike in late summer reaches temperatures over 25°C.

South Suburban Sanitation District

average monthly water temperature for the South Suburban Sanitation District were calculated from measured data gathered five times a week and reported in monthly monitoring reports submitted to ODEQ. These temperatures range from 2.5°C in winter to below 21°C in summer.

Collins Forest Products #1 and #2

Daily measured temperatures for the #1 and #2 discharges from Collins Forest Products were reported in the monthly monitoring reports submitted to ODEQ and were used directly in model input. These temperatures, similar for both discharges, range from about 3 °C in winter to over 25 °C in summer.

Lost River Diversion

Temperatures for the Lost River Diversion input were estimated from bimonthly measurements taken in the Lost River at Wilson Reservoir by USBR between December 28, 1999 and December 18, 2000. These temperatures range from a low of 2.2°C in winter to a high of 30°C in summer.

Klamath Straits Drain

The temperature record for the Klamath Straits Drain (KSD) is a composite of hourly temperatures measured by USBR at both the mouth of KSD and KSD at Stateline for 2000, averaged to daily temperatures. First, daily temperatures were calculated for each location. Data was available at the mouth from 1/15/00 to 3/16/00, 4/6/00 to 4/19/00 and 5/2/00 to 11/22/00. Data from the Stateline location was used to fill the data gaps for 3/20/00 to 4/5/00. Daily air temperatures from KFLO 2000 were used to fill the data gaps from 1/1/00 to 1/14/00 and from 11/23/00 to 12/31/00. If daily average air temperature was less than 0.0 ºC, a water temperature of 0.0 ºC was used. The composite temperature record for KSD ramges from 0 ºC in winter to over 25 0 ºC in summer.

<u>Constituent Concentrations</u>

Link River Concentrations

For model implementation, outflow from Link River simulations was used to define inflow concentrations to the Lake Ewauna to Keno reach. Not all parameters modeled in CE-QUAL-W2 are modeled in RMA-11. Total dissolved solids, suspended solids, total inorganic carbon, and alkalinity are not represented in the river reach models as implemented in this study. Values from Wells (ODEQ, 1995) were used for these parameters. Labile dissolved organic matter (LDOM) was estimated from organic nitrogen and phosphorous concentrations output by RMA-11 by using the stoichiometric equivalence for the nitrogen and phosphorous partitioning in the CE-QUAL-W2 model parameter set. Calibration – validation and model application simulations also used Link River simulated results to represent headwater quality boundary conditions.

Accretion/Depletion Concentrations

Constituent concentrations from the 1992 Wells simulation (ODEQ, 1995) were used in the 2000 simulation. The simulation period for the Wells simulation covered only part of the calendar year, from JD 152 to JD 274, so prior to JD 152, concentrations in 2000 were assumed to be equal to concentrations on JD 152 in 1992. After JD 274, concentrations in 2000 were assumed to be equal to those on JD 274 in 1992.

Tributary Concentrations

Storm water Runoff

Stormwater runoff concentrations from the Wells 1992 simulation (ODEQ, 1995ODEQ, 1995) were applied directly to the 2000 simulation. These concentrations were constant for each constituent throughout entire year.

Columbia Plywood

The monthly monitoring reports submitted by Columbia Plywood to ODEQ generally provide average monthly pH, biological oxygen demand (BOD) and total suspended solids (TSS). Results for a single sample were reported for 2000 (December) and eight samples were taken in 2001. An average of the nine reported concentrations reported in the December 2000 through December 2001 period was used to represent a constant annual input value of 8 mg/l of BOD. TSS was similarly estimated to be 16 mg/l. Inputs for the other water quality parameters were taken from the 1992 Wells simulation (ODEQ, 1995) for Columbia Plywood.

Klamath Falls Water Treatment Plant

Constituent concentrations for the Klamath Falls Water Treatment Plant were based on both monthly ODEQ reports and the 1992 Wells simulation (ODEQ, 1995).

Because reported daily dissolved oxygen and suspended solids values showed modest variation, monthly average values were calculated for model input. Monthly BOD concentrations were estimated from samples collected at biweekly intervals. All other data are monthly estimates based on the 1992 Wells simulation (ODEQ, 1995).

South Suburban Sanitation District

South Suburban Sanitation District reports dissolved oxygen, BOD, TSS, total phosphorus, ammonia, nitrate and pH to ODEQ. The frequency of reporting varied for each parameter, with dissolved oxygen and pH reported 5 times a week, BOD and TSS reported twice a week, and all nutrients reported once a month. All data was converted to monthly averages. Orthophosphate was estimated as 50 percent of total phosphorous concentrations because no data were available. The pH and temperature monthly averages were used to estimate alkalinity and TIC monthly values (Snoeyink and Jenkins, 1980). TDS was estimated to be 200 mg/l (same as 1992 simulation (ODEQ, 1995)). Several parameters were set to zero because there was no available information. These parameters included iron, refractory and labile particulate organic matter, and algae concentration.

Collins Forest Products (Weyerhauser #1 and #3)

Constituent concentrations for Collins Forest Products #1 and #2 were estimated from the monthly water quality reports submitted to ODEQ. These reports provided daily flows and temperatures. BOD and TSS were reported twice a week. Other constituent concentrations were estimated from the 1992 Wells simulation (ODEQ, 1995) input files for Weyerhauser #1 and #3 (Collins Forest Products is the current owner of the same facilities that Weyerhauser owned in 1992).

Lost River Diversion

Lost River Diversion constituent concentrations were estimated from bimonthly data collected by USBR at Wilson Reservoir in 2000, Klamath Straits data from 2000 (for dissolved oxygen), Link Dam 2002 grab samples, and from the 1992 Wells simulation (ODEQ, 1995). Wilson Reservoir data were used only during periods when the Lost River diversion channel was flowing into the Klamath River.

Klamath Straits Drain

Monthly model input values were identified for all water quality constituents at the Klamath Straits Drain. Dissolved oxygen and total dissolved solids values were calculated from USBR datasonde data collected from Klamath Straits Drain during 2000. This sonde was deployed from January through November, and the record shows several periods of missing data (the largest data gaps are from March 16, 2000 through April 6, 2000 and April 19, 2000 through May 2, 2000). Monthly estimates for ammonia, nitrate, orthophosphate, algae, and alkalinity concentrations were based on USBR grab samples collected in 2000. All other constituent concentrations were estimated from the 1992 Wells simulation (ODEQ, 1995).

2.3.2.4 Meteorological Data

Hourly information required for the meteorological input file consisted of air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10), and atmospheric pressure.

Meteorological data for the Lake Ewauna to Keno Dam reach of the Klamath River were derived from meteorological observations near Klamath Falls, OR. The meteorological station at this site (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from reported KFLO data. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure was calculated within CE-QUAL-W2 (elevation of Keno Reservoir: 4085 ft (1245 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

2.3.3 Keno Reach

The Keno reach extends from Keno Dam to the headwaters of J.C. Boyle Reservoir. There are no appreciable streams tributary to this reach. Physical description (e.g., geometry), flow, water quality, meteorological conditions, and other model parameters describing this reach are outlined below. This study uses RMA-2 to represent flow and RMA-11 to represent water quality.

2.3.3.1 River Physical Description

River Location and Path

Coordinates describing river location and path were defined using a digitized version of 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. Key locations in the reach are presented in Table 8 and a model representation of the reach is shown in Figure 5.

Table 8. Klamath River, Keno reach geometry information for the RMA-2 and RMA-11 models

Location	Node	Element	x-coord	y-coord	Site type
Keno Dam	1	1	186.8	165.4	BC, upper
End Keno R reach	117	58	181.0	166.9	BC, lower
A/D Keno reach	73	37	183.7	167.0	A/D
1/4 mi abv J.C. Boyle	110	56	181.4	166.9	Cal/Val and Reporting

BC – boundary condition (flow, constituent concentration, stage)
A/D – accretion/depletion location
Reporting – model output location

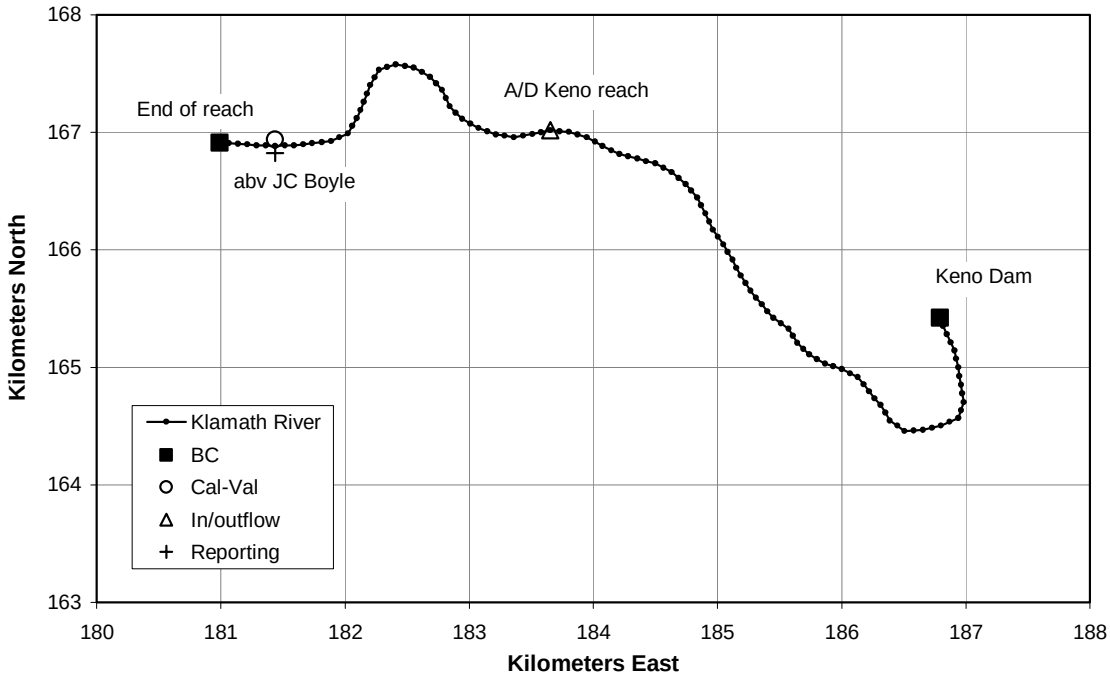


Figure 5. Klamath River, Keno reach representation

River Width

Keno reach widths were obtained from habitat surveys conducted by Tom Payne and Associates. Measurements were completed at roughly eight locations per mile. These measurements were not necessarily uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were assigned to the nearest x-y coordinate. Trapezoidal river cross sections were constructed at evenly spaced intervals of 75 meters. Side slopes were assumed to be 1:1 and river width was based on a seven times running average of measured widths.

Bed Elevation/Slope

Bed slope for the reach was estimated from USGS topographic maps and known elevations at Keno Dam and J.C. Boyle water surface elevations. Reach elevations range from approximately 3796 ft MSL (1157 m) to 4019 ft MSL (1225 m). Elevations were estimated from topographic contours and do not represent the river bed elevations.

Table 9. Klamath River, Keno reach geometry summary

Node spacing	75 meters
Number of nodes	117 nodes in length
Length	5.37 miles from RM228.69-234.06
Elevations	Range: 1157-1225 meters
Widths	Range: 21-57 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps.
Notes	n/a

2.3.3.2 Flow Data

Inflows and Outflows

Inflow to the Keno reach was based on daily flows measured by the USGS gage near Keno (No. 11509500. No appreciable tributary contributions or diversions have been identified for this relatively short reach and accretions/depletions between Keno Dam and J.C. Boyle Dam were assigned to the J.C. Boyle Reservoir reach. However, an element inflow location and small inflow (0.1 cms) has been included at element 37.

Downstream Boundary Condition

The measured elevations at J.C. Boyle dam were used to calculate the downstream elevations for the Keno reach simulation. This approach resulted in a variable stage downstream boundary condition and replicated backwater conditions within the reach. Because river elevations were approximated from topographic maps with twenty-foot contours and stage measurements are accurate, elevation discrepancies arise where rivers meet reservoirs. This discrepancy was estimated to be around 3.1 meters at J.C. Boyle headwaters, so the downstream boundary conditions for the Keno River reach was defined as J.C. Boyle Reservoir elevations plus 3.1 meters (10.2 feet).

2.3.3.3 Water Quality Data

Temperature

Hourly simulated temperatures from the Lake Ewauna CE-QUAL-W2 simulation were used as the temperatures in the Keno reach.

Constituent Concentrations

Hourly simulated constituent concentrations from the Lake Ewauna CE-QUAL-W2 simulation were used as the constituent concentrations in the Keno reach. CE-QUAL-W2 provides total organic and dissolved organic forms of nitrogen and phosphorous as derived output values. To maintain the total mass of organic nitrogen and phosphorous in the system, total organic nitrogen and total organic phosphorous are passed to the downstream river model (RMA-11). Because CE-QUAL-W2 includes the algae fraction

in organic nitrogen and organic phosphorus, the algal component of each nutrient was subtracted from the total.

2.3.3.4 Meteorological Data

Required hourly information for meteorological input consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

Meteorological data for the Klamath River Keno reach were derived from meteorological observations near Klamath Falls, OR. This meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure was calculated based on a J.C. Boyle elevation of 3800 ft (1158 m) and assumed constant throughout the simulation period at 880 mb. Wet bulb temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

2.3.4 J.C. Boyle Reservoir

J.C. Boyle Reservoir primarily serves to regulate peaking flows for the J.C. Boyle Powerhouse (RM 220.4). This reservoir reach extends from the J.C. Boyle headwaters (the end of the Keno reach at RM 227.6) to J.C. Boyle Dam (RM 224.7). There is one tributary represented in the model, located at Spencer Creek. Physical characteristics, flow, water quality, meteorological conditions, and other model parameters are outlined below.

2.3.4.1 Reservoir Physical Data

J.C. Boyle Dam Features

J.C. Boyle Dam has four primary outlets: a spillway, fish ladder, and two outlets into the waterway intake (fish screen bypass and waterway pipeline). There are two additional low level culverts that were used during dam construction – these have been filled with concrete. The details of these outlets are summarized in Table 10.

Table 10. J.C. Boyle Dam outlet features

Outlet	Invert Elevation	Dimension	Operation
Fish ladder	3780.0 ft	24 inch diameter	Manual
Fish Screen Bypass	3757.0 ft	24 inch diameter	Manual
Waterway pipeline	3775.0 ft	14 foot diameter	**
Spillway	3782.0 ft	3 radial gates @ 35 ft width each	Remote control on one gate
Sources: PacifiCorp (2002), PacifiCorp (2000), PacifiCorp drawing: Exhibit L-4			

Reservoir Bathymetry Representation

Unlike the Lake Ewauna to Keno Dam Reservoir reach, there has been no previous modeling effort of J.C. Boyle using CE-QUAL-W2. Reservoir geometry was derived from bathymetric data provided by J.C. Headwaters (Figure 6). Segment length, segment orientation, layer thickness and width were required for the reservoir model. Segments were identified based on changes in the reservoir morphology and widths. The reservoir was divided into sixteen active segments. Segments varied in length from approximately 135 ft (roughly 40 m) to 1600 ft (roughly 490 m). While capturing the general shape of J.C. Boyle Reservoir, the chosen segments also captured pertinent features of the reservoir such as the deep hole in the northwest corner of the reservoir and the discontinuity in the reservoir bed near the dam (Figure 7).

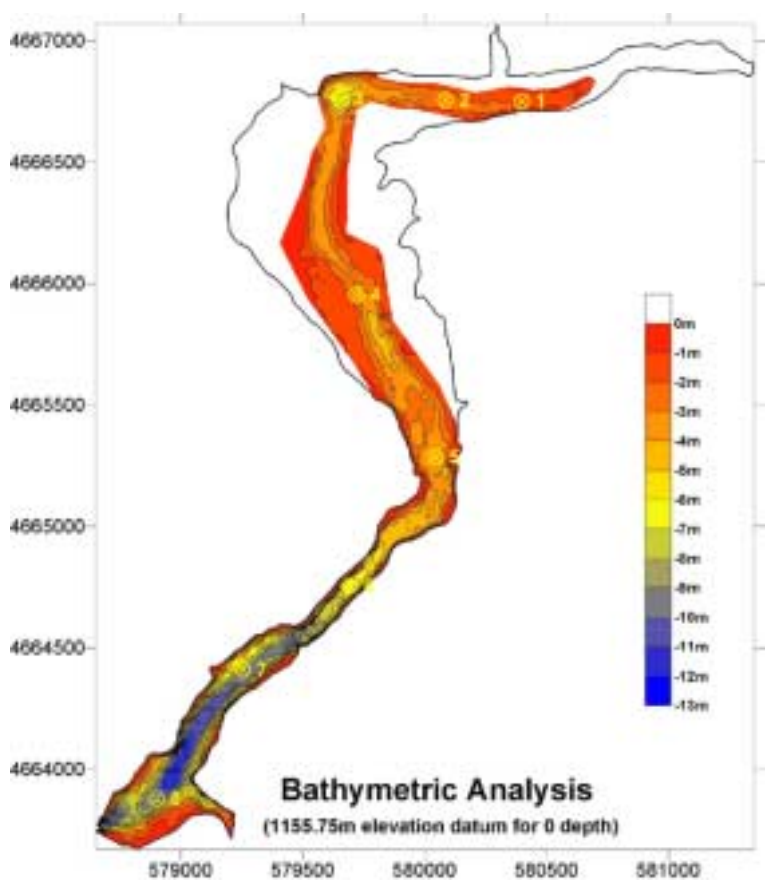


Figure 6. J.C. Boyle Reservoir Bathymetry (J.C. Headwaters)

Cross sections were defined by roughly bisecting each segment and determining the depths as measured from river left to river right (looking downstream). These measurements were used to determine the number of active layers and the layer widths for each segment. Layer thickness was set to one meter. Twelve active layers of varying widths were determined from this method. Although a finer resolution representation was attempted, peaking hydropower operations produced a dynamic water surface elevation and simulations times were long (on the order of a day) because the model was continually adding and subtracting both layers and segments. The 1 meter layer thickness produced reasonable results and the simulation time was approximately 10 minutes, while smaller layer thicknesses resulted in long run times (e.g., greater than 20 hours) due to the continual addition and removal of layers and segments in this small peaking power reservoir.

Manning's friction factor for each segment was assumed to be 0.04. A stage-volume curve was generated from the bathymetry data and compared to the measured stage-volume curve of the reservoir. Adjustments were made as necessary to ensure the simulated reservoir stage-volume relationship was consistent with the observed stage-volume relationship. The second active segment (segment 3) layer widths were increased slightly to increase the volume within that segment because the model experienced solution difficulties due to the characteristics of the accretion/depletion at Spencer Creek. A comparison of modeled and measured stage-volume relationships is shown in Figure 8.

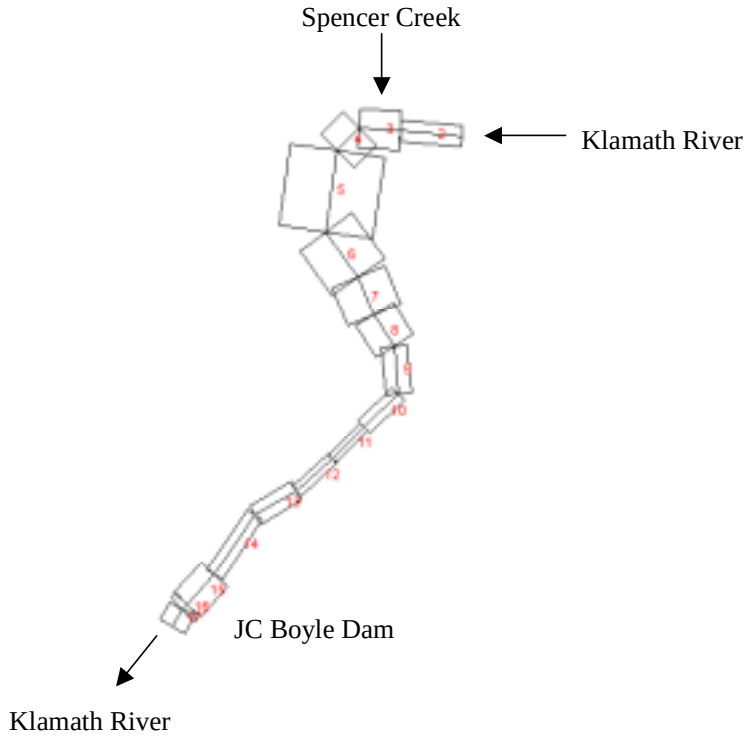


Figure 7. Representation of J.C. Boyle Reservoir in CE-QUAL-W2

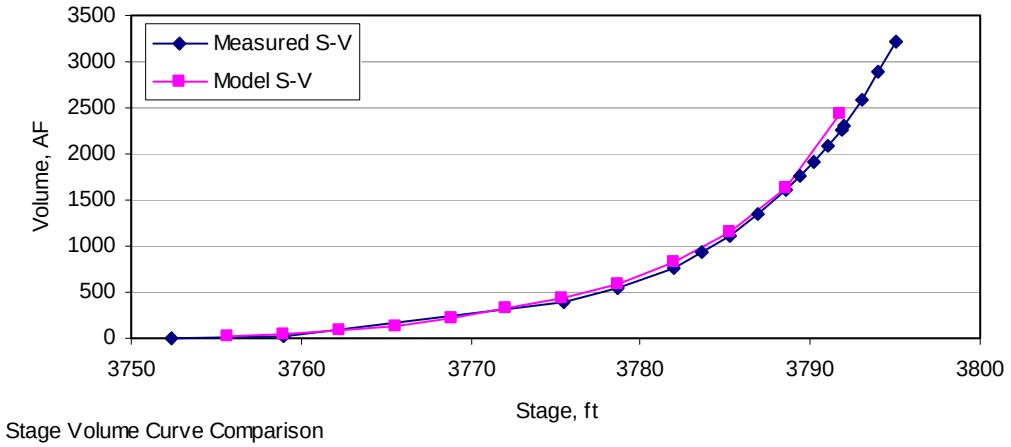


Figure 8. Comparison of measured and model representation of J.C. Boyle Reservoir stage-volume (S-V) relationships

2.3.4.2 Flow Data

Klamath River Inflow

Klamath River inflow to J.C. Boyle Reservoir is not directly measured. A water balance between Keno Dam and J.C. Boyle Dam suggest that accretions within this reach are generally modest. Thus, daily flow rates from the Klamath River near Keno USGS gage 11509500 were used as inflow into J.C. Boyle Reservoir.

Spencer Creek Inflow

Limited Spencer Creek inflow information was available. Net reservoir accretion/depletion was calculated as the difference between the daily average outflow from J.C. Boyle Dam and the daily average inflow (which was derived from the USGS Gage "Klamath River near Keno"). This accretion/depletion for the reservoir, with daily fluctuations ranging from a maximum withdrawal rate of 600 cfs to a maximum accretion rate of about 600 cfs, was located at Spencer Creek.

J.C. Boyle Dam Outflow

The outflow from the J.C. Boyle Reservoir was calculated as the sum of recorded releases to the powerhouse canal, spill from the dam, bypass releases, and fish ladder releases. Hourly data for power canal flows and spill were derived from PacifiCorp records. Fish ladder and bypass releases were assumed constant at 80 cfs and 20 cfs, respectively.

2.3.4.3 Water Quality Data

Temperature

Klamath River Inflow

Inflow temperatures to J.C. Boyle Reservoir are derived from hourly temperatures simulated by RMA-11 (Keno Reach simulation at Node 110).

Spencer Creek Inflow (Accretion/Depletion)

A temperature record for inflow at Spencer Creek was composed from hourly field data recorded by PacifiCorp using Onset Computer Corporation Tidbits® remote logging temperature sensors (Tidbits) in 2001 and 2002. Data was available for 2001 from 5/11 to 12/31 and for 2002 from 1/1 to 5/5. Missing data was linearly interpolated.

Constituent Concentrations

Klamath River Inflow

Hourly constituent concentrations used in model implementation are from CE-QUAL-W2 Lake Ewauna implementation simulation. This input data stream was only used to implement the model (to test the model). For calibration and application, hourly constituent concentrations from Keno River reach simulations (using RMA11) were used and are presented in the calibration and application sections of this document.

Spencer Creek Inflow Water Quality

Concentrations for required constituents at Spencer Creek were estimated from 2002 grab samples. Nine dates were input into the model, representing the seven available grab samples and the first and last day of the year. Labile dissolved organic matter (LDOM) was estimated from total phosphorus and phosphate concentrations using the calculation:

$$LDOM = \frac{TotalPhosphorus - Phosphate}{0.005}$$

The value of 0.005 is a stoichiometric equivalence between phosphate and organic matter.

2.3.4.4 Meteorological Data

Required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

Meteorological data for the J.C. Boyle Reservoir reach were derived from meteorological observations near Klamath Falls, OR. This meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 using the elevation of J.C.

Boyle Reservoir: 3793 ft (1156 m). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

2.3.5 Bypass and Peaking Reach

The Bypass and Peaking reach extends from J.C. Boyle Dam to the headwaters of Copco Reservoir. Noteworthy features of the reach include diversion of main stem flows at J.C. Boyle Dam for hydropower production, the powerhouse penstock return roughly five miles downstream from J.C. Boyle Dam, a large springs complex in the bypass section, and hydropower peaking operations downstream of the powerhouse. There are a few small streams entering the reach, the most significant being Shovel Creek. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below.

2.3.5.1 River Physical Description

River Location and Path

Coordinates describing river location and path were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. This information was translated into a network of nodes and elements for use by the numerical model (see Figure 9). Important locations within the reach, i.e., those of boundary conditions, are presented in Table 11.

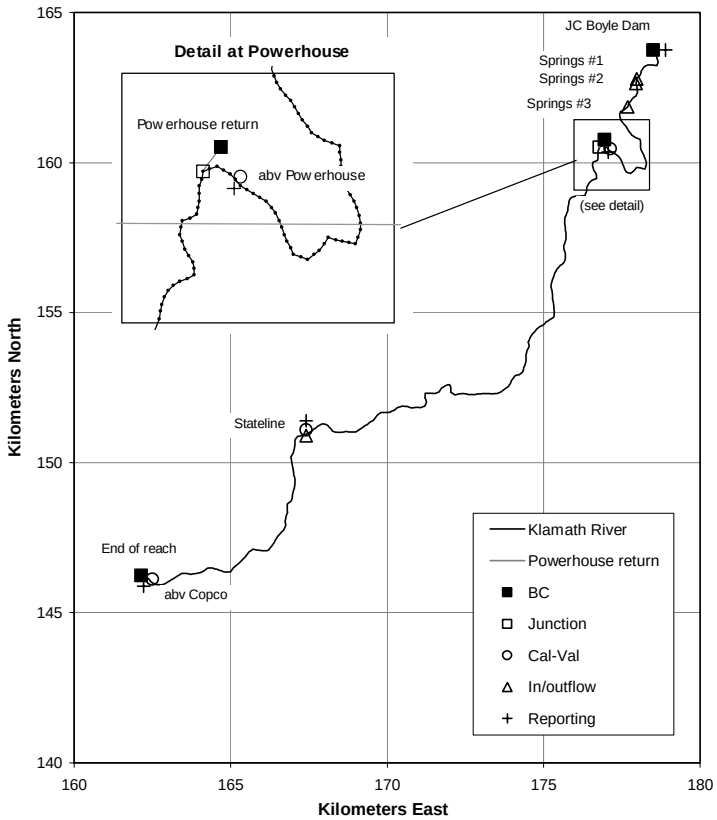


Figure 9. Bypass - Peaking reach representation

Table 11. Geometry information for the Bypass - Peaking reach EC simulation

Location	Node	Element	x-coord	y-coord	Site type
J.C. Boyle Dam	1	1	178.7	163.7	BC, upper
End Peaking reach	453	226	162.2	146.2	BC, lower
J.C. Boyle Powerhouse	95	48	176.9	160.8	BC
Simulated Powerhouse Return	97	49	176.8	160.5	Junction, inflow
1/4 mi abv Powerhouse	91	46	177.1	160.4	Cal-Val
1/4 mi abv Shovel Cr	389	195	166.3	147.2	Cal-Val
1/4 mi abv Copco	447	224	162.5	146.00	Cal-Val
CA-OR Stateline	331	166	167.4	151.1	Cal-Val, A/D
Springs #1	21	11	178.0	162.8	A/D
Springs #2	23	12	178.0	162.6	A/D
Springs #4	35	18	177.7	161.9	A/D

BC – boundary condition
A/D – accretion/depletion location
Cal-Val – calibration and validation location

River Width

Bypass and Peaking reach widths were obtained from habitat surveys completed by Tom Payne and Associates. Measurements were completed at roughly eight locations per

mile. These measurements were not necessarily uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were assigned to the nearest x-y coordinate. Trapezoidal river cross sections were constructed at evenly spaced intervals of 75 meters. Side slopes were assumed to be 1:1 and river width was based on a seven times running average of measured widths. Widths and other geometric characteristics of the Bypass and Peaking reach are summarized in Table 12.

Bed Elevation/Slope

Bed slope for the reach was estimated from USGS topographic maps and known elevations at J.C. Boyle Dam and Copco Reservoir water surface elevations. Reach elevations range from approximately 2565 ft MSL (782 m) to 3760 ft MSL (1146 m). Elevations were estimated from topographic contours and do not represent the river bed elevations.

Table 12. Klamath River, Bypass-Peaking Reach geometry summary

Node spacing	75 meters
Number of nodes	459 nodes in length
Length	20.81 miles from RM204.72-225.53
Elevations	Range: 782-1146 meters
Widths	Range: 19-64 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps.
Notes	1 junction: J.C.B Powerhouse; Nodes 97, 458, 459

2.3.5.2 Flow Data

Inflows and Outflows

The Bypass-Peaking reach has two inflows: releases from J.C. Boyle Dam directly to the Klamath River (Bypass flow) and inflow at the J.C. Boyle Powerhouse tailrace. Measured releases from J.C. Boyle Dam during the 2000 calendar year were obtained from PacifiCorp and used to designate both flows. The springs, located in the bypass reach are represented by three element inflows at elements 11, 12 and 18. These springs were assigned a constant flow of 75 cfs (2.12 cms) each for the entire simulation resulting in a total inflow of 225 cfs (6.36 cms) for that section of the reach. A single accretion/depletion is located at Stateline in the Peaking portion of the reach (element 168). This accretion/depletion was placed at Stateline because there are several inflows in this vicinity, as well as diversions for agriculture. The accretion/depletion was calculated using seven day average values to smooth day to day variations in operations in the peaking reach

Downstream Boundary Condition

The downstream boundary condition for the Bypass and Peaking reach is located at Copco Reservoir and was represented by reservoir elevation. This approach resulted in a variable stage downstream boundary condition and replicated backwater conditions within the reach. Elevations were determined by subtracting 39.21 ft (11.95 m) from the measured Copco Dam water surface elevations, to match the Peaking reach datum and the Copco Reservoir datum.

2.3.5.3 Water Quality Data

Temperature

Both the J.C. Boyle Dam release to the Bypass reach and via the Powerhouse were assigned the simulated hourly temperature releases at J.C. Boyle Dam (from CE-QUAL-W2). It was assumed that the transit time between J.C. Boyle Dam and the powerhouse tailrace, roughly three miles, was approximately twenty minutes at Peaking (T. Olson personal communication). Thus, Powerhouse release temperatures were not lagged.

The springs were assigned constant temperatures of 11.0°C. Accretion/depletions at Stateline were not assigned a temperature.

Constituent Concentrations

Both the J.C. Boyle Dam release to the Bypass and the Powerhouse were assigned the simulated hourly constituent concentrations releases at J.C. Boyle Dam (from CE-QUAL-W2). It was assumed that the transit time between J.C. Boyle Dam and the powerhouse tailrace, roughly three miles, was approximately twenty minutes. Thus, Powerhouse release constituent concentrations were not lagged.

The springs were assigned constant concentrations of 9.7 mg/l estimated as dissolved oxygen saturation at elevation 3600 ft and water temperature of 11°C. All constituent concentrations were assumed zero except nitrate and orthophosphate, which were assumed at 0.15 mg/l. The A/D at Stateline was not assigned water quality characteristics.

2.3.5.4 Meteorological Data

Required hourly information for meteorological input to the models consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

Meteorological data for the Bypass and Peaking reach of the Klamath River were derived from meteorological observations near Klamath Falls, OR. This meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Barometric pressure was calculated based on mean reach elevation of approximately 3160 ft (963 m) and was assumed constant at 904 mb. The methods of determination and calculation of necessary model parameters are outlined in Appendix E.

2.3.6 Copco Reservoir

The Copco Reservoir reach extends from Copco Reservoir headwaters (RM 203.1) to Copco Dam (RM 198.6). There are no tributaries represented in the model: the only inflow represented is Klamath River inflow to the reservoir. The physical data, flow and water quality data, meteorological conditions and other model parameters are outlined below.

2.3.6.1 Reservoir Physical Data

Copco Dam Features

Copco Dam has two primary outlets: a spillway and two waterway intakes that feed Unit 1 and Unit 2 at Copco No. 1 powerhouse. The two penstock intakes are treated as a single outlet in CE-QUAL-W2. The details of these outlets are summarized in Table 13.

Table 13. Copco Dam outlet features

Outlet	Invert Elevation	Dimension	Operation
Penstock Intake (Unit 1)	2575 ft	Two, 10-foot diameter	Remote Operation
Penstock Intake (Unit 2)	2575 ft	14 foot diameter	Remote Operation
Spillway	2594 ft	3 radial gates @ 35 ft width each	Remote control on one gate, others by motorized hoist

Sources: PacifiCorp (2002), PacifiCorp (2000)

Reservoir Bathymetry

Reservoir geometry was derived from bathymetric data of Copco Reservoir provided by J.C. Headwaters (Figure 10). Segment length, segment orientation, layer thickness and width were required for the reservoir model. Segments were identified based on changes in the reservoir morphology and widths. The reservoir was divided into twenty active segments. Segments varied in length from approximately 470 ft (roughly 140 m) to 2340 ft (roughly 715 m). While capturing the general shape of Copco Reservoir, the segment layout also captured the some of the pertinent features of the reservoir such as the deep hole near the dam.

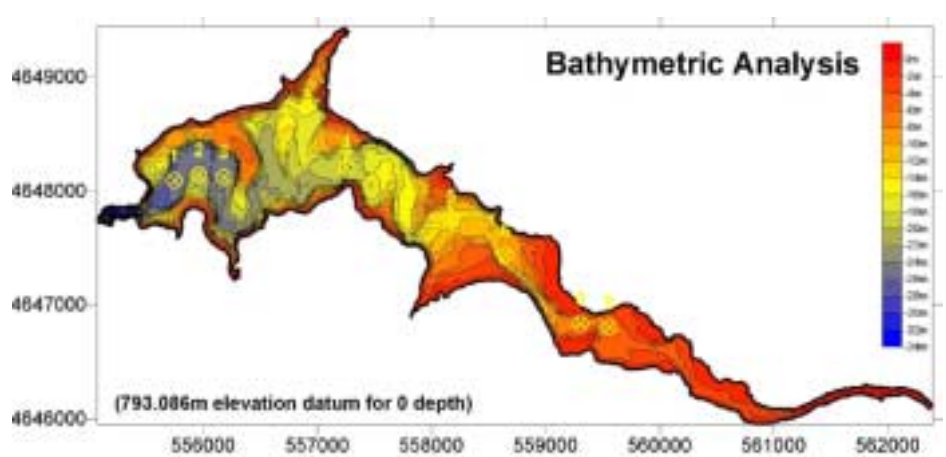


Figure 10. Copco Reservoir bathymetry (J.C. Headwaters)

Cross sections were defined by roughly bisecting each segment and determining the depths as measured from river left to river right (looking downstream). These measurements were used to determine the number of active layers and the layer widths for each segment. The layer thickness used was 6.6 ft (2.0 m). There were sixteen active layers of varying widths determined from this method. The 6.6 ft (2.0 m) layer thickness produced reasonable results and the simulation time was approximately 15 minutes. The final CE-QUAL-W2 representation is shown in Figure 11, and the computed versus measured stage-volume relationships are compared in Figure 12.

The Manning's friction factor for each segment was assumed to be 0.04. A stage-volume curve was generated from the bathymetry data and compared to the measured stage-volume curve of the reservoir to ensure proper volume and storage representation.

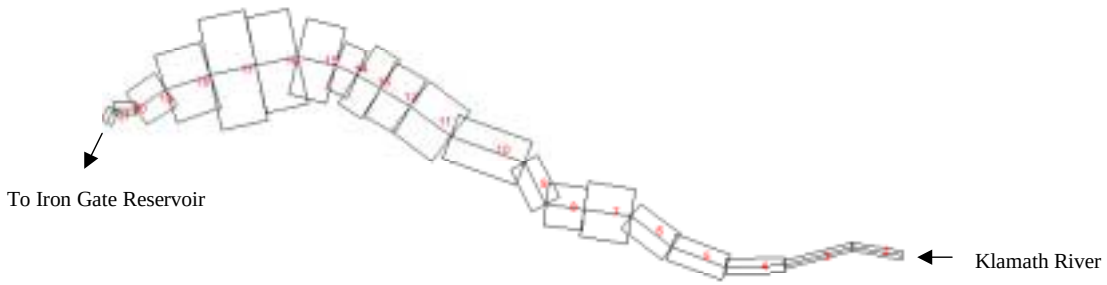


Figure 11. Representation of Copco Reservoir in CE-QUAL-W2

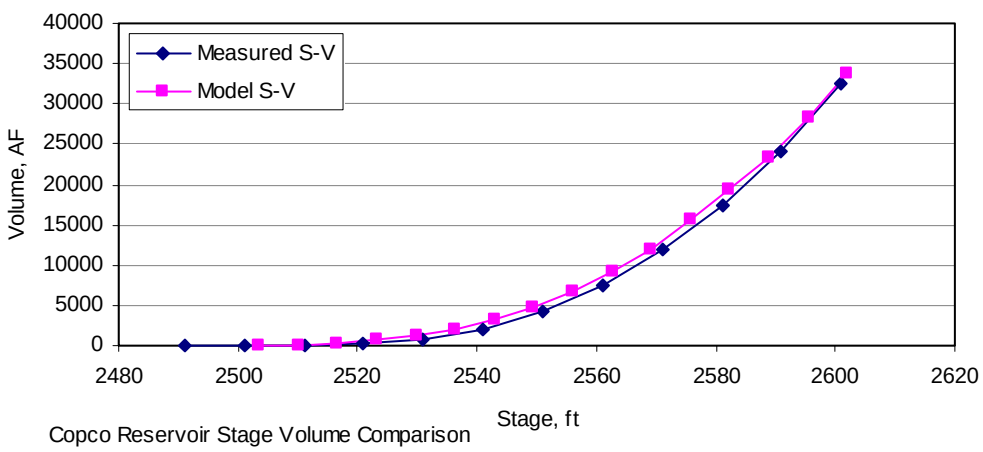


Figure 12. Comparison of measured and model representation of Copco Reservoir stage-volume (S-V) relationships

2.3.6.2 Flow Data

Klamath River Inflow and Accretion/Depletion

The hourly inflows for Copco Reservoir are represented as the sum of the inflow into the reservoir and the estimated accretion /depletion for the reservoir. The inflow into the

reservoir used was the hourly flows from the Bypass-Peaking reach simulation (RMA-2 output: Node 453): there is no flow measurement station immediately above Copco Reservoir. The hourly accretion / depletion was calculated as sum of the daily change in storage in Copco and the daily average outflow from Copco, subtracting the daily average inflows from the Peaking Reach. Then a 7-day average accretion/depletion was calculated. This 7-day average accretion/depletion was expanded to hourly flows as a step function (no linear interpolation was used) and added Klamath River inflows.

Copco Dam Outflow

Hourly outflow for both the Copco powerhouse and the spillway were available from PacifiCorp and were used as the Copco Reservoir outflow flows for model implementation. The two powerhouse units were treated as a single outlet, with a single elevation (2581.04 feet (786.70 meters)).

2.3.6.3 Water Quality Data

Temperature

Klamath River Inflow

Inflow temperatures for Copco Reservoir were the hourly temperatures from the Bypass-Peaking reach (RMA-11: Node 453).

Constituent Concentrations

Klamath River Inflow

For model implementation and application, the hourly constituent concentrations from the RMA-11 output file are used. Not all parameters modeled in CE-QUAL-W2 are modeled in RMA-11. Total dissolved solids, suspended solids, total inorganic carbon, and alkalinity are not explicitly represented in the river model at this time. Labile dissolved organic matter (LDOM) was estimated from organic nitrogen and phosphorous concentrations output by RMA-11 by using the stoichiometric equivalence for the nitrogen and phosphorous partitioning in the CE-QUAL-W2 model parameter set and accounting for the algal component of organic nitrogen and phosphorus. Suspended solids, iron, and tracer concentrations were set to reference levels (these parameters are included in the simulation, but not directly used, except to check issues such as conservation of mass (tracer)).

2.3.6.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

The meteorological data for the Copco Reservoir reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the

following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 (elevation of Copco Reservoir: 2607 ft (765 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

Because Copco Reservoir is roughly 1500 feet lower than Klamath Falls, the air temperature was adjusted to accommodate for the change in elevation. A lapse rate of 3.0°C, based on data from Klamath Falls and a meteorological station at Iron Gate Dam (see Appendix E). Air temperature was adjusted according to the following formula, based on Linacre (1992).

$$T_1 = T_2 + 0.003h$$

Where: T1 = temperature at site 1

T2 = temperature at site 2

h = $E_2 - E_1$, meters

E_1 = Elevation of site 1

E_2 = Elevation of site 2

For the purposes of this study an average elevation of Copco and Iron Gate Reservoirs was applied (2450 ft (746.8 m)). Based on a meteorological station at Copco Village, it was apparent that wind speed was moderated near the headwaters of Copco Reservoir. A second field season of data is being collected to better understand local conditions. For this effort the remaining meteorological parameters from the KFLO station were not modified.

2.3.7 Iron Gate Reservoir

The Iron Gate Reservoir reach extends from the headwaters of Iron Gate Reservoir to Iron Gate Dam. The small Copco #2 Reservoir and river reach between Copco and Iron Gate reservoirs are not represented in the modeling framework (the exception is the Without Project scenario, discussed in the application section). There are three tributaries represented in the Iron Gate Reservoir CE-QUAL-W2 applications: Camp Creek, Jenny Creek, and Fall Creek. The spillway for the dam is modeled as a withdrawal in the last active segment because the spillway structure draws water to the side of the dam, not over or through the dam. Also, due to the shape of the reservoir, two branches were included in the representation. Branch one is the main branch, and receives water from Klamath River (i.e., releases from Copco Reservoir). The Camp Creek arm of Iron Gate Reservoir is represented with a separate branch. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below.

2.3.7.1 Reservoir Physical Data

Iron Gate Dam Features

Iron Gate Dam has four primary outlets: a spillway, penstock, and two fish hatchery intakes. The details of these outlets are summarized in Table 14.

Table 14. Iron Gate Dam outlet features

Outlet	Invert Elevation	Dimension	Operation
Upper Fish Hatchery	2293 ft	24 inch diameter	Manual
Penstock Intake	2309 ft	12 foot diameter	Remote operation
Lower Fish Hatchery	2253 ft	24 inch diameter	Manual
Spillway	2328 ft	Side channel (727 feet in length)	Overflow

Sources: PacifiCorp (2002), PacifiCorp (2000)

Reservoir Bathymetry

Reservoir geometry was derived from bathymetric data of Iron Gate Reservoir provided by J.C. Headwaters (Figure 13). Segments were identified based on changes in the reservoir orientations and widths. Using this method, two branches were created. Branch 1 had twenty-six active segments and Branch 2 had four active segments. The segment length for the entire reservoir varies from approximately 121 ft (roughly 40 m) to approximately 1680 ft (roughly 510 m). Branch 2 had an external upstream boundary and ended at Branch 1, Segment 20.

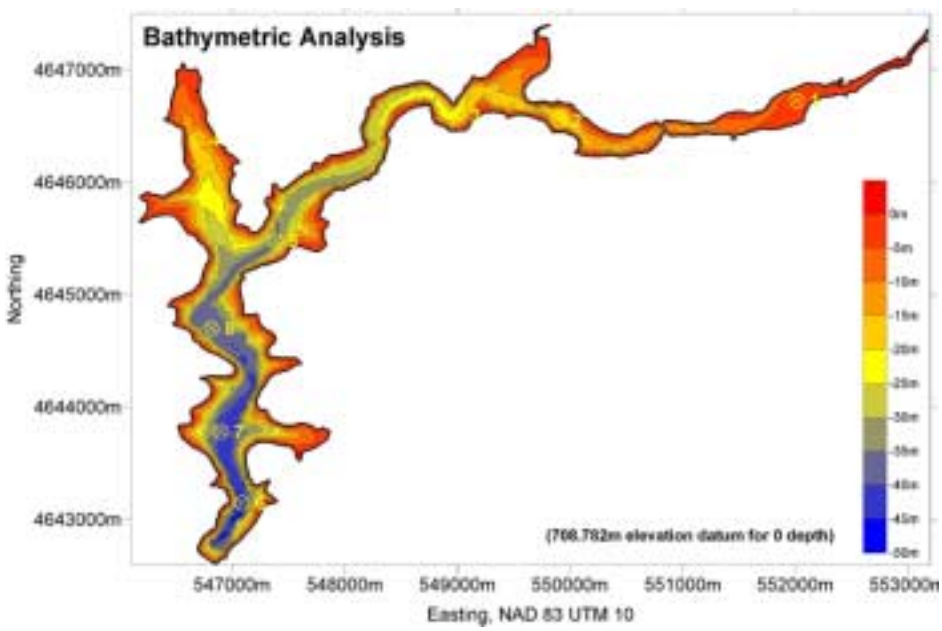


Figure 13. Iron Gate bathymetry (J.C. Headwaters)

Once the segments were determined, each segment was roughly bisected and the changes in depth across each segment were measured from river left to river right (looking downstream). These measurements were used to determine the number of active layers

and the layer widths for each segment. The layer thickness was 8.2 ft (2.5 m) and there were 18 active layers.

Also determined from the bathymetric map of Iron Gate Reservoir were the orientations of each segment. Segment length, segment orientation, layer thickness and width were all used to construct the bathymetry file. The Manning's friction factor for each segment was assumed to be 0.04. A stage-volume curve was generated from the bathymetry data and adjusted to match the measured stage-volume curve of the reservoir (Figure 14).

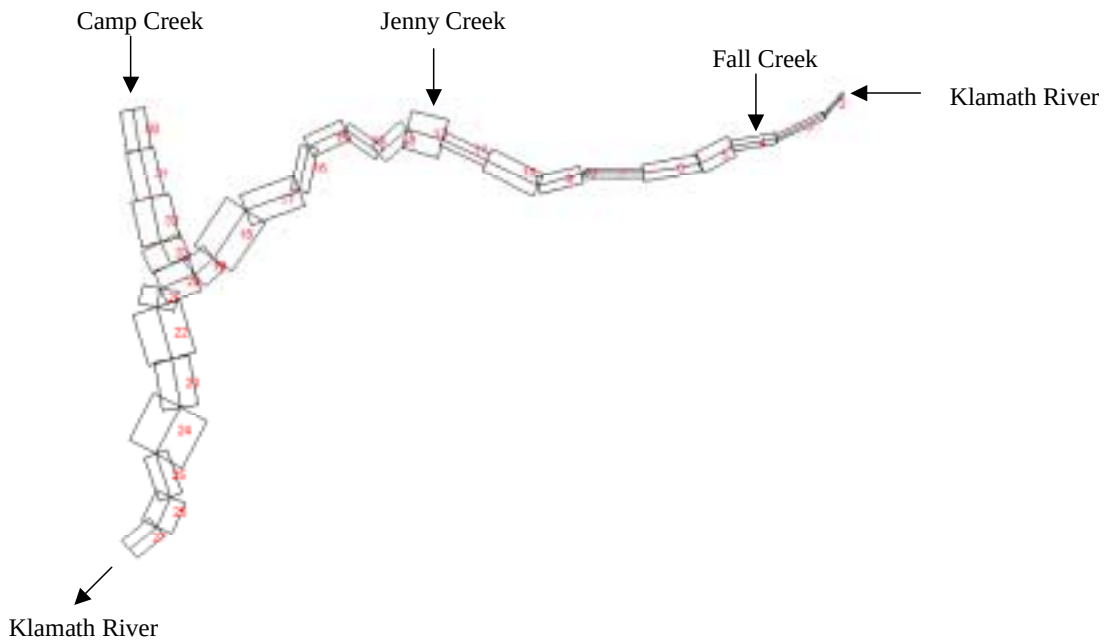


Figure 14. Representation of Iron Gate Reservoir for CE-QUAL-W2

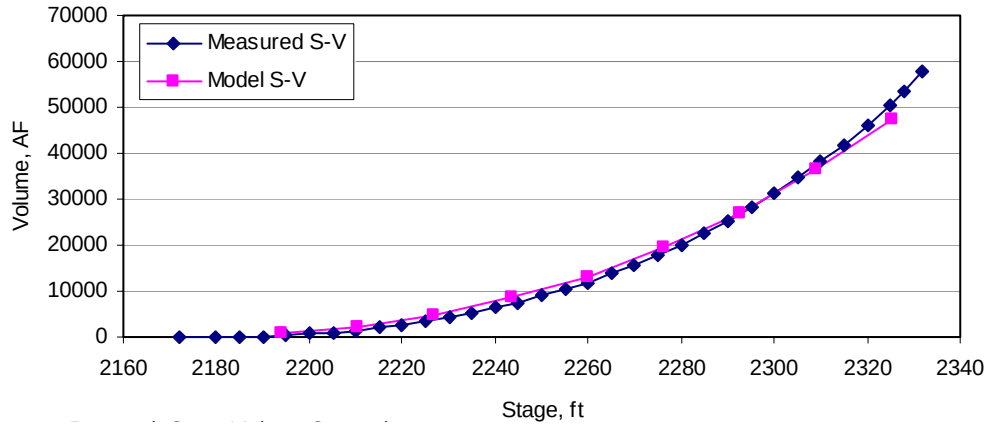


Figure 15. Comparison of measured and model representation of Iron Gate Reservoir stage-volume (S-V) relationships

2.3.7.2 Flow Data

Iron Gate Reservoir Inflow

There is no gage to measure flow into Iron Gate Reservoir; however, hourly flows from the Copco Reservoir were used as representative inflows. Hydropower peaking at Copco No. 1 and No. 2 results in periods when releases to the Klamath River downstream are insignificant. During these periods a flow of 0.035 cfs (0.001 cms) was assumed.

Accretion/Depletion and Tributary Inflow

The hourly accretion/depletion was calculated as sum of the daily inflow to, outflow from, and change in storage in Iron Gate Reservoir. A 7-day running average accretion/depletion was determined from the daily values.

Because limited flow information was available for any of the creeks (Camp, Jenny, and Fall Creeks) flowing into Iron Gate Reservoir, the accretion/depletion was placed at Jenny Creek inflow location (Segment 12). Camp Creek (segment 10) and Fall Creek (segment 4) are active in the model, but flows are set to small numbers or zero, effectively rendering them insignificant. Camp Creek, because it is a branch inflow, was assigned a value of 0.0035 cfs (0.0001 cms) for the entire year. Fall Creek inflow was set to zero.

Iron Gate Dam Outflow

Outflow from Iron Gate Reservoir was determined from PacifiCorp daily flow records for the Powerhouse release and spill, and estimates of fish hatchery releases. A constant flow of 50 cfs (1.42 cms) was assumed for the lower fish hatchery release. The upper fish hatchery release was assumed zero.

2.3.7.3 Water Quality Data

Temperature

Copco Dam Inflow

Hourly Iron Gate Reservoir inflow temperatures were assigned based on simulated Copco Reservoir outflow values produced by CE-QUAL-W2. During off peak hours, the small inflow (0.035 cfs or 0.001 cms) was assigned the water quality of the last time step there was a release from Copco.

Accretion/Depletion and Tributary Inflow Quality

The accretion/depletion for this reach was located at Jenny Creek. However, Jenny Creek has not been monitored for temperature historically. Water temperatures assigned to Jenny Creek flows were monthly estimated temperatures for Bogus Creek (located in the Iron Gate to Turwar reach). The same water temperature is assigned at Fall and Camp Creeks; however, because there are very small or no flows assigned at these tributaries, the impact is negligible.

Constituent Concentrations

Copco Dam Inflow

Hourly Iron Gate Reservoir inflow quality was assigned based on simulated Copco Reservoir outflow values produced by CE-QUAL-W2. During off peak

hours, the small inflow was assigned the water quality of the last time step there was a release from Copco.

Accretion/Depletion and Tributary Inflow Quality

The accretion/depletion for this reach was located at Jenny Creek. Bogus Creek monthly estimated water quality was assigned to the accretion/depletion at Jenny Creek. The same water quality is assigned at Fall and Camp Creeks; however, because there are very small or no flows assigned at these tributaries, the impact is negligible.

2.3.7.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

The meteorological data for the Iron Gate Reservoir reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 (elevation of Iron Gate Reservoir: 2,328 ft (710 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

Because Iron Gate Reservoir is roughly 1700 feet lower than Klamath Falls, the air temperature was adjusted to accommodate for the change in elevation. A lapse rate of 3.0 °C, based on data from Klamath Falls and a meteorological station at Iron Gate Dam (see Appendix E). Air temperature was adjusted according to the following formula, based on Linacre (1992).

$$T_1 = T_2 + 0.003h$$

Where: T1 = temperature at site 1

T2 = temperature at site 2

h = $E_2 - E_1$, meters

E_1 = Elevation of site 1

E_2 = Elevation of site 2

For the purposes of this study an average elevation of Copco and Iron Gate Reservoirs was applied (2450 ft (746.77 m)). Field data did not suggest any additional relationships

between the Klamath Falls and Iron Gate Reservoir site. Thus, the remaining meteorological parameters from the KFLO station were not modified.

2.3.8 Iron Gate Dam to Turwar

The Iron Gate Dam to Turwar reach extends from Iron Gate Dam to the mouth of the Klamath River. There are several main tributaries flowing into the reach: Shasta River, Scott River, Salmon River, and Trinity River. Several creeks are also included within the simulation. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below.

2.3.8.1 River Physical Description

River Location

The x-y coordinates describing the river location were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. This information was translated into a network of nodes and elements for use by the numerical model (Figure 16). Important locations within the reach, i.e., those of boundary conditions or reporting / output locations, are presented in Table 15. Two model grids were developed for the reach, one with roughly 245-foot (75 meter) node spacing and one with 490 foot (150 meter) node spacing. The more refined model grid was constructed first and used for calibration and validation. When longer simulation periods were identified (e.g., months versus days), a coarser grid was constructed to reduce simulation times. Results from the two grids were compared and differences were negligible.

Table 15. Geometry information for the IG-Turwar reach (150 meter grid)

Location	Node	Element	x-coord	y-coord	Site type	Inflow Angle, Radians [a]
Iron Gate Dam	1	1	146.747	142.634	BC, upper	4.040
End IG-Turwar reach	2081	1040	9.821	99.506	BC, lower	-
Bogus Creek	7	4	146.141	142.022	A/D	-
Willow Creek	55	28	142.035	138.739	A/D	-
Cottonwood Creek	86	43	137.904	137.535	A/D	-
Shasta River	144	72	133.963	131.178	A/D	-
Humbug Creek	204	102	127.848	131.402	A/D	-
Beaver Creek	319	160	115.190	135.232	A/D	-
Horse Creek	468	234	99.597	130.180	A/D	-
Scott River	513	257	97.299	125.428	A/D	-
Grider Creek (A/D Scott to Seiad)	656	328	82.714	132.246	A/D	-
Thompson Creek	735	368	74.440	134.626	A/D	-
Indian Creek	906	453	69.371	126.831	A/D	-
Elk Creek	925	463	67.209	125.507	A/D	-
Clear Creek	1000	500	62.733	117.818	A/D	-
Ukonom Creek	1098	549	59.559	107.347	A/D	-
Dillon Creek	1162	581	55.209	102.905	A/D	-
Salmon River	1357	679	58.333	81.788	A/D	-
Camp Creek	1466	733	52.865	71.474	A/D	-
Red Cap Creek	1511	756	49.403	67.773	A/D	-
Bluff Creek	1547	774	45.339	65.584	A/D	-
Trinity River	1609	805	41.415	59.672	A/D	-
Pine Creek	1644	822	36.954	61.269	A/D	-
Tectah Creek	1850	925	24.557	79.833	A/D	-
Blue Creek	1908	954	22.306	86.220	A/D	-
1/4 mi bl Iron Gate	4	2	146.419	142.345	reporting	-
1/4 mi ab Cottonwood	84	42	138.117	137.743	reporting	-
1/4 mi ab Shasta	142	71	134.262	131.198	reporting	-
Walker Bridge	369	185	111.329	131.759	reporting	-
1/4 mi ab Scott	511	256	97.348	125.720	reporting	-
USGS Gage at Seiad Valley	672	336	80.887	133.289	reporting	-
1/4 mi ab Clear Cr.	998	499	62.908	118.058	reporting	-
1/2 mi ab Salmon (Ishi Pishi)	1352	676	58.231	82.372	reporting	-
USGS Gage at Orleans	1454	727	54.016	71.457	reporting	-
1/4 mi ab Bluff Cr.	1545	773	45.357	65.876	reporting	-
1/4 mi ab Trinity	1607	804	41.692	59.692	reporting	-
Martin's Ferry	1651	826	36.505	62.187	reporting	-
Young's Bar	1722	861	31.541	69.894	reporting	-
1/4 mi ab Blue Cr.	1906	953	22.177	85.992	reporting	-
USGS Gage nr Turwar	2024	1012	16.341	96.868	reporting	-

[a] : Radians are measured counter-clockwise from due east

River Width

Klamath River widths from Iron Gate Dam to Turwar were estimated from Meso-habitat surveys completed by US Fish and Wildlife Service. This data set included a reach by reach description of habitat unit type, width, and maximum depth (a total of 1741 units). These measurements were not uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were assigned to the nearest x-y coordinate. Trapezoidal river cross sections were constructed at evenly spaced intervals of 75 meters. Side slopes were assumed to be 1:1 and river width was based on a seven times running average of measured widths.

River Bed Elevation

Bed slope for the reach was estimated from USGS topographic maps and known elevations at Iron Gate Dam. Reach elevations range from approximately sea level to roughly 2200 ft msl (671 m). Elevations were estimated from land surface topographic contours and do not represent the river bed elevations.

Table 16. Klamath River, Iron Gate Dam to Turwar Reach geometry summary

Node spacing	75 meters/150 meters
Number of nodes	2082 nodes/4161 nodes in length
Length	190.54 miles from RM0.00-190.54
Elevations	Range: 0-671 meters
Widths	Range: 29- meters
Side slopes	1:1
Data sources	UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps.
Notes	n/a

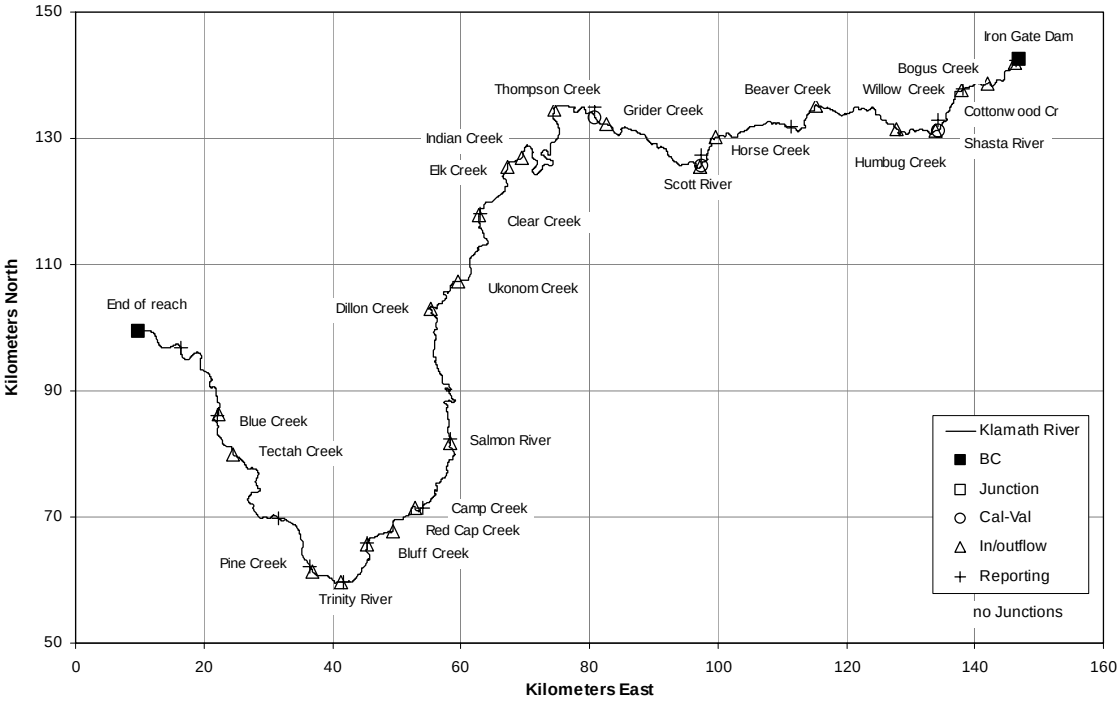


Figure 16. Iron Gate Dam to Turwar reach representation showing tributary names

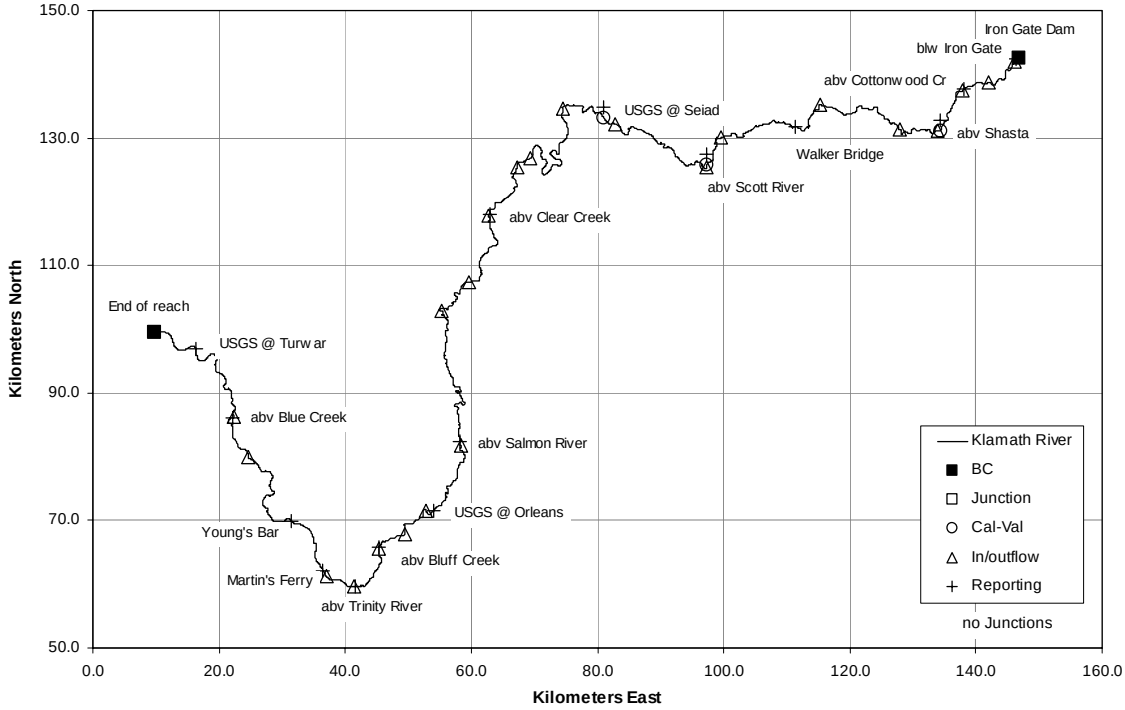


Figure 17. Iron Gate Dam to Turwar reach representation showing reporting location names

2.3.8.2 Flow Data

Inflows

The Iron Gate Dam to Turwar reach includes 23 inflows in addition to the headwater boundary condition at Iron Gate Dam. Measured releases from Iron Gate during the 2000 calendar year as provided by PacifiCorp were used to designate operations.

Observed field data were used for those tributaries that are actively gauged, including the Shasta, Scott, Salmon, and Trinity Rivers, and Indian Creek. The inflows for minor tributaries were defined and quantified based on USGS (1995). The details of the USGS methodology are included in Appendix D. All tributaries in this reach are treated as element inflows.

Element flows (ELM)

There are 23 element flows in the IG-Turwar reach. Tributary contributions were assigned daily data based on USGS gages or 7-day average flows based on accretion calculations. Table 17 summarizes the locations, model node and element information, and type of record employed.

Table 17. Element flow information for the IG-Turwar EC simulation

Location	Node	Element	Flow Type
Bogus Creek	7	4	7 day average
Willow Creek	55	28	7 day average
Cottonwood Creek	86	43	7 day average
Shasta River	144	72	Daily measured
Humbug Creek	204	102	7 day average
Beaver Creek	319	160	7 day average
Horse Creek	468	234	7 day average
Scott River (+ A/D Ft. Jones to Klamath)	513	257	Daily calculated
Grider Creek (A/D Scott to Seiad)	656	328	7 day average
Thompson Creek	735	368	7 day average
Indian Creek	906	453	Daily measured
Elk Creek	925	463	7 day average
Clear Creek	1000	500	7 day average
Ukonom Creek	1098	549	7 day average
Dillon Creek	1162	581	7 day average
Salmon River	1357	679	Daily measured
Camp Creek	1466	733	7 day average
Red Cap Creek	1511	756	7 day average
Bluff Creek	1547	774	7 day average
Trinity River (+ A/D Hoopa to Klamath)	1609	805	Daily calculated
Pine Creek	1644	822	7 day average
Tectah Creek	1850	925	7 day average
Blue Creek	1908	954	7 day average

The Shasta River daily flows were from USGS gage 11517500. The Scott + A/D daily flows were calculated from USGS gage 11519500 (Scott River daily flows) and A/D described in Appendix D. The daily Indian Creek flows were from USGS gage 11521500. The Salmon River daily flows were from USGS gage 11522500. The Trinity + A/D daily flows were calculated from USGS gage 11530000 (Trinity River daily flows) and the A/D described below.

The 7 day accretion / depletion calculations are described in Appendix D. Daily A/D flows were calculated and then averaged over 7 days, except for the Scott River and Trinity River A/D, which were added to their respective river daily flows.

Downstream Boundary Condition

The downstream boundary for the model is placed at River Mile (RM) 0. There is tidal influence at Turwar (RM 5), but this dynamic condition is neglected in the model application. Instead a stage-discharge boundary condition of the form

$$Q = A_1 + A_2(E - E_o)^C$$

is applied, where

Q = flow rate (m^3/s)

$A_1 = 0.0$

$A_2 = 39.481$

E = simulated water surface elevation (representing depth) (m)

E_o = water surface elevation datum (m)

$C = 2.2974$

The coefficients for the stage discharge relationship were derived from the rating curve available for the Klamath River at Turwar USGS gage (15530500) corrected for tidal influence.

2.3.8.3 Water Quality Data

Temperature

Tributary water temperature data for calendar year 2000 and 2001 in the Iron Gate Dam to Turwar reach were largely unavailable, with the exception of major tributaries, including the Shasta, Scott, Salmon, and Trinity Rivers. However, even these records exhibited significant data gaps. Inflow temperatures for the upstream boundary condition include simulated hourly temperatures in the Iron Gate Reservoir. The source of records and final model inputs for major and minor tributaries are outlined below.

<u>Major Tributaries</u>

A complete water temperature record for the Shasta River during 2000 was not available. Thus, hourly temperatures were represented with a composite records constructed from multiple sources. Data from USBR (2003) was used from 3/22/00 – through 11/6/00, while California Department of Fish and Game (Shasta River at Mouth temperatures)

data was used from 1/1/01 to 3/23/01 and 11/6/00 to 12/31/00. Water temperature data were largely complete for 2001.

Scott River hourly temperatures were derived primarily from a datasonde deployed at the mouth of the Scott River from March through November 2000 by USBR. However, there were some gaps in that data. These data gaps were filled with data from the Shasta River composite temperatures that was corrected to match the existing Scott River temperatures. Water temperature data were largely complete for 2001.

Salmon River was assigned hourly temperatures from a composite. Some 2000 data was available for the Salmon River from USBR. The composite was made of 3/22/00 - 4/13/00, 5/2/00 - 5/22/00, and 5/30/00 - 11/13/00 Salmon River temperatures and 1/1/00 - 3/22/00, 5/22/00 - 5/30/00 and 11/13/00 - 12/31/00 Trinity River temperatures. Water temperature data were largely complete for 2001.

The Trinity River hourly water temperatures were obtained from the California Department of Water Resources, California Data Exchange Center (CDEC): site name for Trinity River at Hoopa (HPA). Water temperature data were largely complete for 2000 and 2001.

Minor Tributaries

The tributary water temperatures for 2000 and 2001 were based on hourly (typically) data collected by U.S. Forest Service (USFS) between 1994 and 2001. The exception was Blue Creek data which was supplied by the Yurok Tribe. The USFS temperature database contains all of the stream temperature records available in the Klamath National Forest stream temperature database, as of Oct. 17, 2002. This includes almost 650,000 individual stream records total. Generally, the USFS monitoring efforts did not provide long-term data sets at any one location, but rather several locations were monitored for intermittent periods. To provide representative temperature for the various tributaries composite hourly temperature traces were identified for each creek. These composite data sets were used to calculate monthly average temperatures for each tributary. Certain tributaries lacked data or provided little summer time flow volume and thus were not assigned a water temperature at this time. A brief discussion of each inflow temperature for tributary is outlined below and the monthly temperatures are presented in Table 18.

Bogus Creek had no temperature data available. Shovel Creek composite monthly temperatures were used for Bogus Creek. Shovel Creek composite monthly temperatures were estimated as follows. No winter data for Shovel Creek was available. No 2000 data was available. Observed 2001 hourly temperatures (available for 5/9/01 to 10/15/01) were filled with composite Spencer Creek hourly data. Composite Shovel Creek hourly data was then aggregated to daily and then to monthly averages.

Willow, Cottonwood, and Humbug Creeks were not assigned temperatures because they only minor flows during the summer.

Beaver Creek: No 2000 data was available. A composite temperature record was made of 6/30/99 - 9/13/99 Beaver Creek daily temperatures, and 1/1 - 6/29 and 9/14 - 12/31 composite Elk Creek daily temperatures, and then aggregated to monthly average temperatures.

Horse Creek: No 2000 data was available. A composite temperature record was made of 7/1/99 - 9/14/99 Horse Creek daily temperatures and 1/1 - 6/30 and 9/15 - 12/31 composite Elk Creek daily temperatures, and then aggregated to monthly average temperatures.

Grider Creek: Only summer 2000 temperatures were available for Grider Creek. A composite temperature record was made of 7/1/00 - 10/13/00 Grider Creek daily temperatures, and 1/1 - 6/29 and 10/14 - 12/31 composite Elk Creek daily temperatures. Elk Creek temperatures were used because both creeks had sources in the Marble Mountains. The daily composite Grider Creek temperature record was aggregated to monthly average temperatures.

Thompson Creek: No 2000 data was available. An incomplete record available was for 2001. After comparing the existing Thompson Creek data to other creeks' records, Blue Creek 2000 temperatures were chosen because the small amount of existing Thompson Creek temperature record matched the 2000 Blue Creek temperatures. The composite Thompson Creek temperatures were aggregated to monthly average temperatures.

Blue Creek: Only summer 2000 temperatures were available for Indian Creek. A composite temperature record was made up of 7/1/00 - 9/27/00 Indian Creek daily temperatures, and 1/1 - 6/30 and 9/28 - 12/31 composite Clear Creek daily temperatures. Clear Creek temperatures were used because the sources for both creeks are adjacent to each other in the Siskiyou Mountains. The composite Indian creek daily temperatures were aggregated to monthly average temperatures.

Elk Creek: Only summer 2000 temperatures were available for Elk Creek. However, there were other years available. A composite temperature record was made up of 1/1/93 - 6/30/93, 7/1/00 - 10/3/00 and 10/4/93 - 12/31/93 Elk Creek daily temperatures. The composite Elk Creek data was aggregated to monthly average temperatures.

Clear Creek: No 2000 temperature data was available for Clear Creek near the mouth. A composite temperature record was made of 1993 Clear Creek daily temperatures, which were aggregated to monthly average temperatures.

Ukonom Creek: No 2000 temperature data was available. A composite temperature record was made of 1993 Ukomon Creek daily temperatures, which were aggregated to monthly average temperatures.

Dillon Creek: No 2000 temperature data was available. A composite temperature record was made of 1/1/94 - 9/30/94 and 10/1/92 - 12/31/92 Dillon Creek daily temperatures, which were aggregated to monthly average temperatures.

Camp Creek: No 2000 temperature data was available. A composite temperature record was made up of 2000 Blue Creek daily temperatures. Blue Creek temperatures were chosen because the existing record for Camp Creek matched the 2000 record for Blue Creek. The composite Camp creek daily temperatures were aggregated to monthly average temperatures.

Red Cap Creek: No 2000 temperature data was available. A composite temperature record was made of 1/1 - 7/30 composite Dillon Creek daily temperatures, and 7/31/92 - 12/31/92 Red Cap Creek daily temperatures. Dillon Creek temperatures were chosen because the two creeks are somewhat adjacent to each other and their sources share the

same approximate elevation. The composite Red Cap Creek daily temperatures were aggregated to monthly average temperatures.

Bluff Creek: There was no temperature data available for Bluff Creek. A composite temperature record for Bluff Creek was created using Blue Creek daily temperatures. Blue Creek temperatures were chosen because they were a complete record. The composite daily Bluff Creek temperatures were aggregated to monthly average temperatures.

Pine Creek: There was no temperature data available for Pine Creek. A composite temperature record for Pine Creek was created using Blue Creek daily temperatures. Blue Creek temperatures were chosen because they were a complete record. The composite daily Pine Creek temperatures were aggregated to monthly average temperatures.

Tectah Creek: Some 2000 data was available. A composite temperature record was made of 4/29/00 - 9/15/00 Tectah Creek daily temperatures and 1/1 - 4/28 and 9/16 - 12/31 Blue Creek daily temperatures. The composite daily Tectah Creek temperatures were aggregated to monthly average temperatures.

Blue Creek: Blue Creek had daily temperatures available for 2000. No composite record was necessary. The daily Blue Creek temperatures were aggregated to monthly average temperatures.

Table 18. Minor tributary inflow temperatures for Iron Gate to Turwar reach model

	Temperature, ºC														
JDAY	1	15	46	75	106	136	167	197	228	259	289	320	350	366	367
Bogus Creek	0.13	0.19	0.52	3.39	7.79	12.43	12.76	14.06	14.50	12.43	8.31	2.87	0.06	0.13	0.13
Beaver Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.16	14.03	15.55	14.31	11.09	4.79	4.04	4.00	4.00
Horse Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	13.13	14.08	13.64	11.09	4.79	4.04	4.00	4.00
Grider Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	16.31	16.82	13.95	10.80	4.79	4.04	4.00	4.00
Thompson Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Indian Creek	5.00	5.11	5.55	6.76	7.33	8.74	11.61	16.88	18.41	15.69	12.08	5.74	4.60	5.00	5.00
Elk Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	17.62	18.15	14.95	11.09	4.79	4.04	4.00	4.00
Clear Creek	5.00	5.13	5.50	6.95	7.39	8.76	11.96	15.78	17.29	15.06	11.83	5.45	4.56	5.00	5.00
Ukonom Creek	5.00	5.05	5.26	6.74	7.38	8.17	10.71	13.05	13.95	12.37	10.66	5.52	4.88	5.00	5.00
Dillon Creek	5.00	6.93	6.19	7.67	9.52	12.46	15.49	20.21	18.58	16.92	11.80	7.63	4.93	5.00	5.00
Camp Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Red Cap Creek	6.50	6.93	6.19	7.67	9.52	12.46	15.49	20.30	19.37	16.62	13.06	9.22	6.23	6.50	6.50
Bluff Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Pine Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Tectah Creek	7.90	7.76	8.26	8.18	9.94	10.02	12.51	13.73	14.10	14.48	13.50	9.98	8.03	7.90	7.90
Blue Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89

Constituent Concentrations

Constituent concentrations for the tributary inflows between Iron Gate Dam and the Pacific Ocean were assigned for all streams identified in Table 17 with the exception of Willow, Cottonwood, and Humbug Creeks. There was no data available for these tributaries and they contribute only minor flow in the summer months.

Constituent concentrations for the upstream boundary condition were provided by the Iron Gate Reservoir CE-QUAL-W2 simulation, and passed to the Iron Gate to Turwar reach in the manner described for the Keno reach.

Dissolved oxygen at all minor tributaries was estimated assuming 100 percent saturated conditions. This assumption is based on most of these streams reach the Klamath River after flowing

- through step canyon reaches that are several miles long
- through watersheds that have little or no water resources development and/or
- through watersheds where organic loads and other oxygen demanding processes are modest.

Review of available data (USBR, 2003) indicates this is a reasonable assumption for modeling applications. However, any diurnal variations due to primary production are not represented.

Dissolved oxygen concentrations were based on the hourly (Shasta, Scott, Salmon, and Trinity Rivers) or monthly (all remaining tributaries) temperature data identified above and atmospheric pressure corrected for elevation. Because the atmospheric correction through the study reach was small, average elevations for three sub-reaches were used in the calculation. The average elevation from Iron Gate Dam to the USGS Gage at Seiad Valley (1759.9 ft (536.4 m)) was used to correct atmospheric pressure for all tributaries within that reach. Likewise, the average elevation for USGS Gage at Seiad Valley to Trinity River reach (810.0 ft (246.9 m)) and from the Trinity River to the end of the IG-Turwar reach (150.0 ft (45.7 m)) were used to correct atmospheric pressure for all tributaries within those reaches. The methodology for dissolved oxygen saturation calculation and atmospheric pressure correction are included in Appendix F.

Representation of chemical constituents (e.g., nutrients, BOD, and algae) was based largely on USFWS (1999), USBR (2003), and EPA (1997). Overall, there was little data available for most tributaries, and the minor tributaries generally had no available water quality data of this type. The Shasta and Scott Rivers had sufficient data from USBR (2003) to represent seasonal variations. Table 19 summarizes the estimated water quality boundary conditions for the Shasta and Scott Rivers, as well as other major and minor tributaries. As noted above, many of these tributary watersheds are lightly populated, have minimal water resources development, and although several areas reside within active timber management areas, the water quality out of most tributaries is of good quality.

Table 19. Water quality boundary conditions for constituent concentrations for Klamath River tributaries between Iron Gate Dam and Turwar

Parameter		Shasta R.		Scott R [a]		All Other Tributaries [b]
		1/1- 7/15	7/16-12/31	1/1- 7/15	7/16-12/31	1/1-12/31
Organic N (D [c])	(mg/l)	0.45	0.45	0.20	0.20	0.15
NH_4^+	(mg/l)	0.15	0.05	0.15	0.05	0.05
NO_2^-	(mg/l)	0.00	0.00	0.00	0.00	0.00
NO_3^-	(mg/l)	0.05	0.05	0.15	0.05	0.05
Organic P (D [c])	(mg/l)	0.05	0.05	0.05	0.05	0.05
PO_4^{3-}	(mg/l)	0.45	0.15	0.10	0.05	0.05
BOD	(mg/l)	2.00	2.00	2.00	2.00	2.00
Algae	(mg/l)	1.00	1.00	1.00	1.00	1.00
Dissolved Oxygen	(mg/l)	Based on saturation dissolved oxygen				

[a] based on synoptic at mouth
[b] Including Salmon River, Trinity River and all minor tributaries
[c] D – Dissolved

2.3.8.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

The meteorological data for the Klamath River Iron Gate to Turwar reach was derived from meteorological observations near Klamath Falls, OR; however, it is clear that atmospheric conditions vary appreciably throughout the study reach due to elevation, orographic features, proximity to the Pacific Ocean, and the shear size of the study area. To more effectively address local meteorological conditions with data collected at a distance location, an assessment of available observations at several locations throughout the reach was completed to determine meteorological variability throughout the basin and, to the extent feasible, adjust parameters to more fully represent local conditions.

Air temperature, dew point (for wet bulb), and wind speed were examined at several locations and lapse rates for air temperature and dew point identified. No clear relationship was identified for relating wind speed at different locations. Adjustments to air temperature and dew point for the Iron Gate Dam to Turwar reach are shown in Table 20 and Table 21. Appendix E contains additional details on comparison of meteorological conditions throughout the study area.

Table 20. Air temperature corrections, based on month for Klamath River temperature modeling

Month	Correction: Klamath Falls (°C)	Correction: Iron Gate to Orleans (°C)	Correction: Orleans to Turwar (°C)
January	0.0	0.0	3.5
February	0.0	0.0	3.5
March	0.0	0.0	2.5
April	0.0	2.5	1.5
May	0.0	2.5	0.5
June	0.0	2.5	0.0
July	0.0	2.5	0.0
August	0.0	2.5	0.5
September	0.0	2.5	1.5
October	0.0	2.5	2.5
November	0.0	2.5	3.5
December	0.0	0.0	3.5
Positive corrections are added to the KFLO data to arrive at local conditions			

Table 21. Dew point temperature corrections, based on month for Klamath River temperature modeling

Month	Correction: Klamath Falls (°C)	Correction: Iron Gate to Orleans (°C)	Correction: Orleans to Turwar (°C)
January	0.0	0.0	8.0
February	0.0	0.0	8.0
March	0.0	0.0	8.0
April	0.0	0.0	8.0
May	0.0	0.0	5.5
June	0.0	0.0	4.0
July	0.0	0.0	4.0
August	0.0	0.0	5.5
September	0.0	0.0	5.5
October	0.0	0.0	8.0
November	0.0	0.0	8.0
December	0.0	0.0	8.0
Positive corrections are added to the KFLO data to arrive at local conditions			

3 Model Calibration and Validation

Model calibration and validation is the stage wherein model parameters are adjusted to fit model results to field observations (calibration), and then the model is tested on an independent set of data (often termed validation). This process provides a means to test the model and quantify its ability to replicate field conditions for the selected parameter values. The results of model calibration and validation, as well as the final set of model parameters are presented for each river reach.

The reservoir reaches were not formally calibrated for flow. Inflows and outflows are specified as input values in CE-QUAL-W2 and these were determined based on changes in observed or assumed storage. Existing data are insufficient to test the actual hydrodynamic performance of these models. Probably the most useful method of assessing hydrodynamic performance would be the implementation of a dye study, but this is beyond the scope of this project. The river reaches were calibrated for flow. The specific approach is outlined in the Flow Calibration section included below.

All river and reservoirs reaches were formally calibrated for water temperature and dissolved oxygen. The models were not specifically calibrated for nutrients, phytoplankton, or benthic algae. There was insufficient data in most cases (the exception is the Klamath River below Iron Gate Dam) to test the models rigorously for simulation of nutrient concentrations. However, these data were not discounted. Available nutrient data were plotted versus simulation results to ensure the model produced realistic response to system conditions. Temperature, dissolved oxygen, nutrients and algae data are all presented herein.

Although the reservoir models were all applied over a calendar year during calibration, there was generally little or no data between late fall and mid spring. Model results are presented for the entire year, but late fall to mid spring calibration and validation was not completed for this analysis.

3.1 Flow Calibration

Hydrodynamic calibration typically requires varying channel roughness (e.g., Manning coefficient, n) through a range of values while comparing simulated transit time and river stage with measured data. Transit time can be estimated from stream velocity measurements or tracking changes in river stage under varying flow conditions. Although USGS gages are located near Seiad Valley (RM 129), Orleans (RM 56), and Turwar (RM5), travel time was difficult to ascertain accurately due to the long distance and uncertainty in ungaged tributary flows and other accretions.

To overcome limitations of independent calibration of flow, Deas and Orlob (1997) present a method for iterative calibration wherein both the hydrodynamic and water quality models were used jointly. Application requires modeling on a sub-daily time step and availability of associated sub-daily water temperature data (e.g., hourly). Both criteria were fulfilled for this project. The method is outlined below in the context of the Klamath River.

3.1.1 Iterative Calibration: Background

Iterative calibration of flow and temperature was completed for the Keno, J.C. Boyle to Copco Reservoir, and Iron Gate Dam to Turwar Reaches. The Link River reach was deemed too short for effective application of the methodology. The upstream boundary conditions for these three reaches (Keno Dam, J.C. Boyle Dam and powerhouse release, and Iron Gate Dam) provide unique temperature signals that can be identified in downstream reaches. Because the heat budget is driven primarily by solar energy, river temperature downstream of the reservoir responds to daily cycles of heating and cooling. In response to this cycle, a characteristic diurnal temperature pattern is produced, the advective transport of which serves as a "tracer" of the flow. Thus, diurnal variations in water temperature provide a signal similar to that of a conservative tracer that is superimposed on the mean daily thermal profile. This signal is effectively reproduced in model results, and can be "fit" to measured data in the process of model calibration. This approach is not generally applicable to unregulated rivers.

Calibration parameters for the hydrodynamic model include bed roughness (Manning coefficient) and turbulent exchange coefficients, although in this exercise longitudinal mixing was assumed minimal (i.e., turbulent exchange coefficients were not varied). In the water quality model, temperature calibration parameters include evaporative cooling coefficients, where evaporation, E, is represented by

$$E = (a+bW)(e_s-e_a) \qquad (6.1)$$

where a and b are empirical evaporation coefficients, W is wind velocity, e_s is saturation vapor pressure, and e_a is actual atmospheric vapor pressure.

The calibration technique requires that the hydrodynamic model initially be applied to simulate a flow field that is then used as input to the water quality model. Computed hourly water temperature data are then compared to measured field data. Three possible relationships between phase and amplitude of computed and measured values may occur: (1) both phase and amplitude are correct; (2) phase is correct, but amplitude is incorrect; and, (3) phase is incorrect. The calibration technique is represented schematically in Figure 18.

Phase of the diurnal temperature variation is directly related to travel time. Travel time, in turn, is determined by water velocity, and is thus a function of bed roughness. The amplitude of diurnal temperature variations is affected by two processes: travel time (i.e., exposure time), and evaporation coefficients. The possible outcomes and model steps of the calibration process are described below.

Case 1: Phase correct, amplitude correct - If the simulated phase and amplitude of the diurnal variation in water temperature match measured data, the calibration is complete.

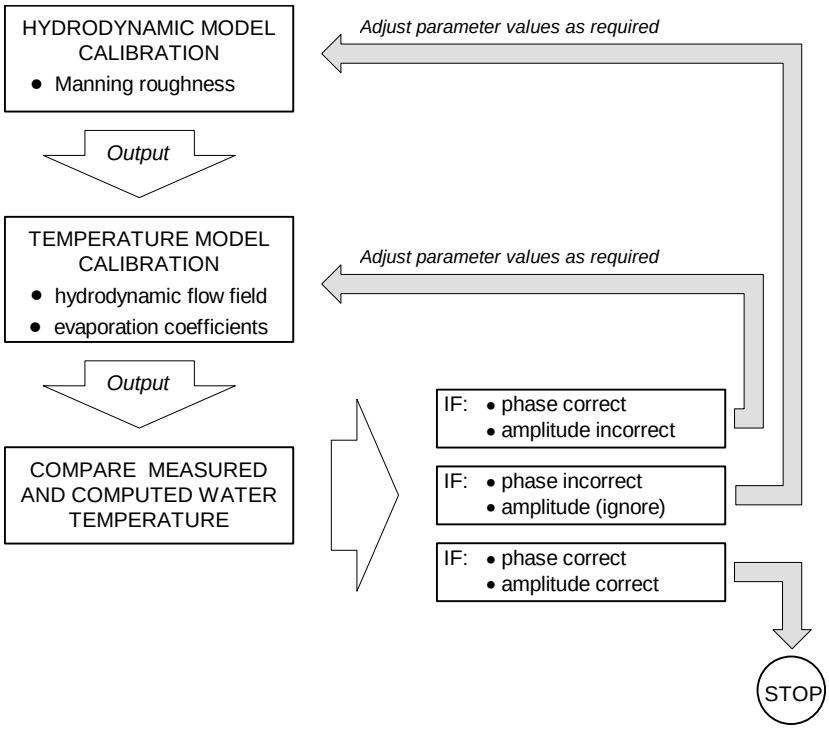


Figure 18. Schematic of iterative hydrodynamic and water temperature model calibration process

Case 2: Phase correct, amplitude incorrect - If the phase of simulated diurnal temperature variation matches measured data, but amplitude is incorrect, the applied Manning roughness coefficient is representative and hydrodynamic calibration is complete. Subsequently, evaporation coefficients (*a* and *b*) may be adjusted to improve/calibrate diurnal temperature amplitude.

Case 3: Phase incorrect - If the phase of simulated diurnal temperature variation does not coincide with measured field data, transit time in the river has been compromised. For excessive roughness values, average river velocities are reduced and transit time is increased; the converse is true for roughness values that are too small. The result is a temperature tracer signal that is displaced upstream or downstream, respectively. Amplitude of the signal is ignored because replication of the phase is necessary prior to assessing the amplitude, i.e., increased or decreased travel time will lead to greater or lesser heating of river water, directly affecting amplitude. Under these conditions, the Manning coefficient must be modified appropriately and both the hydrodynamic and water quality models re-run. Water quality model calibration coefficients remain unchanged because amplitude calibration cannot be completed until the phase of the tracer signal is correctly determined.

The steps of calibrating for phase and subsequently calibrating for amplitude are illustrated for an idealized example in Figure 19. The initial simulated temperatures illustrate both a phase shift and amplitude error. Calibration of channel roughness corrects for phase and, because travel time has been changed, also affects amplitude error. Subsequently, the amplitude is calibrated with evaporation coefficients. In practice, simulated phase and amplitude may not consistently match measured data due to short-term variations in upstream operations, local meteorology, and tributary influences.

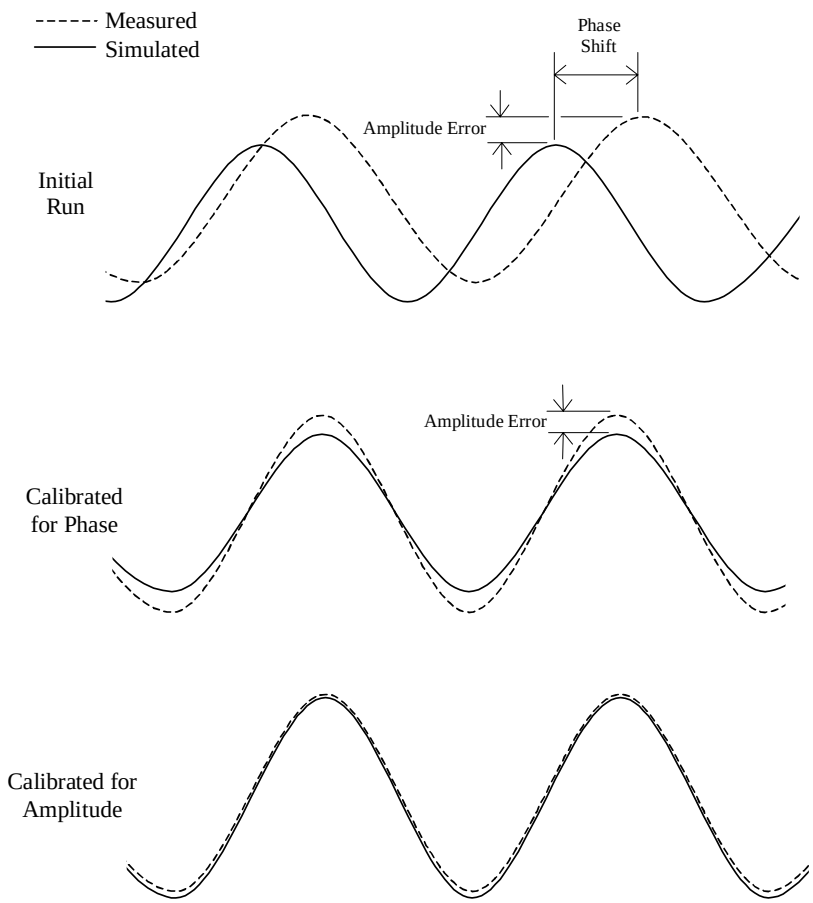


Figure 19. Example calibration of phase and amplitude for diurnal temperature trace

The final values for Manning roughness and evaporative heat flux coefficients are included for each reach in the summary table at the end of the calibration presentation.

3.1.2 Slope Factor

Preliminary runs, with a water surface slope based on the elevation of the upstream and downstream end of each reach (gross slope), showed that model results in the steep river reaches were not effectively represented. The water surface slope of steep rivers is generally significantly less than the overall gross slope of the river profile. Further, steep rivers are typically not uniform in slope, but consist of short cascades or riffles, combined with intermediate pools and runs. RMA-2 includes a slope factor (SF) and associated logic that reduces the effective bed slope of the stream and assumes travel time through the short cascade sections is negligible compared to the transit time through runs or pools. Figure 20 shows a schematic of initial model application (Case 1; SF = 0) and model application with slope factor applied (Case 2: 1>SF>0). For cases 1 and 2 the stream reaches have equivalent vertical elevation change (z) and horizontal distance. But, by neglecting the short cascade reach the transit time in the river is more closely simulated.

To estimate slope factor, uniform flow was assumed and Manning's equation applied.

$$Q = [1.49AR^{2/3}S^{1/2}] / n \qquad (4.2)$$

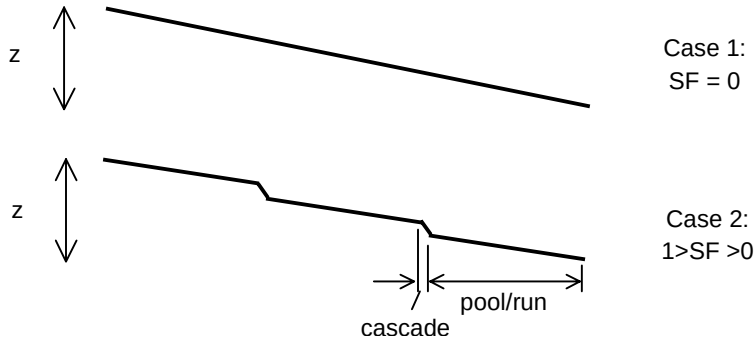


Figure 20. Slope factor application for a representative river reach

Where Q is flow rate, A is cross sectional area, R is hydraulic radius, S is bed slope (or water surface slope), and n is a channel roughness coefficient. Using this equation for a known cross sectional area, hydraulic radius, and an estimated value of Manning n, the slope required to deliver a known flow rate can be determined.

Based on typical summer flow rates the slope factor for the Link and Keno reaches was set at 0.90, the bypass and peaking reaches slope factor was 0.95, and the factor for the Klamath River from Iron Gate Dam to Turwar was set at 0.80. These value were not changed throughout calibration. The assumption is that small discrepancies in the slope factor can be accommodated in selection of an appropriate Manning coefficient. For this reason, use of the Manning coefficient determined herein for application in other flow models should be done with great consideration and care.

3.1.3 Calibration Measures and Methods

Calibration required comparison of several alternative parameter sets. Selecting final parameter values may include professional judgment, graphical comparisons of simulated versus measured data, and statistical analysis of simulated and measured data, to name a few. Though each measure has merits and demerits, statistical analyses were used as the primary method to select final calibration parameters for the flow and temperature models. Graphical comparisons and professional judgment were used to assess general model performance and provided significant insight, but proved difficult to quantify differences over long time periods and at multiple locations along the river. Thus, several basic statistics were applied to the simulated temperature data and associated error to provide additional insight into model performance and to quantify model uncertainty: bias, mean absolute error, and root mean squared error.

These summary statistics are presented in the temperature calibration section for each river reach. The final values of channel roughness and other hydrodynamic parameters are included in the summary table that concludes each calibration section.

3.2 Link River

The RMA suite of models for Link River was calibrated and validated for May 21-23, 2002 and July 16-18, 2002, respectively. Water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) data were collected during field season 2002 to support the modeling task.

3.2.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

3.2.1.1 Boundary Conditions

The boundary condition data was derived from samples collected at Link Dam. Water temperature and dissolved oxygen data were available from water quality probes at hourly intervals. Grab samples were collected once per day for three days. Due to the inherent variability and infrequent sampling interval of the grab data, the boundary condition values for nutrients, BOD, and algae were assumed to be a constant value for the calibration and validation period, based on the grab sample data from 2002 (Appendix F).

The water quality boundary conditions derived for Link Dam were also applied to the return flows at East Side and West Side powerhouse. The water quality values for the calibration and validation period are shown in Table 22 and Figure 21 and Figure 22.

Table 22. Link River reach calibration and validation water quality boundary conditions

Parameter	Units	Dates	
		5/21/02 - 5/23/02	7/16/02 - 7/18/02
BOD	mg/l	3.0	5.0
DO	mg/l	variable	Variable
Org N	mg/l	0.70	1.80
NH_4^+	mg/l	0.10	0.25
NO_2^-	mg/l	0.00	0.00
NO_3^-	mg/l	0.05	0.10
Org P	mg/l	0.25	0.40
PO_4^{3-}	mg/l	0.10	0.10
Algae	mg/l	2.0	22.0
Tw	°C	variable	variable

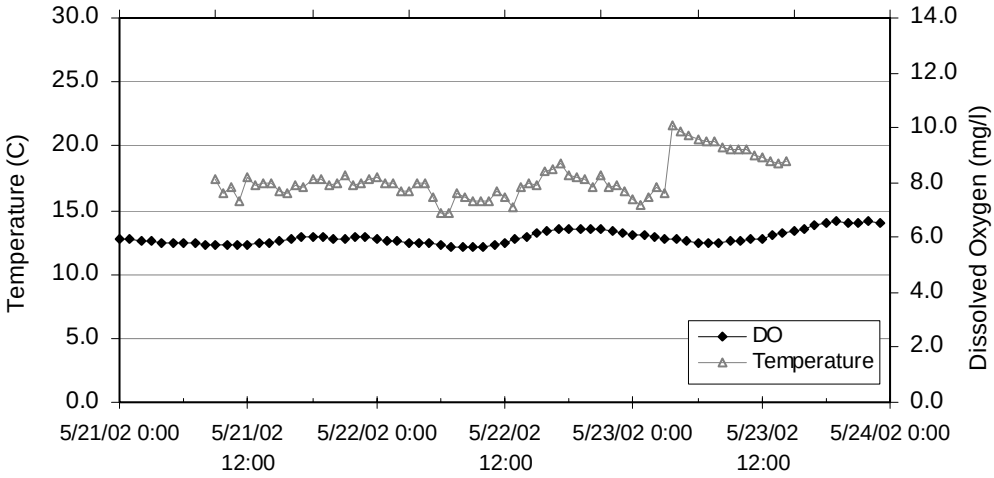


Figure 21. Link River reach temperature and dissolved oxygen calibration boundary conditions

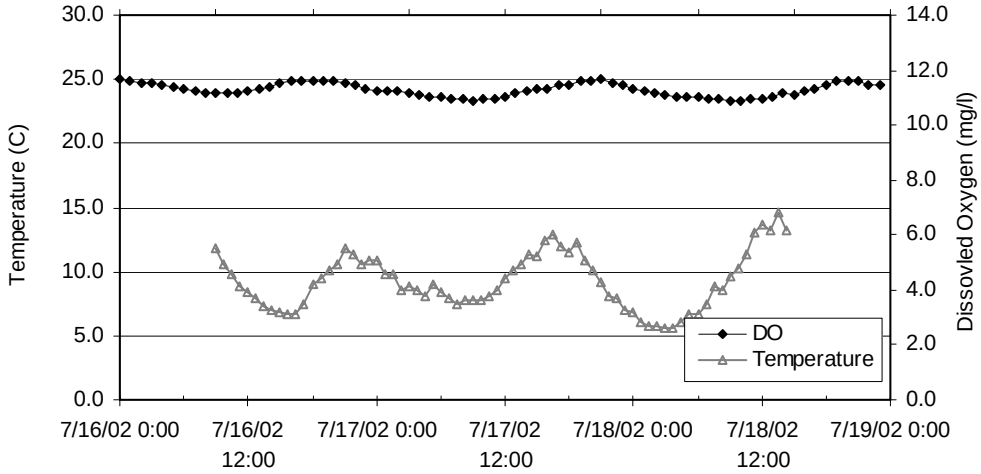


Figure 22. Link River reach temperature and dissolved oxygen validation boundary conditions

3.2.1.2 Initial conditions

The model was run for three days prior to both the calibration and validation periods to provide an initial condition for simulation. The initial bed algae mass was estimated at 5 g/m^2.

3.2.1.3 Calibration and Validation Points

The calibration and validation point for the Link River reach was Link River at Lake Ewauna. These data are displayed in the following section with model results.

3.2.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The nutrient data were

primarily derived from field data, which were typically sampled once per day, resulting in sparse data that are not readily amenable for such statistical analysis. All model parameters for the Link River reach are summarized in Table 25 at the end of this section.

3.2.2.1 Water Temperature

Water temperature calibration required varying evaporation heat flux coefficients (presented in Table 25) that govern the mass transfer formulation represented in the numerical model heat budget. No other parameters were varied. The hourly results are presented graphically in Figure 23 and Figure 24. The diurnal range and phase is well represented for spring temperatures in the neighborhood of 12°C-14°C, as well as in the summer period, when temperatures reach almost 25°C. Tabulated statistics (Table 23) illustrate that simulated results on an hourly and daily basis are within about 0.2°C of observations. These results are not unexpected given the short river reach.

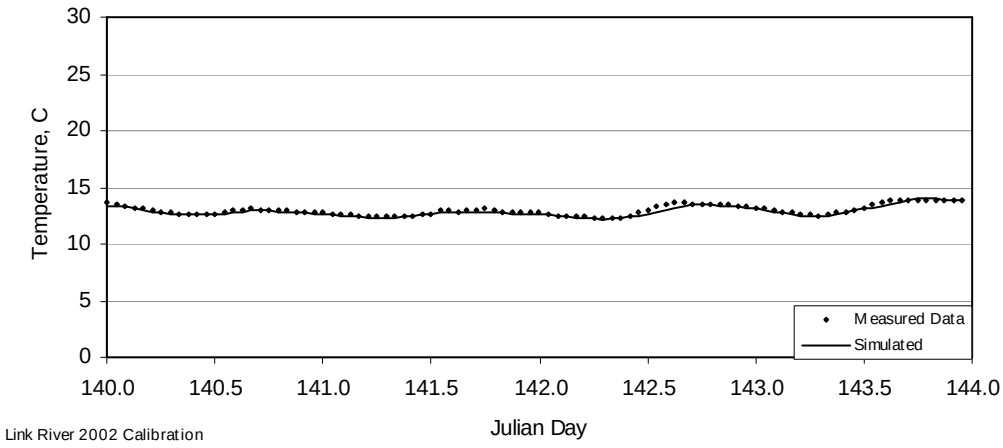


Figure 23. Link River simulated versus measured water temperature, May 20-23, 2002

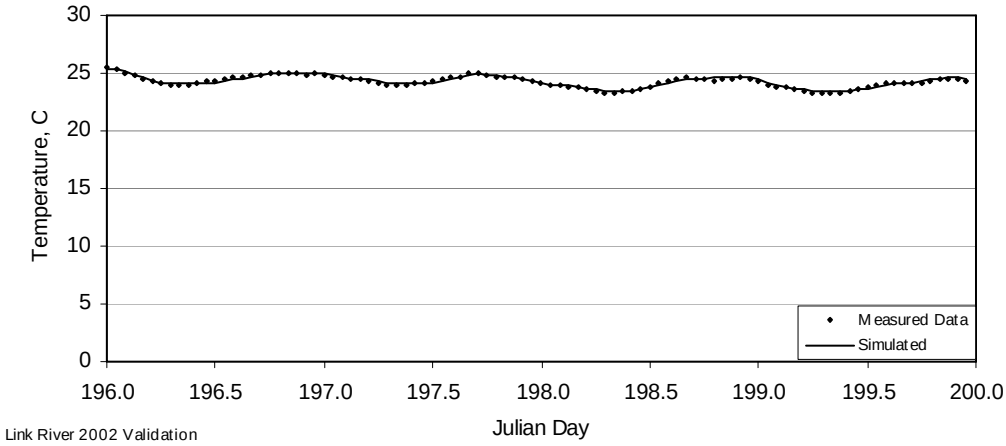


Figure 24. Link River simulated versus measured water temperature, July 15-18, 2002

Table 23. Link River hourly and daily calibration and validation period statistics for water temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	°C	-0.11	0.02	-0.11	0.02
Mean absolute error (MAE)	°C	0.13	0.11	0.11	0.03
Root mean squared error (RMSE)	°C	0.16	0.12	0.12	0.03
n	-	95	96	4	4

[a] Mean bias = simulated – measured

3.2.2.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates, and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeled in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from Upper Klamath Lake, growth rates were set to very low numbers in river reaches.

The hourly results are presented graphically in Figure 25 and Figure 26. The diurnal range and phase is well represented for spring dissolved oxygen (DO) conditions in the neighborhood of 8-10 mg/l, as well as in the summer period, when DO concentrations vary from about 4 to 6 mg/l. Tabulated statistics (Table 24) illustrate that simulated results on an hourly and daily basis are within about 1 mg/l of observed values. Some of the disparity between simulated and observed values is probably due to Link Dam dissolved oxygen conditions being imposed as boundary conditions at East and West Side powerhouses.

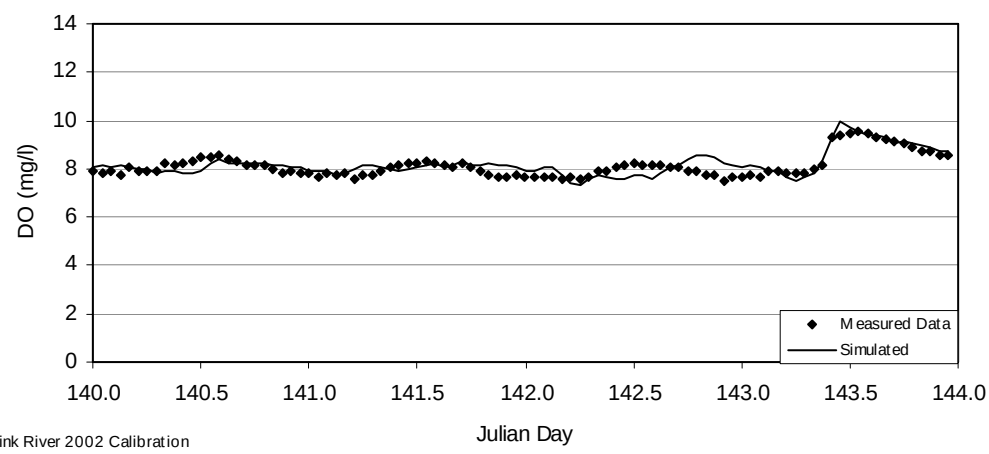


Figure 25. Link River simulated versus measured dissolved oxygen, May 20-23, 2002

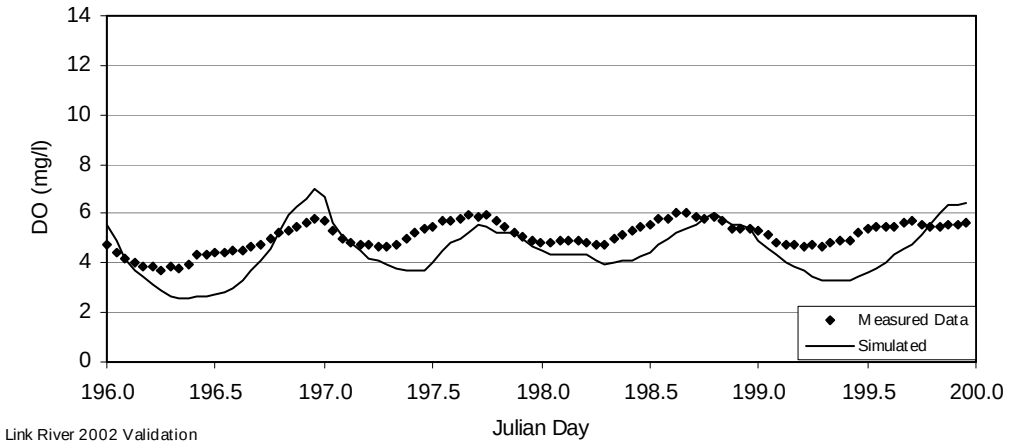


Figure 26. Link River simulated versus measured dissolved oxygen, July 15-18, 2002

Table 24. Link River hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias	mg/l	0.08	-0.60	0.08	-0.60
Mean absolute error (MAE)	mg/l	0.25	0.80	0.08	0.60
Root mean squared error (RMSE)	mg/l	0.31	0.95	0.10	0.61
n	-	95	95	4	4

[a] Mean bias = simulated – measured

3.2.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Link River reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 27 through Figure 32. Simulated concentrations for ammonia, nitrate, and orthophosphate were consistent with field observations.

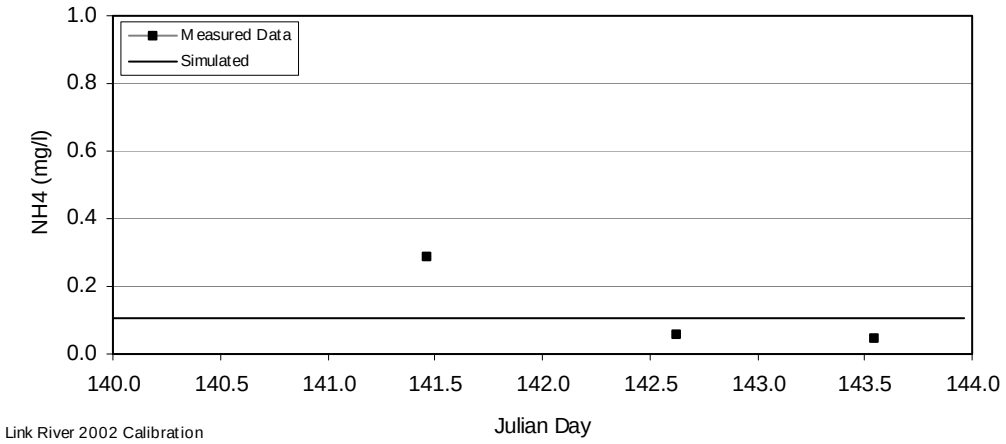


Figure 27. Link River simulated versus measured ammonia, May 20-23, 2002

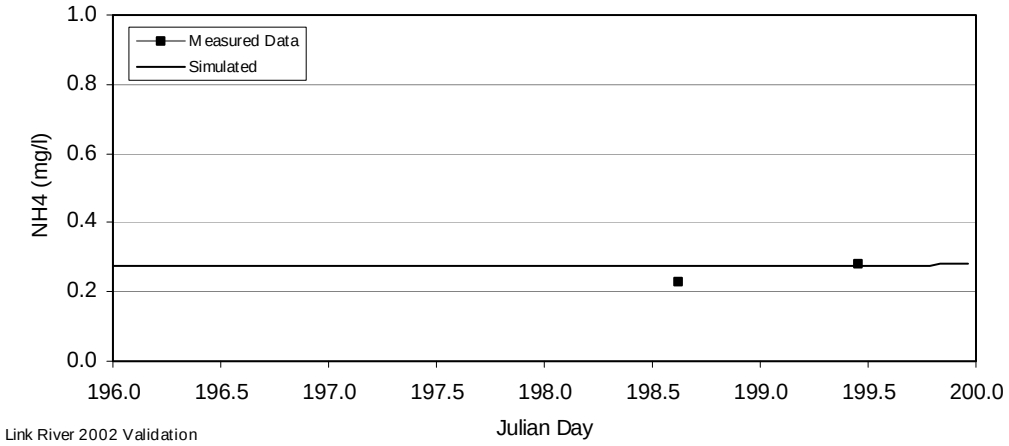


Figure 28. Link River simulated versus measured ammonia, July 15-18, 2002

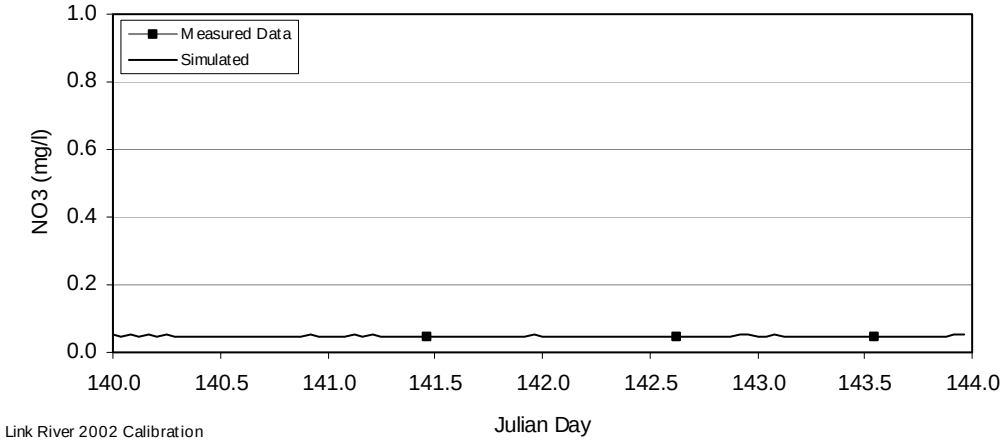


Figure 29. Link River simulated versus measured nitrate, May 20-23, 2002

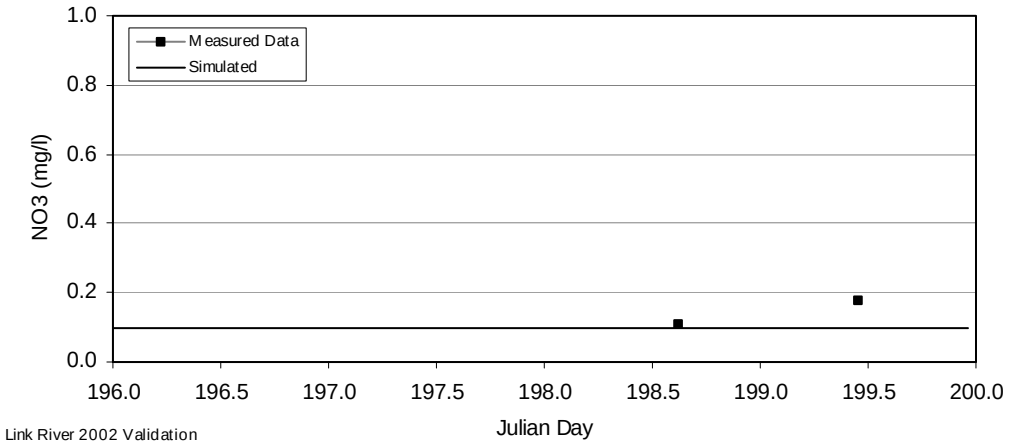


Figure 30. Link River simulated versus measured nitrate, July 15-18, 2002

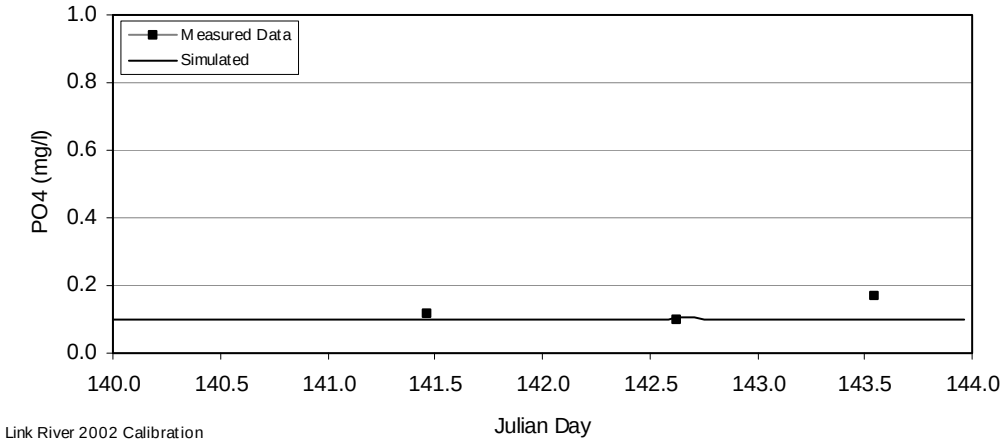


Figure 31. Link River simulated versus measured orthophosphate, May 20-23, 2002

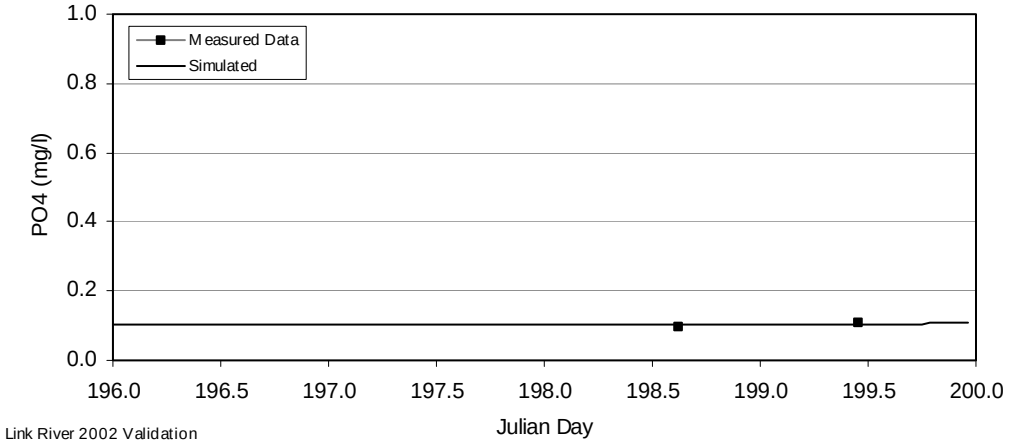


Figure 32. Link River simulated versus measured orthophosphate, July 15-18, 2002

3.2.2.4 Summary of Parameters

Table 25. RMA-2 and RMA-11 Model, rates, coefficients, constants for the Link River reach

Variable Name	Description, units	Value
	Time step, hr	1.0
	Space step, m	75
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
	Slope Factor	0.80
ELEV	Elevation of site, m	1192.0
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coefficient a, m hr^{-1} mb^{-1}	0.000015
EVAPB	Evaporative heat flux coefficient b, m hr^{-1} mb^{-1} $(m/h)^{-1}$	0.000005
EXTINC	Light Extinction coefficient, used when algae is not simulated, 1/m	1.5
ALP0	Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.072
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.010
LAMB1	Linear algal self-shading coefficient, phytoplankton, 1/m	n/a
LAMB2	Non-linear algal self shading coefficient, phytoplankton, 1/m	n/a
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.01
RESP	Local respiration rate of algae, phytoplankton, 1/d	0.05
SIG1	Settling rate of algae, phytoplankton, 1/d	0.0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m^{-2} s^{-1}	0.01
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.01
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.001
PREFN	Preference factor for NH3-N, phytoplankton	0.6
ABLP0	Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A	50
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
LAMB1	Linear algal self shading coefficient, bed algae, 1/m	n/a
LAMB2	Non-linear self shading coefficient, bed algae, 1/m	n/a
MUMAX	Maximum specific growth rate, bed algae, 1/d	1.0
RESP	Local respiration rate of algae, bed algae, 1/d	0.60
MORT	Mortality, bed algae, 1/d	0.0
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.01
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.002
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m^{-2} s^{-1}	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.3
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.5
BET3	Rate constant: hydrolysis Org N to NH3-N, 1/d	0.3
BET4	Rate constant: transformation Org P to P-D, 1/d	0.3
KNINH	First order nitrification inhibition coefficient, mg^{-1}	n/a
ALP3	Rate O_2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.6
ALP4	Rate O_2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.6
ABLP3	Rate O_2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.6
ABLP4	Rate O_2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.6
ALP5	Rate O_2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O_2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
K1	Deoxygenation rate constant: BOD, 1/d	0.3
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	3.0
SIG6	BOD settling rate constant, 1/d	0.0

n/a – not applicable

Table 26. RMA-11 model temperature factors for the Link River reach

Variable Name	Description	Value
Water Column		
THET1	Algal growth rate temperature factor	1.047
THET2	Algal respiration rate temperature factor	1.047
THET3	Algal settling rate temperature factor	1.047
THET4	Organic nitrogen decay rate temperature factor	1.047
THET5	Organic nitrogen settling rate temperature factor	1.024
THET6	Ammonia nitrogen decay rate temperature factor	1.083
THET7	Ammonia nitrogen benthic sources rate temperature factor	1.074
THET8	Nitrite nitrogen decay rate temperature factor	1.047
THET9	Organic phosphorous decay rate temperature factor	1.047
THET10	Organic phosphorous settling rate temperature factor	1.024
THET11	Orthophosphate benthic sources rate temperature factor	1.074
THET12	BOD decay rate temperature factor	1.047
THET13	BOD settling rate temperature factor	1.024
THET14	DO benthic demand rate temperature factor	1.000
THET15	DO reaeration rate temperature factor	1.024
Bed		
BTHET1	Bed algae growth rate temperature factor	1.047
BTHET2	Bed algae respiration rate temperature factor	1.047
BTHET3	Bed algae settling rate temperature factor	1.000
BTHET4	Bed organic nitrogen decay rate temperature factor	1.000
BTHET5	Bed organic nitrogen settling rate temperature factor	1.000
BTHET6	Bed ammonia nitrogen decay rate temperature factor	1.000
BTHET7	Bed ammonia nitrogen benthic sources rate temperature factor	1.000
BTHET8	Bed nitrite nitrogen decay	1.000
BTHET9	Bed organic phosphorous decay rate temperature factor	1.000
BTHET12	Bed BOD decay rate temperature factor	n/a

3.3 Lake Ewauna-Keno Dam Reach

The CE-QUAL-W2 model for the Lake Ewauna to Keno Dam reach was calibrated for 2001 and tested using 2000 data. Water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) data were collected at multiple locations during the 2001 field season and at three locations (Klamath River at Miller Island, Klamath River at Highway 66 bridge, and Klamath Straits Drain at Highway 97) during the 2000 field season by the U.S. Bureau of Reclamation.

The Lake Ewauna-Keno Reach is a complex reach with multiple inputs and outputs. The headwater boundary condition is Link River, which essentially represents Upper Klamath Lake – a highly dynamic hyper-eutrophic body of water. Other inputs include municipal waste water treatment plant effluent, industrial (primarily wood processing) discharges, agricultural discharges, and stormwater runoff. Although variable in size, the persistence and long-term nature of these discharges into this impoundment have created a water quality condition that is wholly uncommon in rivers of this size in the western United States. Namely, persistent and extreme anoxia, elevated nutrient levels, highly variable

(in space and time) algal standing crop, appreciable BOD, and SOD demands. Available data have lead to a preliminary characterization of pertinent system processes.

Additional field work and model testing completed during the summer of 2003 has identified that this reach is dominated by the inflow quantity and quality at Upper Klamath Lake. Further, this boundary condition is highly variable in time, presumably in response to conditions in Upper Klamath Lake during late spring through fall periods, including but not limited to primary production (algal standing crop, blooms and die-offs), storage, flow conditions, and meteorological conditions (incident solar radiation, wind conditions). Because there is a measurable current throughout much of Keno Reservoir, the inputs from Upper Klamath Lake are actively transported downstream, impacting water quality throughout the reservoir length. This current, coupled with the shallow nature of the impoundment and intermittent winds, preclude strong thermal stratification of the system. The reservoir does stratify on a diurnal basis under calm conditions. The water velocity is not sufficient to preclude the development of large densities of phytoplankton, which actively colonize the top few feet of the water body. The high level of primary production, coupled with the large load of organic matter (living and dead algal tissue), creates a system that is almost wholly anoxic in the aphotic zone and experiences large diurnal variation in dissolved oxygen concentration in the photic zone. At certain locations there have been periods where the entire water column experiences dissolved oxygen concentrations less than 1 mg/l.

The large load of nutrients and organic matter from Upper Klamath Lake, imparts an appreciable oxygen demand on the system, wherein the system experiences a severe and persistent dissolved oxygen sag in the region from Lake Ewauna to below the Klamath Straits drain. The river system tends to recover somewhat by the time it reaches the Keno area, but concentrations often remain well below saturation in summer months. The role of sediment oxygen demand has been briefly explored with the CE-QUAL-W2 model and appears to play a modest role compared to the impacts of Upper Klamath Lake inflows.

U.S. Bureau of Reclamation operations occasionally have a dramatic affect on the water quality of the reservoir. Namely, there are periods where Link Dam releases are reduced and Lost River diversion channel inputs are increased. For example, in the fall of 2000 Link Dam releases were reduced to about 100 cfs and the Lost River diversion channel flows increased to around 700 cfs. During these operations the reservoir water quality was dominated by Lost River diversion channel water inflow. Another conditions that can affect water quality in the Klamath River downstream of the Lost River Diversion Channel is when diversions to the Reclamation project occur. If large amounts of water are diverted the residence time downstream of this point can potentially increase depending on the operations of the other withdrawal points and the Klamath Straits Drain. These may be short term events, but they can have impacts on water quality. The Klamath Straits Drain rarely exceeds 200 cfs in discharge and plays a lesser role; however, the drain is experiences a more persistent flow regime, while the Lost River diversion channel is often off line or diverting water from the river to the Reclamation Project.

Lake Ewauna/Keno Reservoir is a complex system and although significant improvements in characterizing the system have been identified, more studies will be

required to improve the water quality simulation of the system. Probably the most important issue is characterizing the boundary conditions (primarily Link Dam, but also Lost River diversion channel and Klamath Straits Drain) on a timescale sufficiently short to capture the dynamics of the system – probably on the order of several days to a week.

3.3.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

3.3.1.1 Boundary Conditions

The upstream and downstream flow boundary conditions utilized 2000 and 2001 existing conditions. The upstream boundary conditions for temperature and constituent concentrations were passed from the calibrated Link River model simulation. All other boundary conditions were derived as documented in the model implementation section. (Note: selected boundary condition data for 2001 and presented in Appendix H in graphical or tabular form.)

3.3.1.2 Initial conditions

The residence time in the reach is approximately 10 days, thus the first half of January is used to "warmed up" the model and results from this period are not applicable to analysis for both 2000 and 2001.

3.3.1.3 Calibration Points

There are two calibration and validation points within the Lake Ewauna to Keno Dam reach for the simulated years. The first is located at the Miller Island boat ramp. The second is located in the Keno Reservoir at the Highway 66 Bridge. These data are displayed in the following section with model results.

3.3.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. The model was run for the entire calendar year (2000 and 2001). Model performance was evaluated for the first week of the months of June through October to cover a wide range of seasons. Graphical presentation of these weekly periods also includes the 10 days prior to and 10 days following the selected week. This information, although not included in the statistical summary, provides insight into any trends the model is or is not representing in this dynamic and complex reach.

Field observations for temperature and dissolved oxygen were available from water quality probes on an hourly interval, allowing for summary statistics to be calculated on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled monthly or semimonthly; resulting in sparse data that are not readily amenable for such statistical analysis. All model parameters for the Lake Ewauna to Keno Dam reach are summarized in Table 35 at the end of this section.

3.3.2.1 Water Temperature

Water temperature calibration included varying the three wind speed evaporation coefficients specified by the user in CE-QUAL-W2. CE-QUAL-W2 simulated seasonal variations in water temperature effectively at both Miller Island (approximate river mile and Highway 66 near Keno. CE-QUAL W-2 was applied to this reach for the entire year. Residence time ranges from a few days to roughly two weeks and the system does not seasonally stratify.

Miller Island

The entire calendar year was simulated and temperature results for the first week of the months June through October 2000 and 2001 are shown in Figure 34 and Figure 35 and Figure 36 and Figure 37, respectively. Seasonal trends and short-term meteorological conditions are reflected in the model simulations. Summary statistics for the first week of each month for 2000 and 2001 are provided in Table 27 and Table 28, respectively.

The simulated hourly and mean daily temperature is represented to within about 1°C for 2000, and generally well under 1°C for 2001. The model matched short term variations as well as seasonal trends. However, simulated results did not reproduce a component of the diurnal variation evident in field observations. It is important to note that in 2000 the US Bureau of Reclamation datasonde was deployed at the Miller Island boat ramp dock in approximately 4 feet of water. This location did not represent actual mid-channel conditions. Further, the location was subject to mixing due to boat launching activities. Close examination of the trace shows increases in water temperatures on the order of 7°C within an hour (see Julian Day 173), which is highly unlikely. Thus attempting to calibrate to the peak daily temperatures was not appropriate. Associated dissolved oxygen data, pH and electrical conductivity also suggest that this location was not desirable. During the 2001 field season, the Bureau of Reclamation moved the sampling location to mid-channel, suspending the sonde from a buoy. The 2001 data, while still illustrating mid- to late-afternoon peaks, do not exhibit such drastic deviations.

Upon close examination, the daily temperature peaks are actually deviations from a smother sinusoidal temperature trace. Figure 33 illustrates the observed temperature at Miller Island (at a depth of approximately 1 meter) with an estimated sinusoidal signal sketched in on Julian days 207, 208, and 212. These deviations occur in the late afternoon, and after observing conditions at Miller Island and Keno, as well as other locations, in the summer of 2003 it is postulated that this upward deviation is due to late afternoon wind mixing. Local meteorological data suggest that during summer periods afternoon winds are typical, especially in the vicinity of Keno where the river cuts through the Cascades. During these afternoon wind events, the mixing energy is presumed to be sufficient to overcome at least a portion of the diurnal stratification wherein surface waters are mixed downward by wind, possibly aided by local velocities (current) within the reservoir. Field data from August 2003 suggest there are considerable temperature differences in the top meter: in the vicinity of Miller Island surface waters (depth of 0.1 m) were 28°C, while at 0.5 and 1.0 meters water temperatures were 25.1°C and 22.5°C, respectively. Towards sunset the thermal loading drastically diminishes and winds die down and water temperatures return to the typical smooth sinusoidal pattern. Examination of the observed data at Highway 66 suggests this

occurs at Keno as well. Attempts to refine the model to address these afternoon deviations were not attempted.

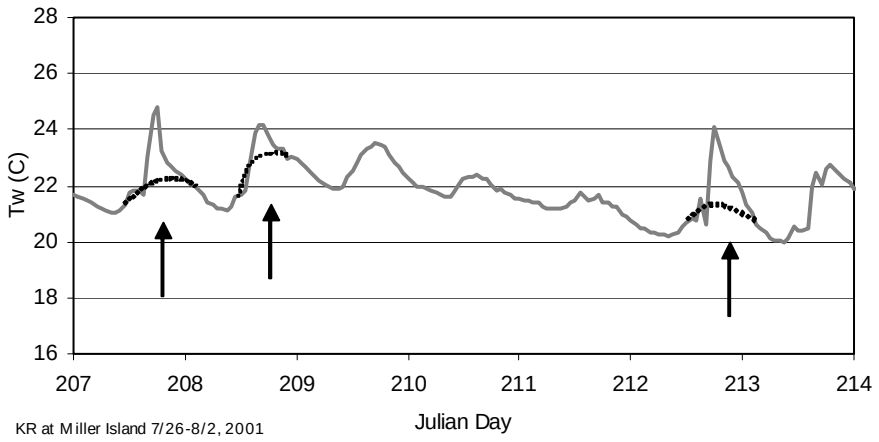
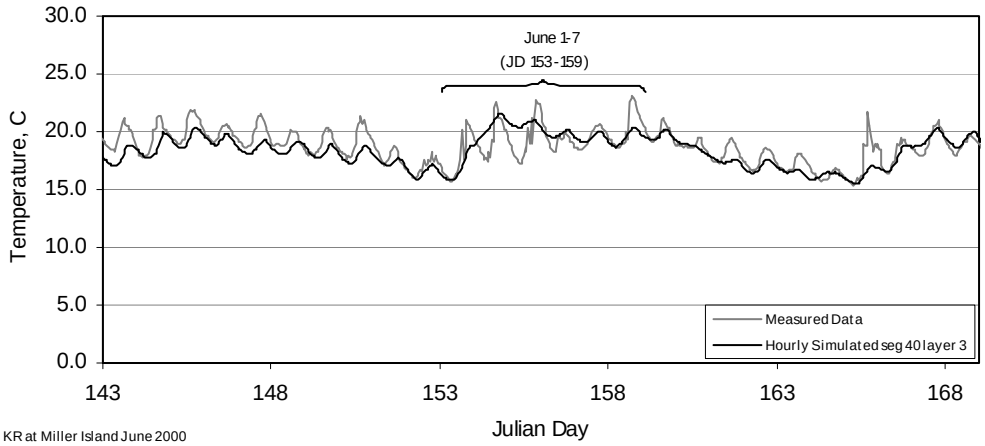


Figure 33. Observed water temperature at Miller Island (2001) showing afternoon deviations from the typical sinusoidal pattern of water temperatures (estimated with the dashed line and marked by arrows)



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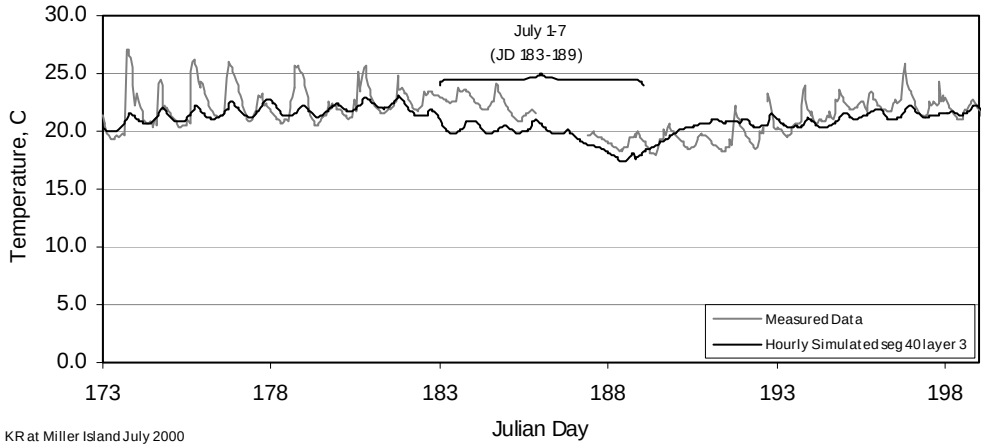

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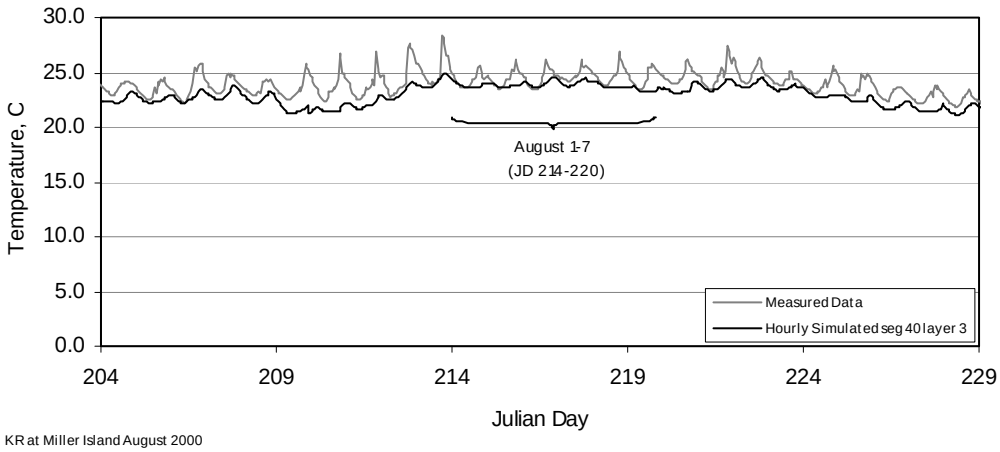

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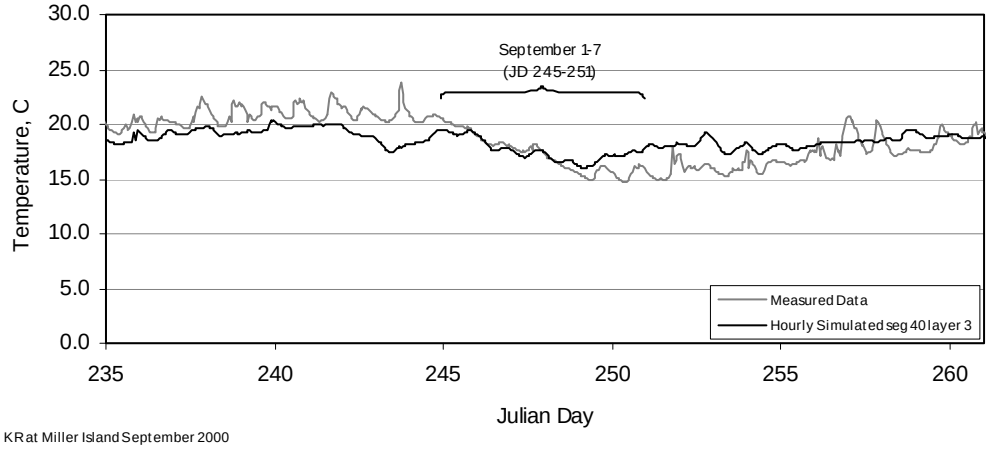
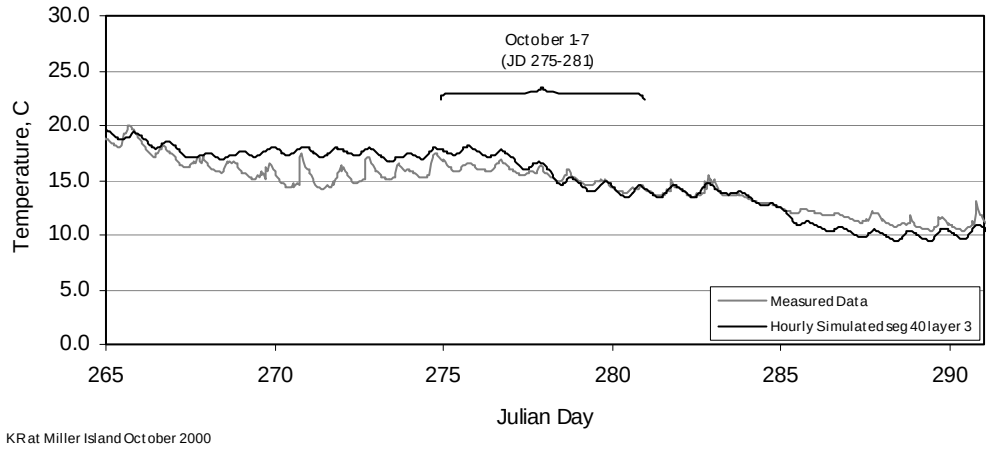
Figure 34. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000



(a)

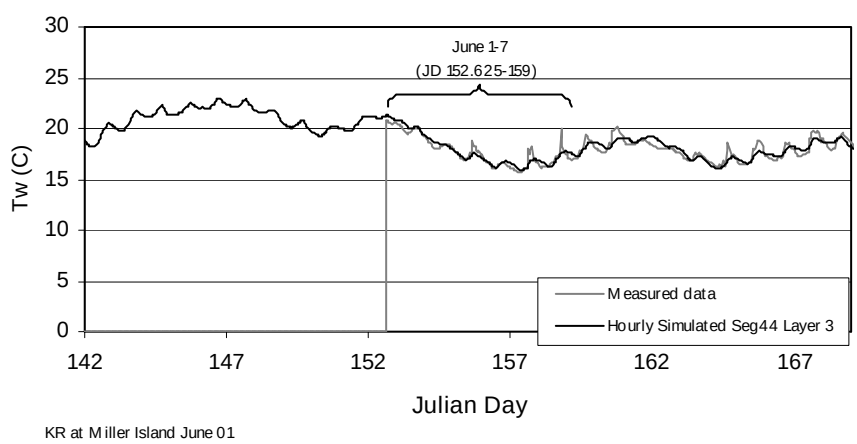


(b)

Figure 35. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2000

Table 27. Lake Ewauna-Keno Reach hourly and daily calibration period statistics for temperature at Miller Island 2000

Statistic	Unit	Jun 1-7	Jul 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	C	0.09	-1.48	-0.80	0.65	0.39
Mean absolute error (MAE)	C	0.94	1.53	0.83	1.01	0.63
Root mean squared error (RMSE)	C	1.26	1.78	1.08	1.34	0.82
N	-	168	131	168	168	168
Daily						
Mean Bias	C	0.09	-1.62	-0.80	0.65	0.91
Mean absolute error (MAE)	C	0.66	1.62	0.80	0.99	0.56
Root mean squared error (RMSE)	C	0.78	1.88	0.85	1.69	0.77
N	-	7	4	7	7	7



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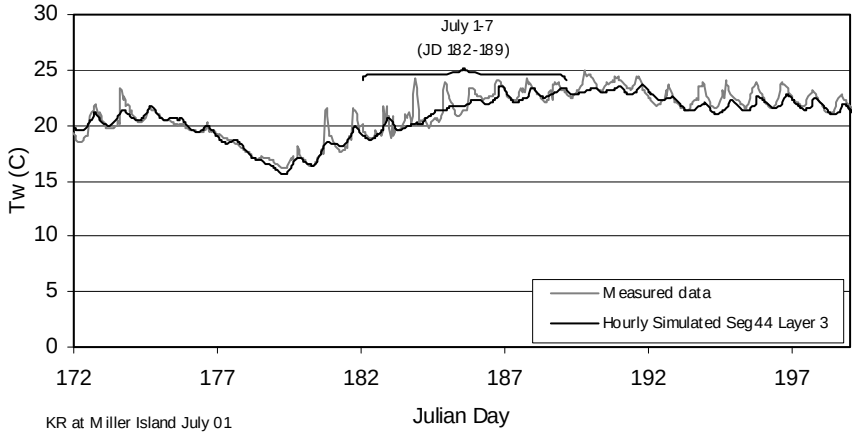

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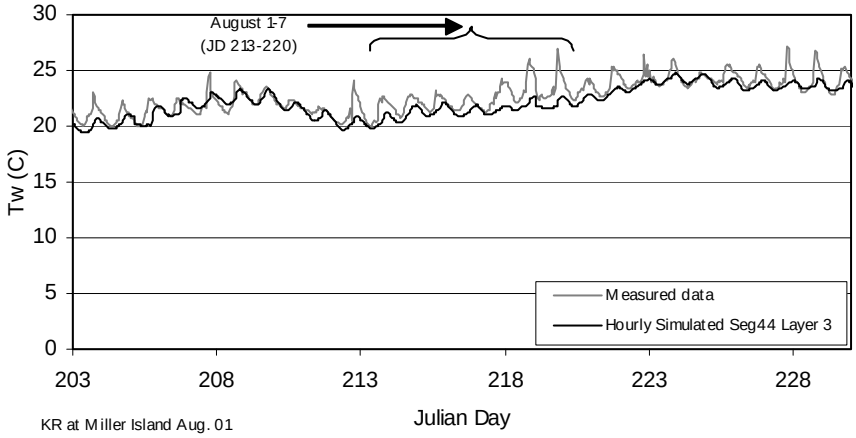
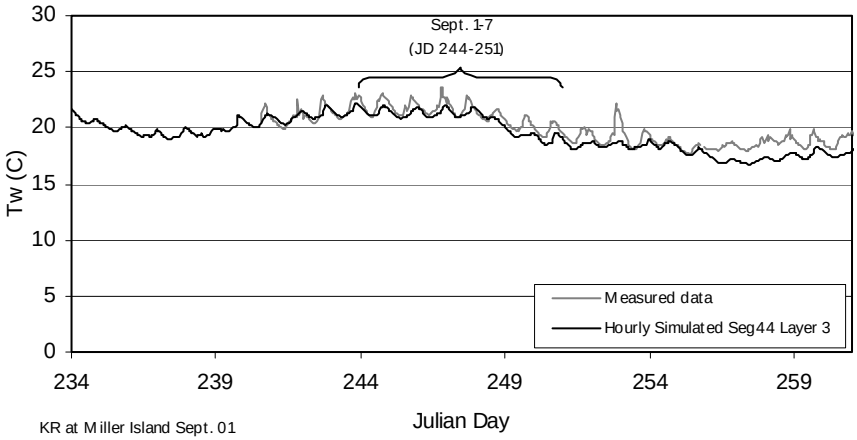


(c)

Figure 36. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001



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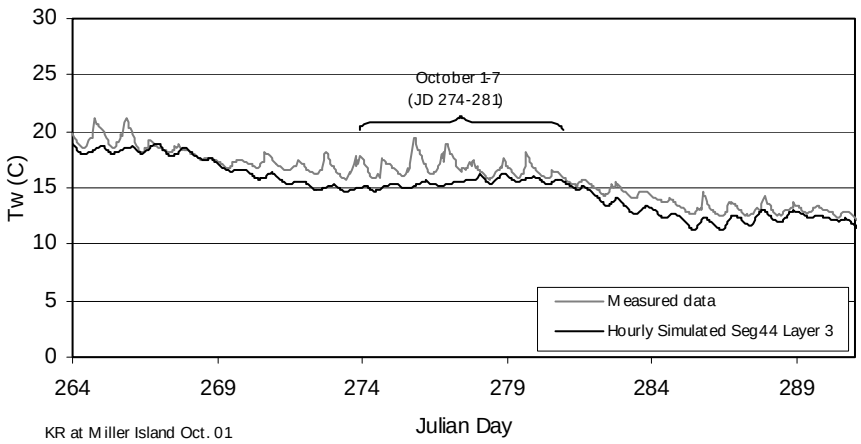


(b)

Figure 37. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2001

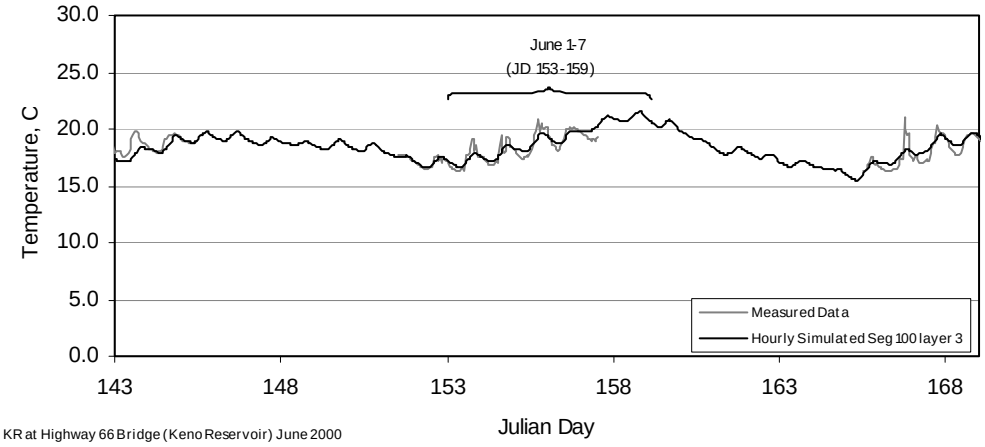
Table 28. Lake Ewauna-Keno Reach hourly and daily calibration period statistics for temperature at Miller Island 2001

Statistic	Unit	Jun 1-7	Jul 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	C	0.08	-0.29	-1.06	-0.56	-1.31
Mean absolute error (MAE)	C	0.32	0.61	1.06	0.61	1.31
Root mean squared error (RMSE)	C	0.45	0.86	1.35	0.75	1.56
N	-	153	168	168	168	168
Daily						
Mean Bias	C	0.05	-0.32	-1.07	-0.56	-1.31
Mean absolute error (MAE)	C	0.15	0.33	1.07	0.56	1.31
Root mean squared error (RMSE)	C	0.19	0.39	1.15	0.60	1.43
N	-	6	7	7	7	7

Highway 66 Bridge near Keno

Both 2000 and 2001 were simulated for the calendar year and results shown in Figure 38 through Figure 41. Hourly and daily summary statistics are included in Table 29 and Table 30 for 2000 and 2001, respectively. Seasonal trends and short-term meteorological conditions are clearly reflected in the model results and the models are within 1°C if observed values for all calibration periods. The US Bureau of Reclamation data sonde at Highway 66 has was suspended from a buoy in both 2000 and 2001. Windy conditions, similar to Miller Island are also present in the Keno area.

In general the models perform well over a wide range of conditions at both Miller Island and at Highway 66 near Keno.



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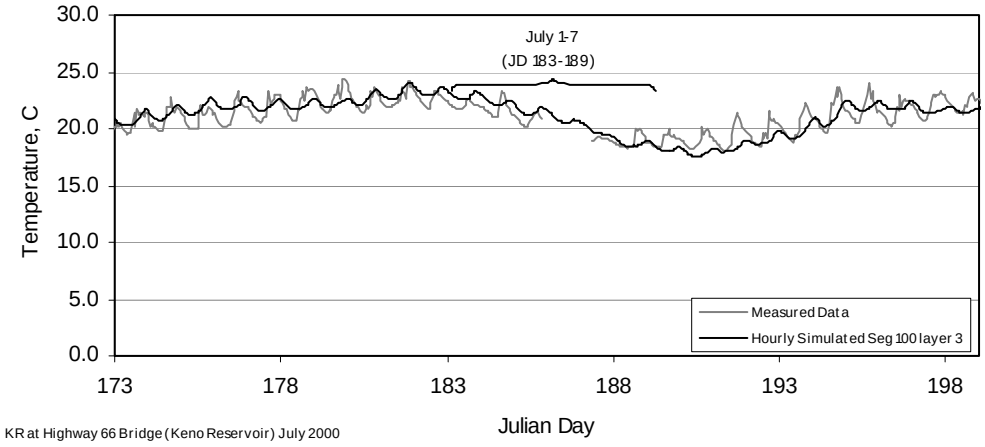

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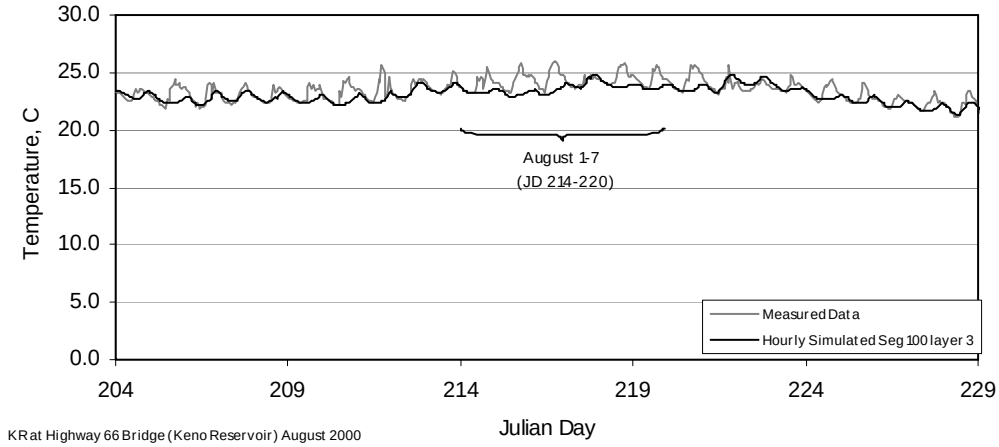

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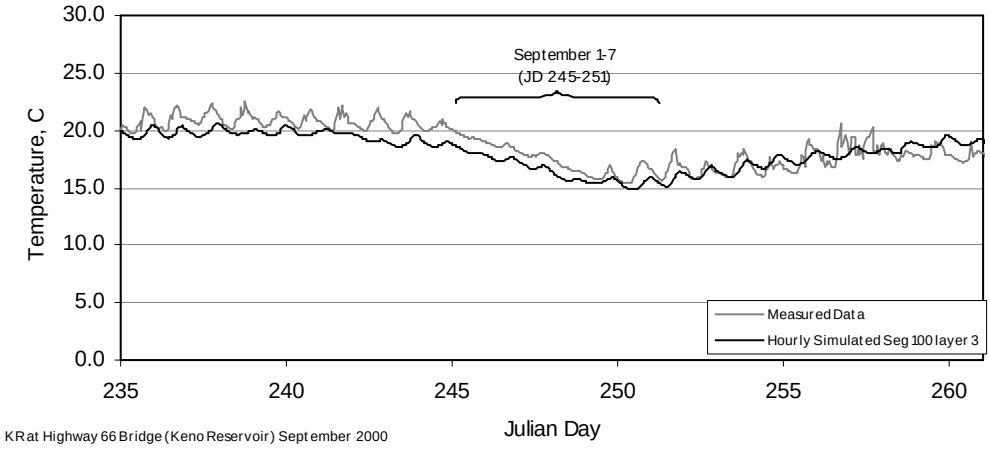
Figure 38. Temperature simulation results for Lake Ewauna to Keno Reach for Klamath River at Highway 66 bridge (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000



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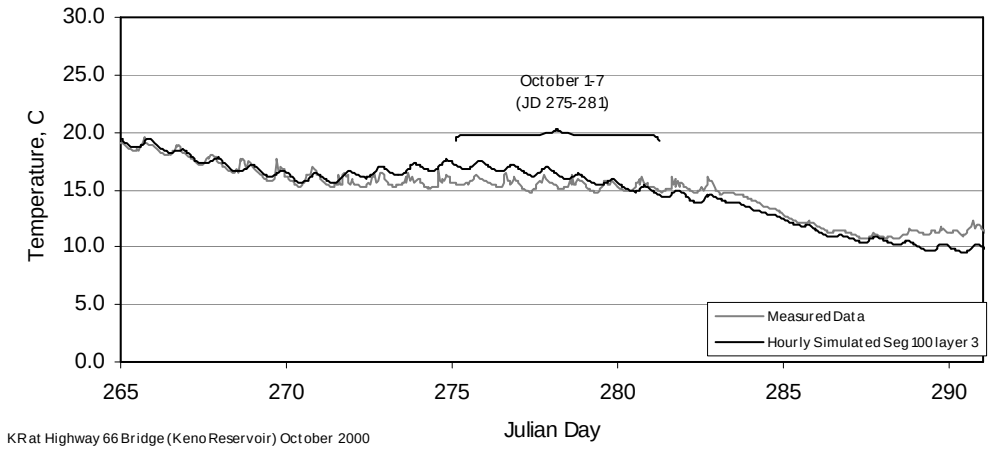
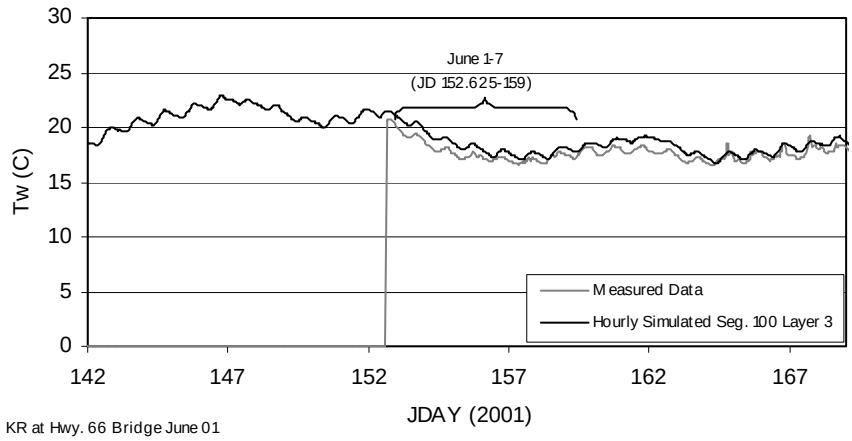


(b)

Figure 39. Temperature simulation results for Lake Ewauna to Keno for Klamath River at Highway 66 (a) September 1-7 and (b) October 1-7, 2000

Table 29. Lake Ewauna-Keno Reach hourly and daily period statistics for temperature at Highway 66, 2000

Statistic	Unit	June 1-7	July 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	C	0.06	0.27	-0.75	-0.97	0.60
Mean absolute error (MAE)	C	0.46	0.70	0.79	0.97	0.85
Root mean squared error (RMSE)	C	0.56	0.83	1.08	1.07	0.98
N	-	110	132	168	168	168
Daily						
Mean Bias	C	-0.03	0.14	-0.75	-0.97	0.29
Mean absolute error (MAE)	C	0.03	0.58	0.75	0.97	0.82
Root mean squared error (RMSE)	C	0.03	0.61	0.83	1.32	0.93
N	-	4	4	7	7	7



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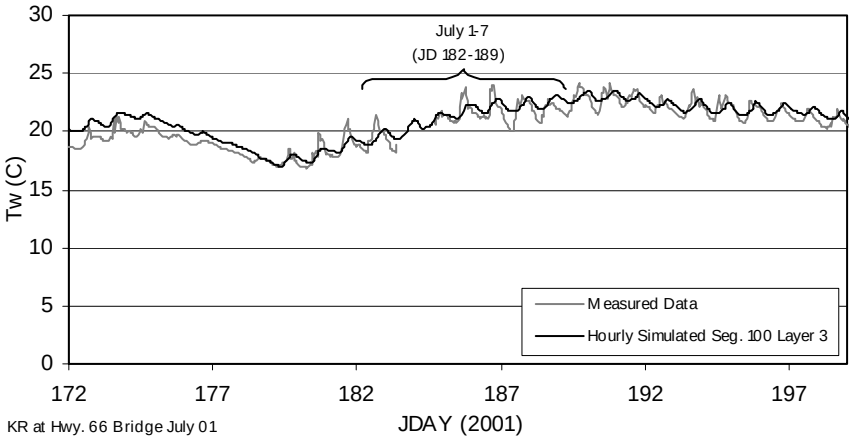

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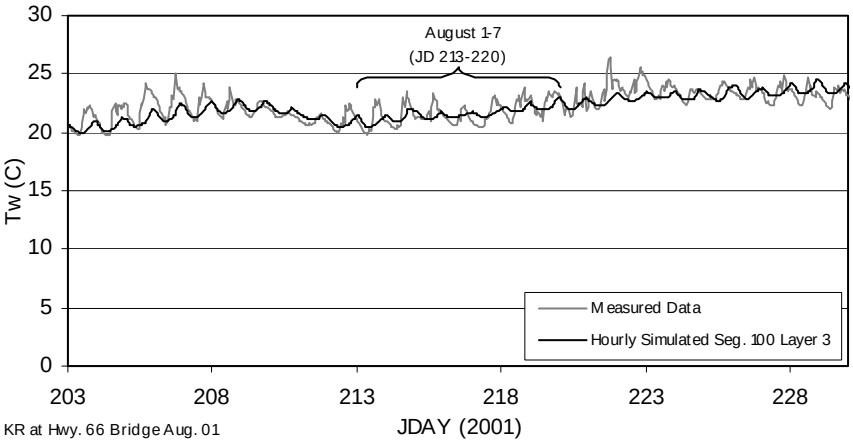

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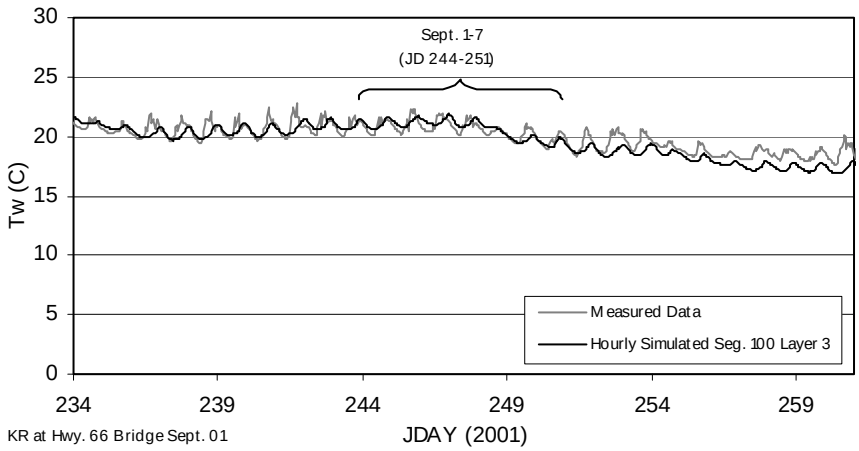
Figure 40. Temperature simulation results for Lake Ewauna to Keno Reach for Klamath River at Highway 66 bridge (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001



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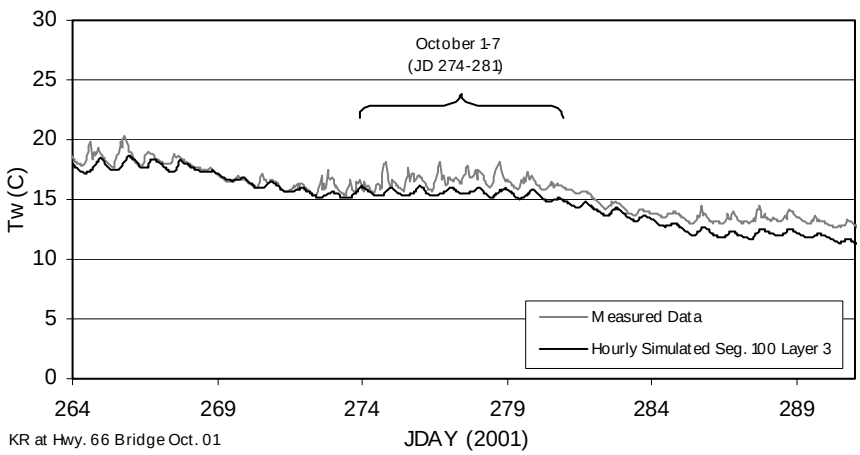


(b)

Figure 41. Temperature simulation results for Lake Ewauna to Keno for Klamath River at Highway 66 (a) September 1-7 and (b) October 1-7, 2001

Table 30. Lake Ewauna-Keno Reach hourly and daily period statistics for temperature at Highway 66, 2001

Statistic	Unit	June 1-7	July 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	C	0.76	0.27	-0.09	0.06	-1.03
Mean absolute error (MAE)	C	0.76	0.66	0.65	0.41	1.04
Root mean squared error (RMSE)	C	0.81	0.80	0.80	0.49	1.17
N	-	153	138	168	168	168
Daily						
Mean Bias	C	0.76	0.19	-0.10	0.06	-1.04
Mean absolute error (MAE)	C	0.76	0.34	0.19	0.21	1.04
Root mean squared error (RMSE)	C	0.81	0.40	0.21	0.22	1.05
N	-	6	5	7	7	7

3.3.2.2 Dissolved Oxygen

Dissolved oxygen response of Lake Ewauna to Keno Dam is unique for a river system of this size and morphology. The system receives appreciable organic loads from Upper Klamath Lake as well as small, but low quality return flows from municipal, industrial, and agricultural sources. However, an overriding system condition is the severe, persistent anoxia that develops within the system from near the bottom of Lake Ewauna proper to near Keno Dam. Although there are a suite of parameters available for model calibration, including algal growth, respiration and mortality rates, nutrient decay rates, organic matter decay rates, and SOD (zero order), the critical factor is the considerable organic load from Upper Klamath Lake – and the characterization of that boundary condition at Link Dam.

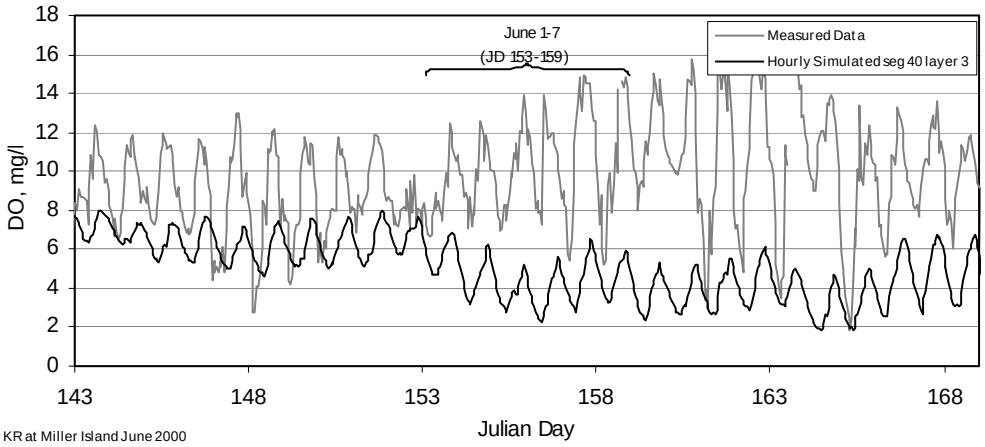
Initial model calibration identified the need for additional field information and year 2001 was added to the analysis. Results for both 2000 and 2001 suggest that general seasonal trends are represented, as are diurnal variations and periods of anoxia. Further, trends in dissolved oxygen concentration for many of the multi-week periods shown in the figures are well represented. However, the model performance is spotty with certain periods not well represented. Simulated results at Highway 66 are notably better than those at Miller Island. Based on field data and model simulations, it is postulated that the region of extreme water quality conditions originates in the stretch from Lake Ewauna to somewhere in the vicinity of Miller Island – a reach of roughly seven or eight miles. Thus results at the upper site – Miller Island – are more directly impacted than those at the lower River site near Keno Dam. The dynamic nature of the Lake Ewauna/Keno reach is primarily driven by the organic load originating in Upper Klamath Lake. The long, narrow aspect of Keno Reservoir results in a much reduced surface area for primary production to occur versus the broad aspect of Upper Klamath Lake. Given the large organic load (dead algae, as well as living algae that flows into the narrow Lake Ewauna/Keno reach and resides below the photic zone and subsequently dies) and the measurable current, it appears that the reservoir experiences an oxygen sag with the largest oxygen deficits occurring between Lake Ewauna to downstream of Miller Island and then showing modest recovery by the time waters reach Keno.

A limited amount of model testing was completed with CE-QUAL-W2 to determine the sensitivity of dissolved oxygen to influent algae and BOD concentrations from Link Dam and the model is quite sensitive to short term variations in these parameters at the upstream boundary conditions. It is estimated that improved results could be obtained if water quality information were collected on a more frequent basis (e.g. twice weekly) to more completely represent water quality conditions of waters leaving Upper Klamath Lake.

Additional model simulations were completed to determine if algal populations, and thus dissolved oxygen, would be affected if respiratory requirements were not met during anoxic periods. The model was modified to limit algal growth based on respiratory needs of phytoplankton. Specifically, if there was insufficient dissolved oxygen in the water column to support respiration of algae, algal mortality was increased

While there was no field data to test the model logic, but sensitivity testing of the model parameters while assessing phytoplankton, DO, and nutrient level responses indicated that algal respiratory requirements is probably not the primary factor behind the persistent

anoxia, elevated nutrients and low algal counts that are prone to occur in this reach. Advection from upstream reaches tends to re-colonize downstream reaches on the order of days Further research into this issue has focused on algal inhibition by one of several factors, potentially including impacts of pharmaceutical/human health and personal care products in municipal treated effluent, phenolic compounds associated with organic matter – including that within the sediments (source: tannins, humic substances, lignin), production of hydrogen peroxide, other chemical constituents or reactions that may lead to inhibition or toxicity. Additional analyses and field studies have been completed in 2003 to refine model representation of dissolved oxygen, as well as other factors, in this reach; however, additional studies are needed to more fully characterize the complex dynamics of this reach and its relationship with Upper Klamath Lake.



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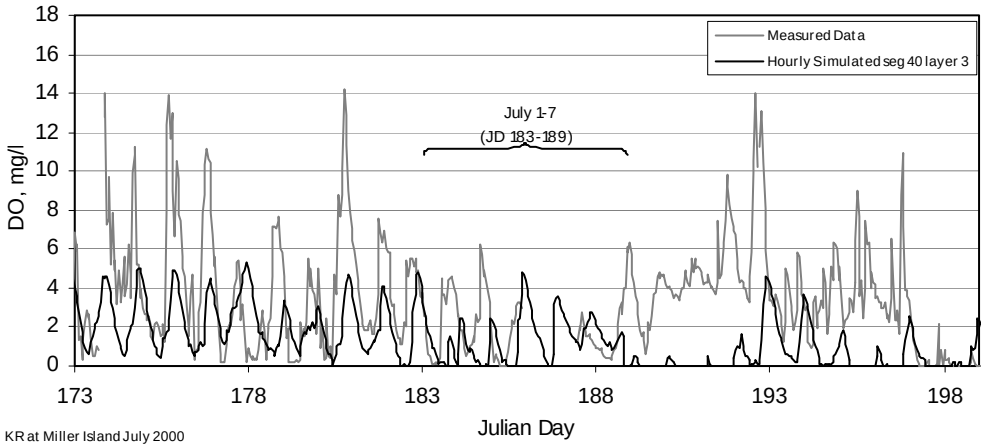

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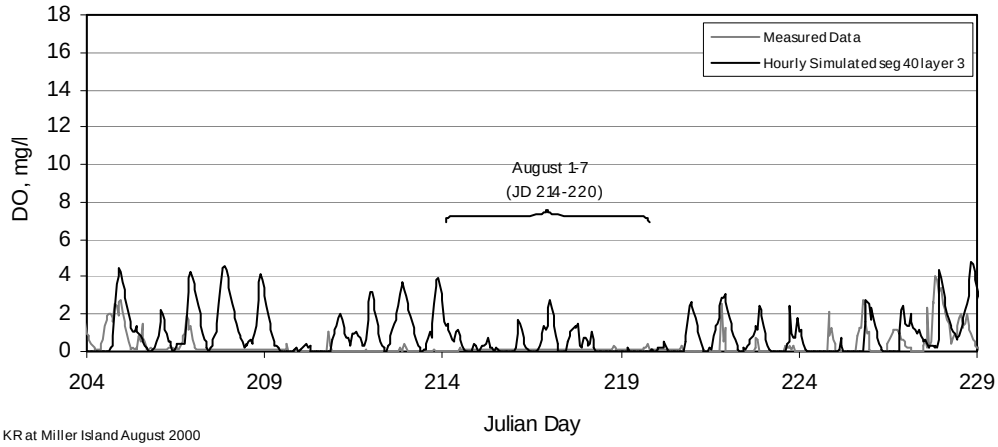
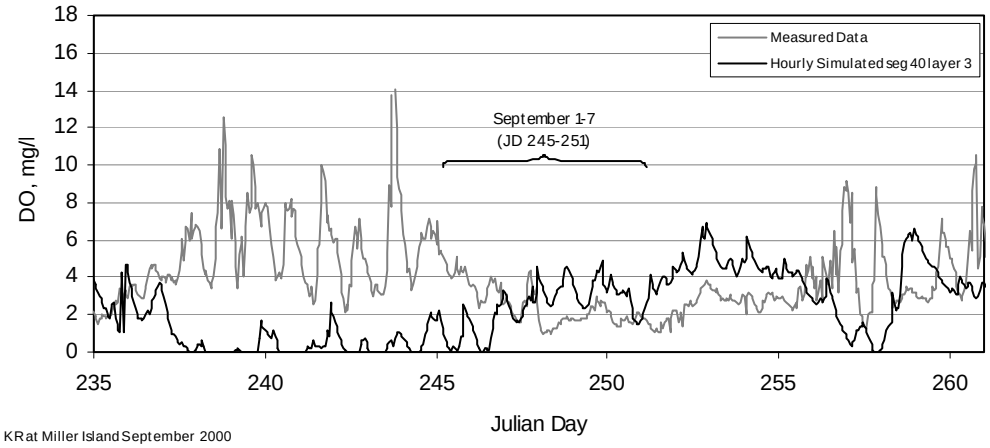
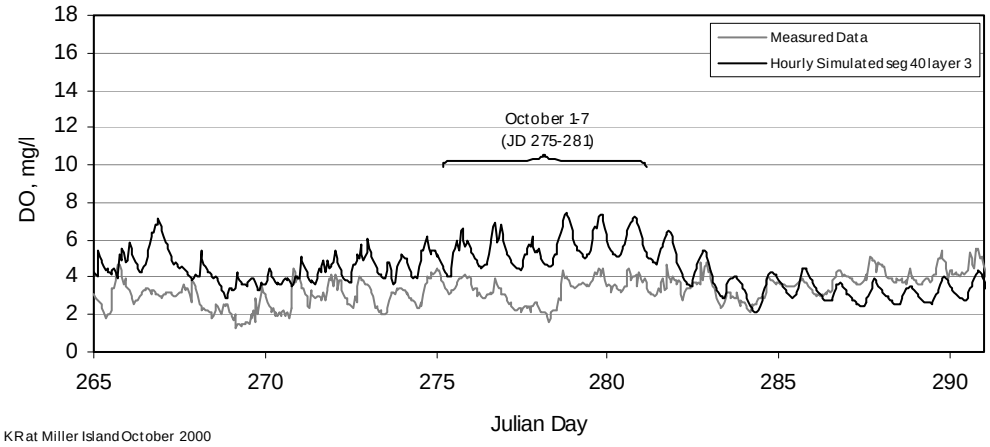


(c)

Figure 42. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000



(a)

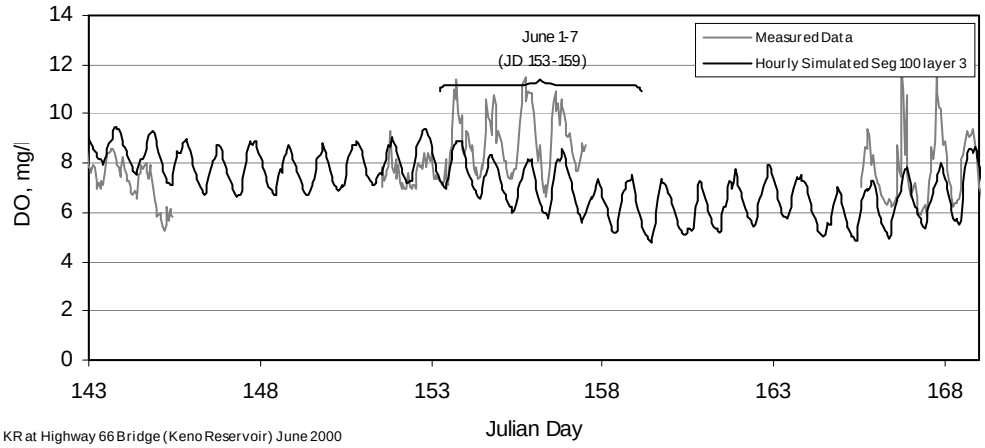


(b)

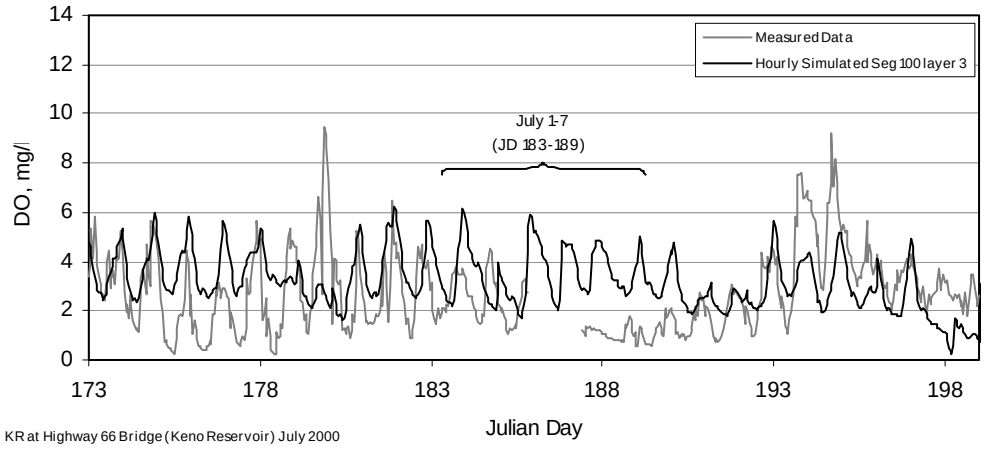
Figure 43. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2000

Table 31. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Miller Island, 2000

Statistic	Unit	Jun 1-7	Jul 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	mg/l	-5.94	-1.41	0.20	0.05	2.25
Mean absolute error (MAE)	mg/l	5.94	1.95	0.33	1.79	2.25
Root mean squared error (RMSE)	mg/l	6.40	2.56	0.57	2.13	2.36
N	-	168	126	152	168	168
Daily						
Mean Bias	mg/l	-5.89	-1.80	0.30	0.05	2.25
Mean absolute error (MAE)	mg/l	5.89	1.80	0.34	1.72	2.25
Root mean squared error (RMSE)	mg/l	6.07	1.99	0.43	1.98	2.30
N	-	7	4	7	7	7



(a)



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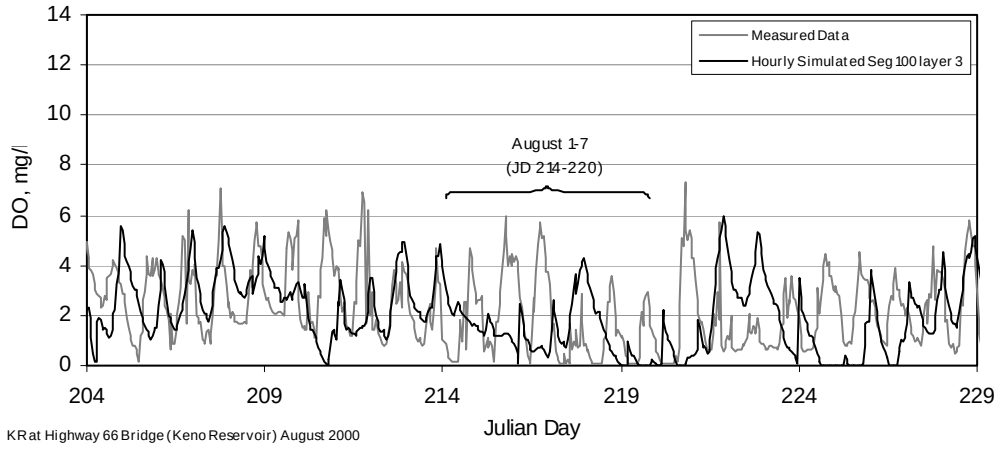
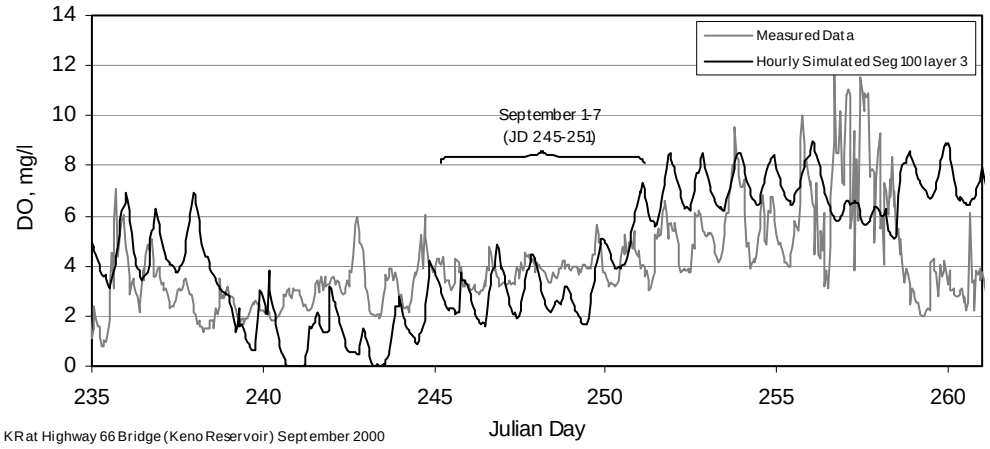
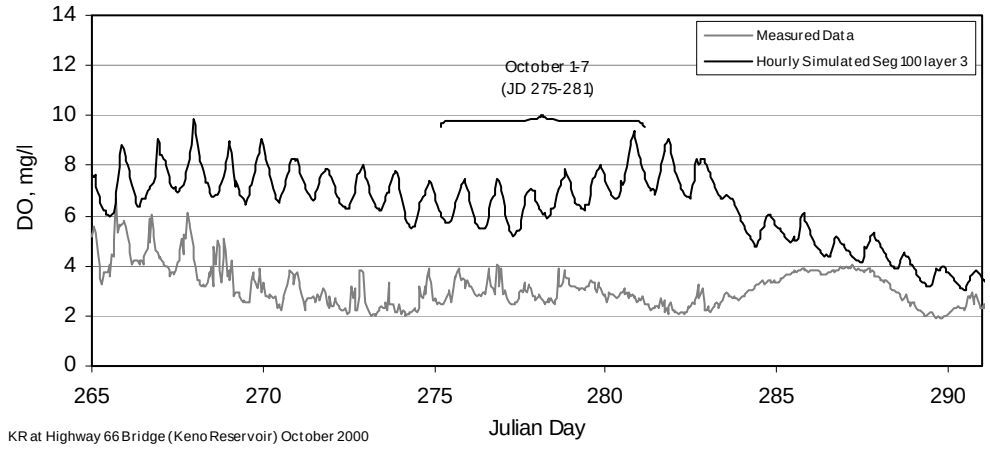


(c)

Figure 44. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000



(a)

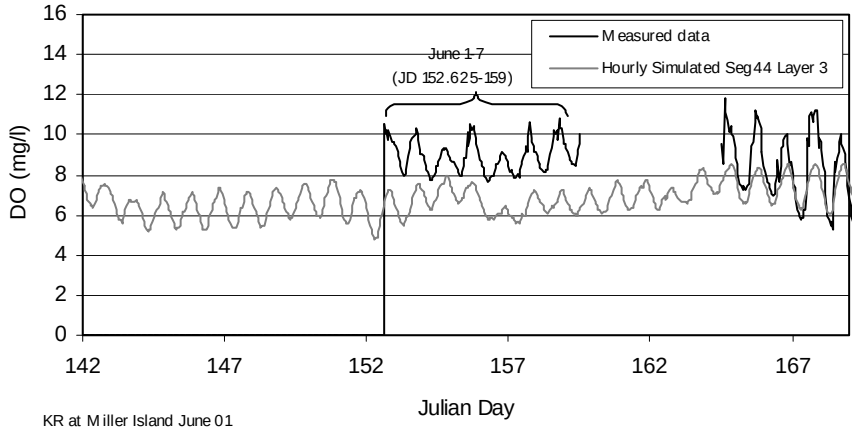


(b)

Figure 45. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) September 1-7, (b) October 1-7, 2000

Table 32. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Highway 66, 2000

Statistic	Unit	June 1-7	July 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	mg/l	-1.50	1.54	-0.48	-0.24	3.96
Mean absolute error (MAE)	mg/l	1.55	1.86	1.80	1.15	3.96
Root mean squared error (RMSE)	mg/l	1.78	2.06	2.26	1.38	4.09
N	-	110	132	168	168	168
Daily						
Mean Bias	mg/l	-1.42	1.55	-0.48	-0.24	3.96
Mean absolute error (MAE)	mg/l	1.42	1.55	1.15	1.00	3.96
Root mean squared error (RMSE)	mg/l	1.56	1.72	1.27	1.11	4.05
N	-	4	4	7	7	7



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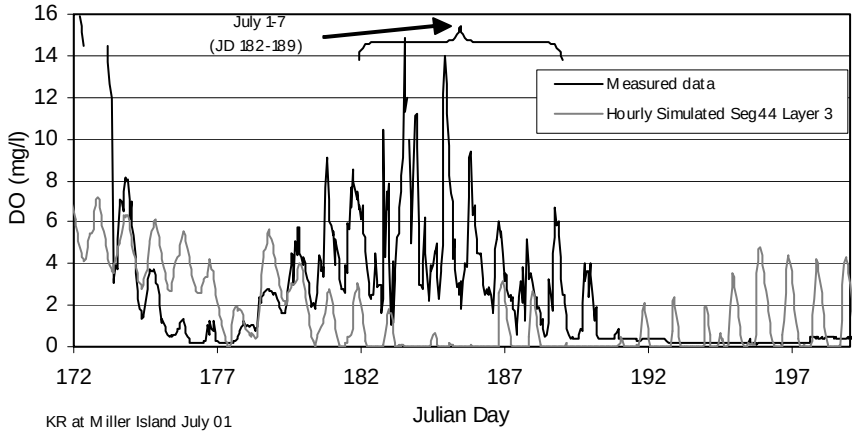

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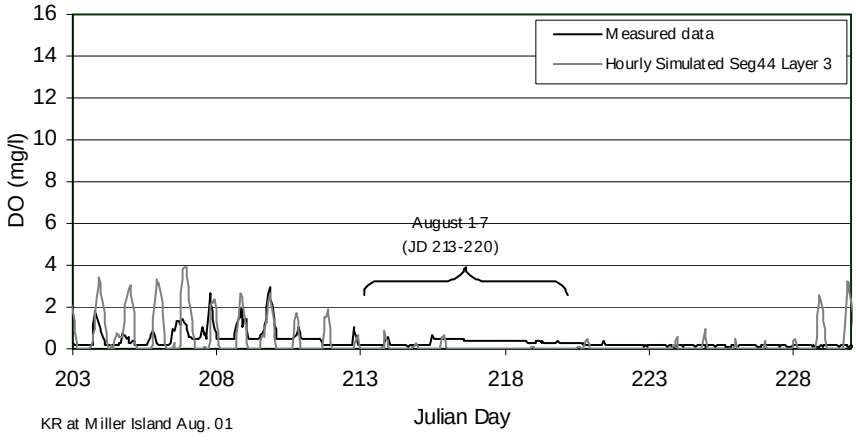
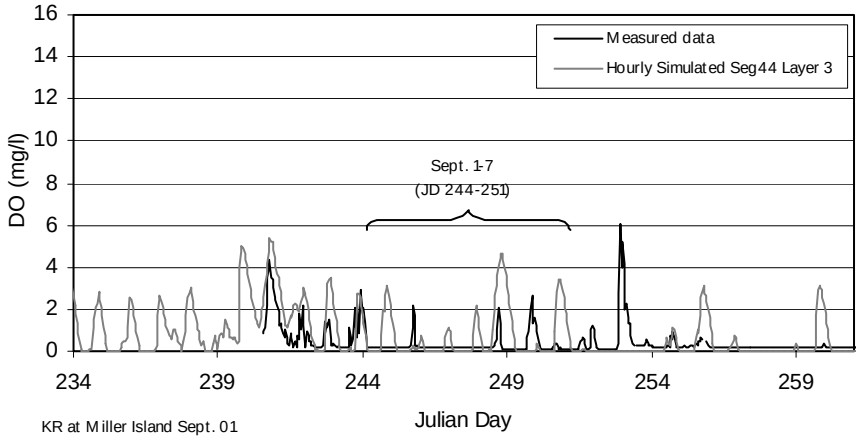
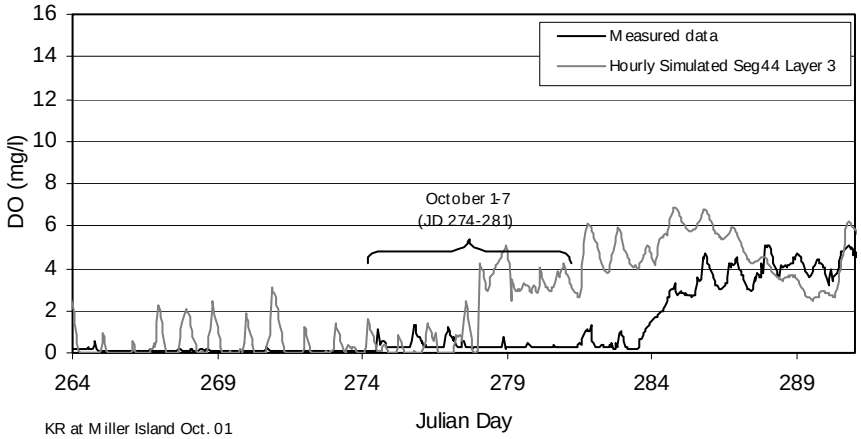


(c)

Figure 46. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001



(a)

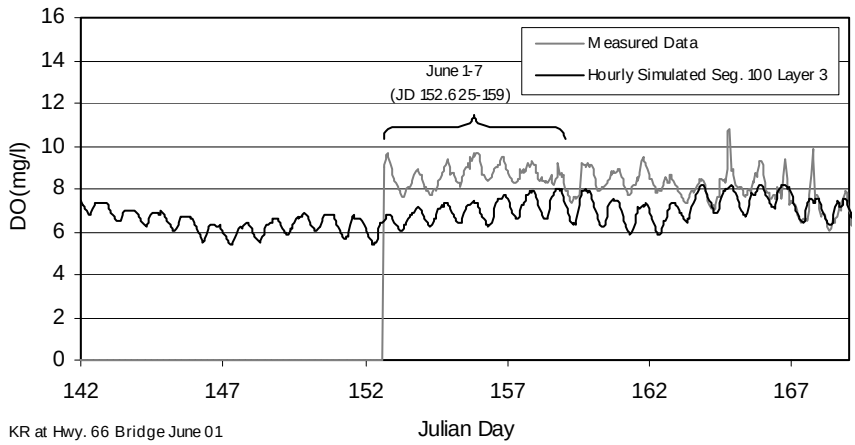


(b)

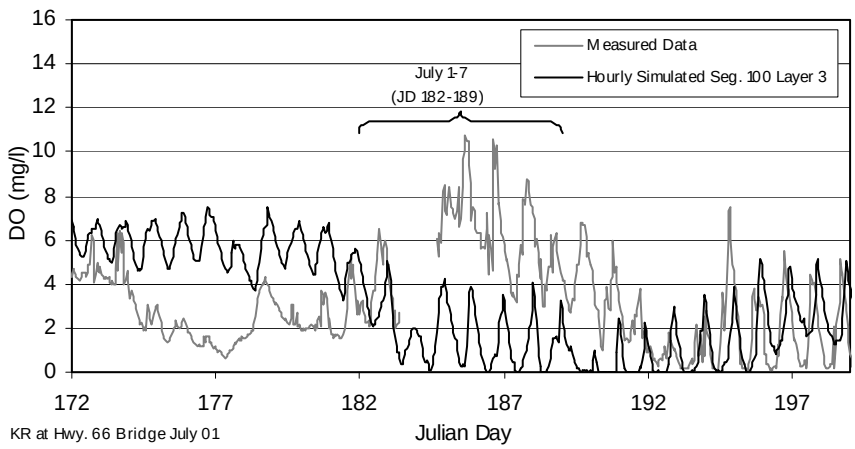
Figure 47. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2001

Table 33. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Miller Island, 2001

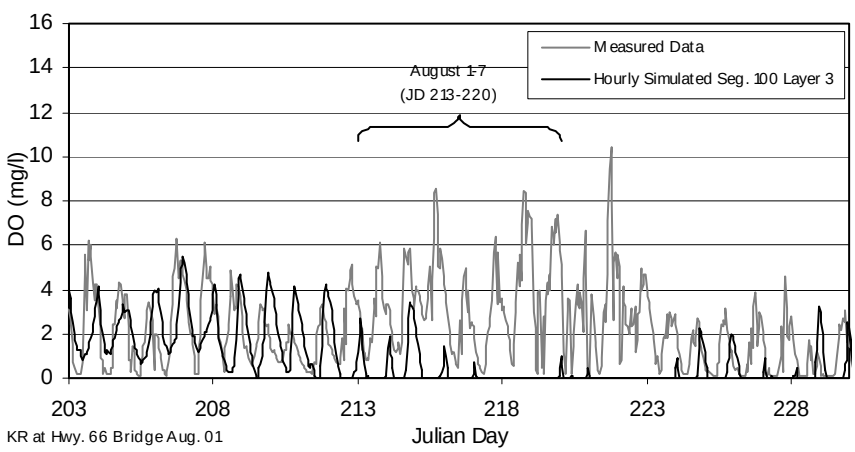
Statistic	Unit	Jun 1-7	Jul 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	mg/l	-2.26	-4.19	-0.29	0.42	1.41
Mean absolute error (MAE)	mg/l	2.26	4.20	0.30	0.82	1.70
Root mean squared error (RMSE)	mg/l	2.34	5.13	0.32	1.33	2.24
N	-	144	167	168	168	168
Daily						
Mean Bias	mg/l	-2.26	-4.21	-0.29	0.42	1.41
Mean absolute error (MAE)	mg/l	2.26	4.21	0.29	0.46	1.51
Root mean squared error (RMSE)	mg/l	2.29	4.53	0.30	0.68	2.14
N	-	6	7	7	7	7



(a)

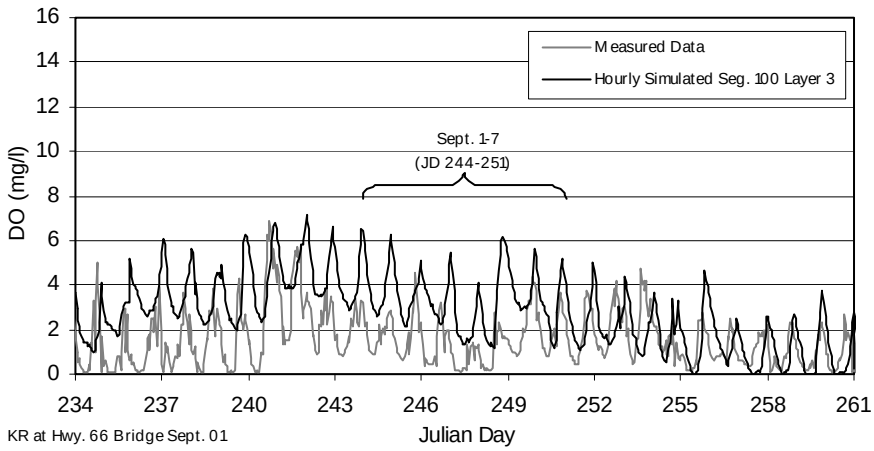


(b)



(c)

Figure 48. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001



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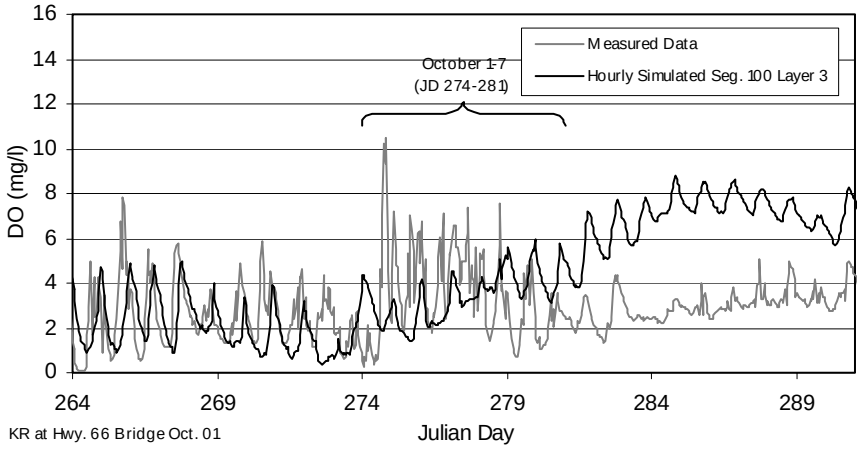


(b)

Figure 49. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) September 1-7, (b) October 1-7, 2001

Table 34. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Highway 66, 2001

Statistic	Unit	June 1-7	July 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	mg/l	-1.50	1.54	-0.48	-0.24	3.96
Mean absolute error (MAE)	mg/l	1.55	1.86	1.80	1.15	3.96
Root mean squared error (RMSE)	mg/l	1.78	2.06	2.26	1.38	4.09
N	-	110	132	168	168	168
Daily						
Mean Bias	mg/l	-1.42	1.55	-0.48	-0.24	3.96
Mean absolute error (MAE)	mg/l	1.42	1.55	1.15	1.00	3.96
Root mean squared error (RMSE)	mg/l	1.56	1.72	1.27	1.11	4.05
N	-	4	4	7	7	7

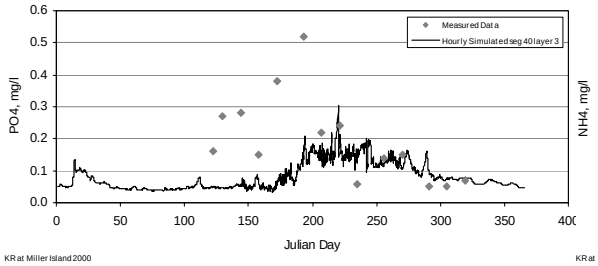
3.3.2.3 Nutrients and Phytoplankton

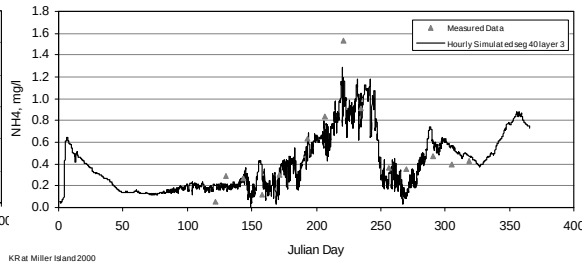
Nutrient concentrations were not formally calibrated in the Lake Ewauna to Keno Dam reach; however, examination of model performance was compared with limited available field data.

As noted previously, the upstream boundary condition at Link Dam plays a critical role in the water quality response of Lake Ewauna/Keno Reservoir during spring through fall periods. Most sampling programs to date have either collected data infrequently (e.g., semi-monthly, monthly, quarterly). A limited amount of daily monitoring was done in 2002 (two periods of three days each). However, observations of data sonde data at Link Dam, Link River at Lake Ewauna, and other downstream locations, as well as the infrequent grab sample data suggest that past monitoring efforts do not sufficiently represent the dynamic water quality conditions present at Link Dam. The transit time through the reservoir during summer periods ranges from approximately 7 to 14 days depending on time of year, local operations, and water year type. Thus monitoring programs that span either a few days or multiple weeks are insufficient to fully characterize the spatial and temporal conditions between Link River and Keno Dam. The monitoring and modeling effort has provided critical insight into the temporal and spatial variability and response of system processes, including thermal, dissolved oxygen, and nutrient conditions. The model has been used to assess variable boundary conditions at Link Dam, Lost River, and Klamath Straits drain and has identified the need for more detailed Link Dam and Lost River inflow water quality conditions.

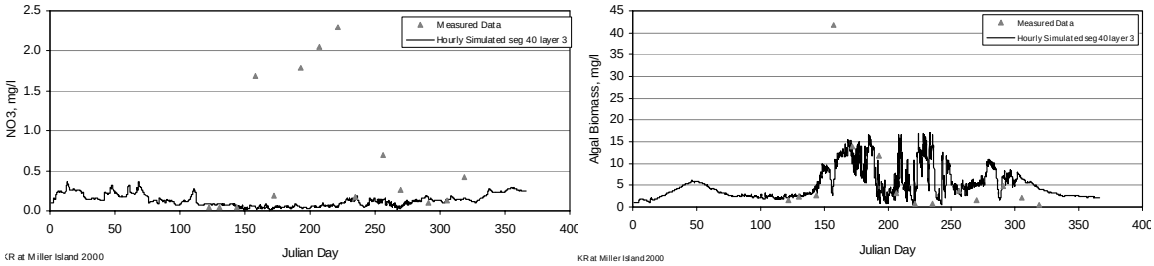
When anoxia occurs within this reach, algal concentrations decline, and a corresponding increase in nutrients occurs. It is apparent from field observations that under anoxia there is decreased phytoplankton present reducing the opportunity of increase oxygen levels through photosynthesis, as well as elevated nutrient levels. Field observations also indicate that pH falls from a range of 8.5 to 9.5 under aerobic conditions to around 7 during periods of severe anoxia (Watercourse, 2003), further indicating the absence of algal production in this weakly buffered system.

The model generally under-predicted orthophosphate during the first part of the season, but was in general agreement after July. Ammonia was well represented throughout the simulation, while nitrate was systematically under predicted. The model over predicted algal biomass, especially in the Keno region. Further model and field studies are planned for 2003 to refine model representation of system conditions in this reach.



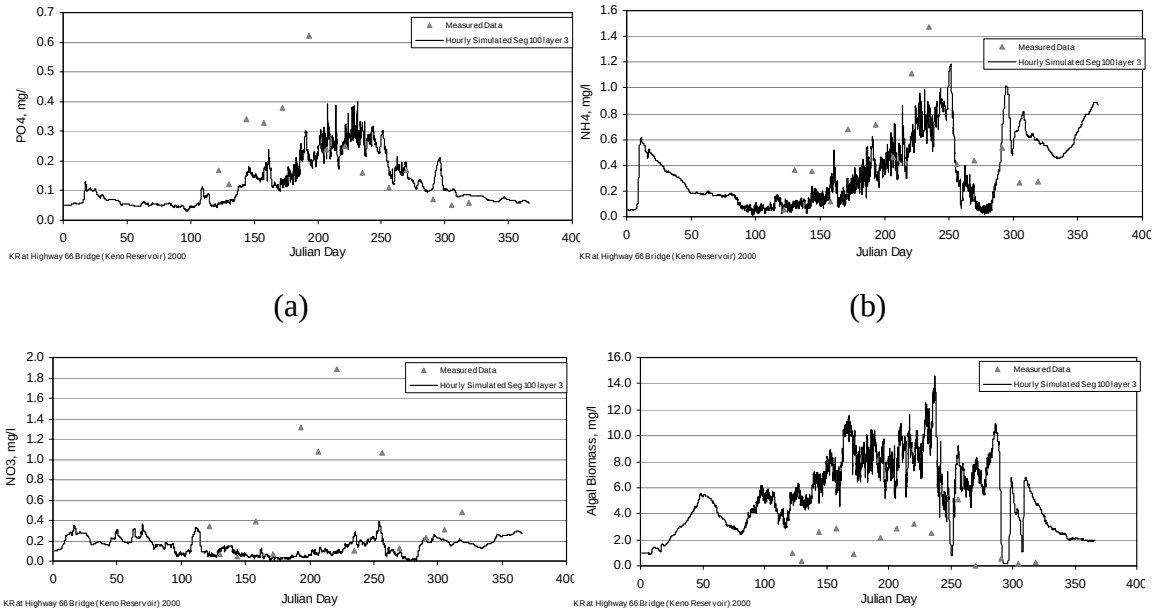


(a) (b)



(c) (d)

Figure 50. Simulated (line) and observed (triangles) nutrients and algal biomass for Klamath River at Miller Island in the Lake Ewauna to Keno Dam reach. (a) phosphate; (b) ammonia; (c) nitrate; (d) algal biomass



(a) (b)

(c) (d)

Figure 51. Simulated (line) and observed (triangles) nutrient and algal biomass for Klamath River at Highway 66 bridge in the Lake Ewauna to Keno Dam reach. (a) phosphate; (b) ammonia; (c) nitrate; (d) algal biomass.

3.3.2.4 Summary of Parameters

Table 35. Significant control file parameters for the Lake Ewauna to Keno Dam reach calibration

Parameter Name	Description	EC Lake Ewauna Value	Default Value
DLT MIN	Minimum timestep, sec	5.0	N/A
DLT MAX	Maximum timestep, sec	500	N/A
SLOPE	Waterbody bottom slope	0.0	N/A
LAT	Latitude, degrees	42.13	N/A
LONG	Longitude, degrees	121.95	N/A
EBOT	Bottom elevation of waterbody, m	1236.25	N/A
CFW	C coefficient in the wind speed formulation	1.0	2.0
WINDH	Wind speed measurement height, m	2.0	N/A
TSED	Sediment (ground) Temperature, C	12.0	N/A
FI	Interfacial friction factor	0.04	N/A
TSEDF	Heat lost to sediments that is added back to water column, fraction	0.01	N/A
EXH2O	Extinction for pure water, m^{-1}	0.25	0.25 (for full WQ sim)
CGQ10 (Tracer)	Arhennius temperature rate multiplier	0	0
CG0DK (Tracer)	0-order decay rate, 1/day	0	0
CG1DK (Tracer)	1st-order decay rate, 1/day	0	0
CGS (Tracer)	Settling rate, m/day	0	0
CGQ10 (Age)	Arhennius temperature rate multiplier	0	0
CG0DK (Age)	0-order decay rate, 1/day	-1.0	-1.0
CG1DK (Age)	1st-order decay rate, 1/day	0	0
CGS (Age)	Settling rate, m/day	0	0
CGQ10 (Coliform)	Arhennius temperature rate multiplier	1.04	N/A
CG0DK (Coliform)	0-order decay rate, 1/day	0	N/A
CG1DK (Coliform)	1st-order decay rate, 1/day	1.4	N/A
CGS (Coliform)	Settling rate, m/day	1.0	N/A
AG	Maximum algal growth rate, 1/day	3.0	2.0
AR	Maximum algal respiration rate, 1/day	0.05	0.04
ASAT	Light saturation intensity at a maximum photosynthetic rate, W/m^2	100.0	75.0
AT1	Lower temperature for algal growth, C	5.0	5.0
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03	0.001
PARTP	Phosphorus partitioning coefficient for suspended solids	0.001	0.0
NH4REL	Sediment release rate of ammonium, fraction of SOD	0.07	0.001
NH4DK	Ammonium decay rate, 1/day	0.1	0.12
NO3DK	Nitrate decay rate, 1/day	0.1	0.03
NO3S	De-nitrification rate from sediments, m/day	0	1.0
CO2REL	Sediment carbon dioxide release rate, fraction of SOD	0.01	0.1
O2AR	Oxygen stoichiometry for algal respiration	1.4	1.1
O2AG	Oxygen stoichiometry for algal primary production	1.5	1.4
SOD	Zero-order sediment oxygen demand for each segment, $g\ O_2 / m^2 day$	2.0 (for each segment)	N/A

3.4 Keno Reach

The Keno reach extends from Keno Dam to the headwaters of J.C. Boyle Reservoir, a distance of about 5.4 miles. The RMA suite of models for the Klamath River Keno reach was calibrated and validated using data from the periods of May 21-23, 2002 and September 10-12, 2002, respectively.

3.4.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and observations in the Klamath River above J.C. Boyle were required (calibration/validation points). There were no intermediate locations within this short reach that required inflow for outflow boundary condition or that were used for calibration and validation.

3.4.1.1 Boundary Conditions

The boundary condition data was derived from samples collected at Keno Dam and Highway 66. Hourly water temperature and dissolved oxygen data were available from water quality probes deployed by the US Bureau of Reclamation at Highway 66 near Keno. Grab samples were collected once per day for three days below Keno Dam. Due to the inherent variability and infrequent sampling interval of the grab data, the boundary condition values for nutrients, BOD, and algae were assumed to be a constant value for the calibration and validation period, based on the grab sample data from 2002 (Appendix F). The water quality values for the calibration and validation period are shown in Table 22 and Figure 21 and Figure 22.

Table 36. Keno Dam to J.C. Boyle Reservoir, Klamath River reach calibration and validation water quality boundary conditions

Parameter	Units	Dates	
		5/21/02 - 5/23/02	9/10/02 – 9/12/02
BOD	mg/l	3.0	5.0
DO	mg/l	variable	variable
Org N	mg/l	0.80	1.50
NH_4^+	mg/l	0.10	0.15
NO_2^-	mg/l	0.00	0.00
NO_3^-	mg/l	0.10	0.20
Org P	mg/l	0.30	0.05
PO_4^{3-}	mg/l	0.20	0.20
Algae	mg/l	2.0	4.2
Tw	°C	variable	variable

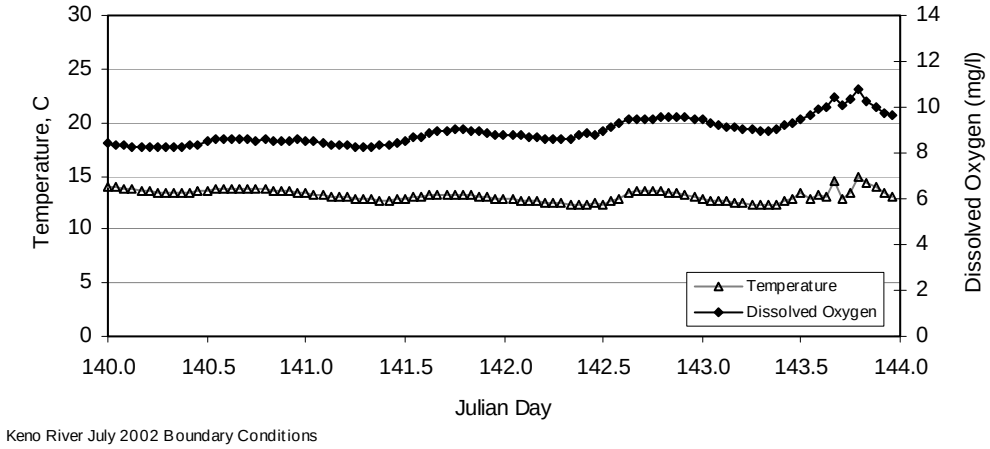


Figure 52. Keno Dam temperature and dissolved oxygen calibration boundary conditions

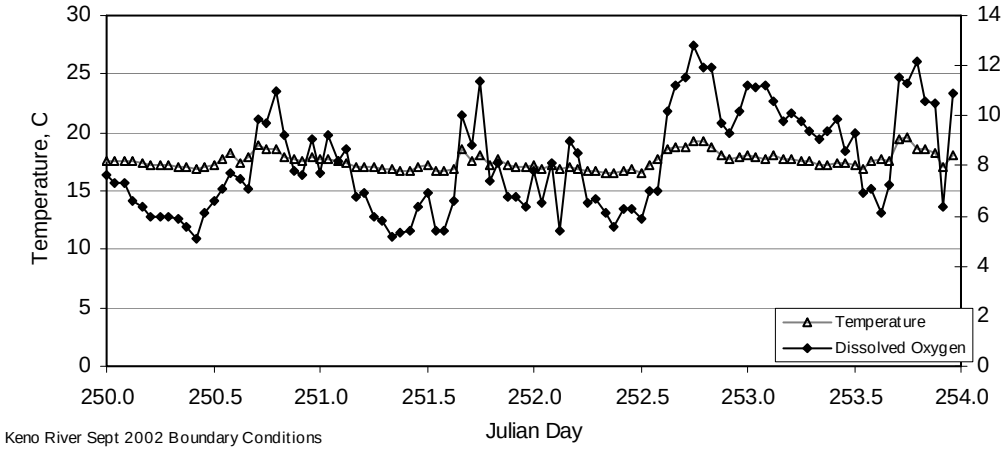


Figure 53. Keno Dam temperature and dissolved oxygen validation boundary conditions

3.4.1.2 Initial conditions

The model was run for one day prior to both the calibration and validation periods to provide an initial condition for simulation. The initial bed algae mass was estimated at 5 g/m^2.

3.4.1.3 Calibration and Validation Points

The calibration and validation point for the Keno reach was Klamath River above J.C. Boyle Reservoir. During May and July water quality probes and tidbit temperature devices were employed to represent conditions above J.C. Boyle Reservoir. These data are displayed in the following section with model results.

3.4.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary

statistics to be calculated both on an hourly and daily basis. The exception is validation during the September period: grab sample temperatures and dissolved oxygen data were available, but the sonde deployed during the data gathering effort malfunctioned and hourly data were not available. The nutrient data were primarily derived from field data, which were sampled once per day. All model parameters for the Keno reach are summarized in Table 39 at the end of this section.

3.4.2.1 Water Temperature

Water temperature calibration required varying evaporation heat flux coefficients (presented in Table 39) that govern the mass transfer formulation represented in the numerical model heat budget. No other parameters were varied. The hourly results are presented graphically in Figure 54 through Figure 56. Summary statistics are included in Table 37. The diurnal range and phase is well represented for spring temperatures in the neighborhood of 12°C-15°C. Limited data for the September period late summer period was available for temperature. To further test the model available data from mid-July were used to test the model. Phase and diurnal range are well represented under conditions when observations conditions exceeded 25°C. Hourly bias for the July simulation was –0.19°C with a mean absolute error of 0.54°C. Tabulated statistics (Table 37) illustrate that simulated results on an hourly and daily basis are within 1°C of observations.

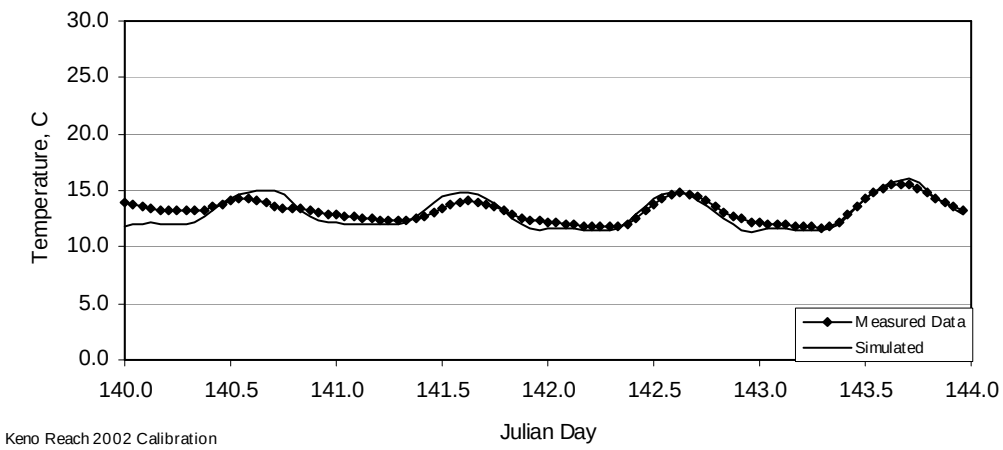


Figure 54. Klamath River, Keno to J.C. Boyle, simulated versus measured water temperature, May 20-23, 2002

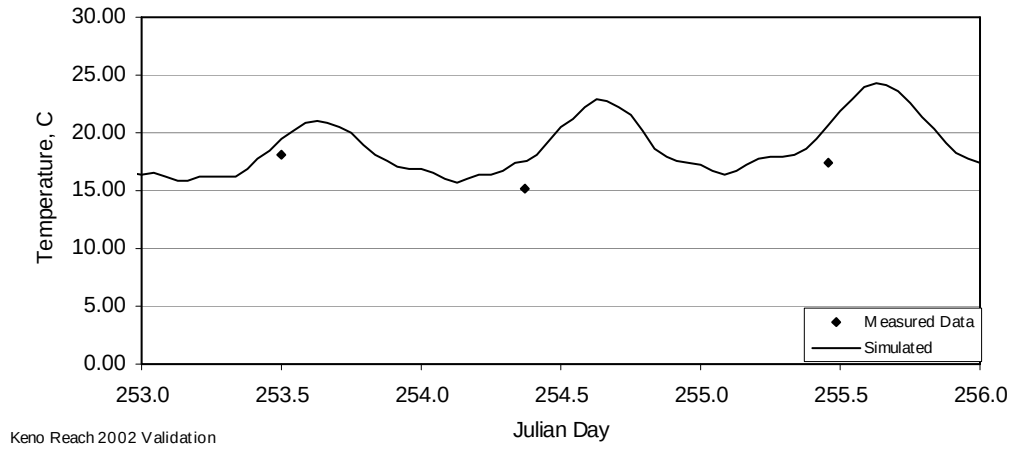


Figure 55. Klamath River, Keno to J.C. Boyle, simulated versus measured water temperature, September 10-12, 2002

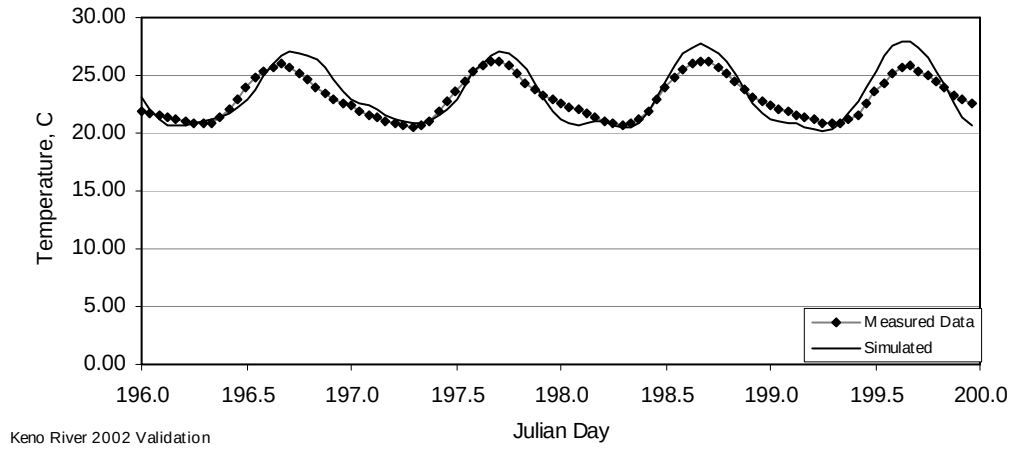


Figure 56. Klamath River, Keno to J.C. Boyle, simulated versus measured water temperature, July 14-17, 2002

Table 37. Klamath River, Keno to J.C. Boyle, hourly and daily calibration and validation period statistics for temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	°C	-0.19	n/a	-0.17	n/a
Mean absolute error (MAE)	°C	0.54	n/a	0.17	n/a
Root mean squared error (RMSE)	°C	0.68	n/a	0.23	n/a
n	-	96	n/a	4	n/a

[a] Mean bias = simulated – measured

3.4.2.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates, and respiration rates, organic and inorganic nutrient decay

rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeled in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from upstream of Keno Dam, growth rates for plankton were set to very low numbers in river reaches.

The hourly results are presented graphically in Figure 57 and Figure 58. Field observations suggest a moderated diurnal range in this reach, and the model replicates these conditions as well as overall magnitude of dissolved oxygen concentrations. The hourly bias of –0.46 mg/l and the mean absolute error of 0.50 mg/l presented in Table 38 illustrate that simulated results on an hourly and daily basis are within about 1 mg/l of observed values.

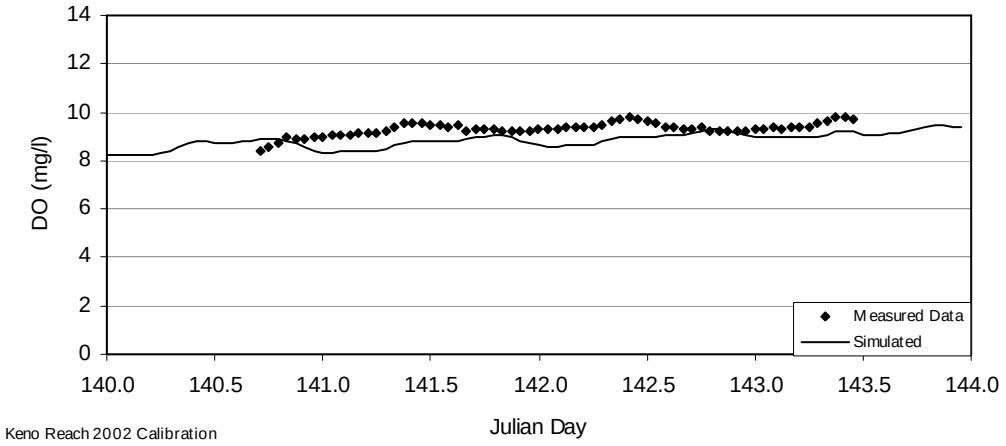


Figure 57. Klamath River, Keno to J.C. Boyle, simulated versus measured dissolved oxygen, May 20-23, 2002

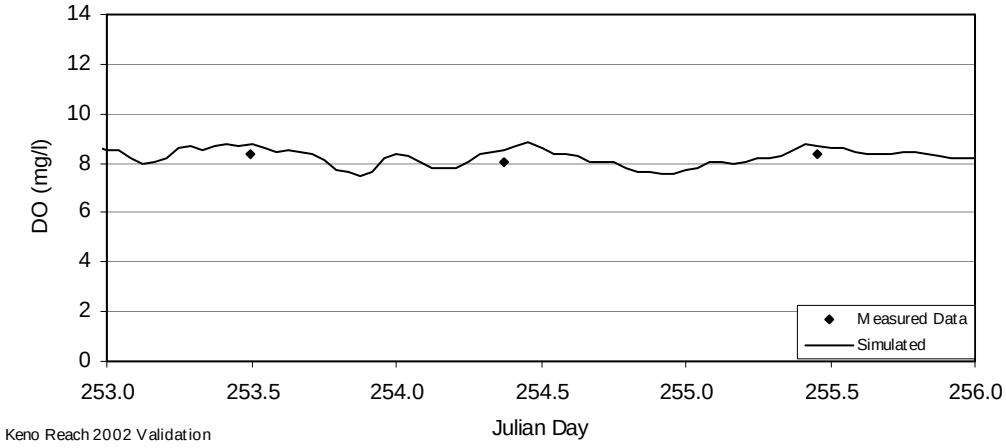


Figure 58. Klamath River, Keno to J.C. Boyle, simulated versus measured dissolved oxygen, September 10-12, 2002

Table 38. Klamath River, Keno to J.C. Boyle, hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	-0.46	n/a	-0.47	n/a
Mean absolute error (MAE)	mg/l	0.50	n/a	0.47	n/a
Root mean squared error (RMSE)	mg/l	0.55	n/a	0.48	n/a
n	-	67	n/a	3	n/a

[a] Mean bias = simulated – measured

3.4.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Keno reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 59 through Figure 64. Simulated concentrations for ammonia, nitrate, and orthophosphate were consistent with field observations. There is some scatter in the observed data that is not replicated within the model. Because upstream boundary conditions were maintained at constant values for these simulations, such results in a short reach are not unexpected.

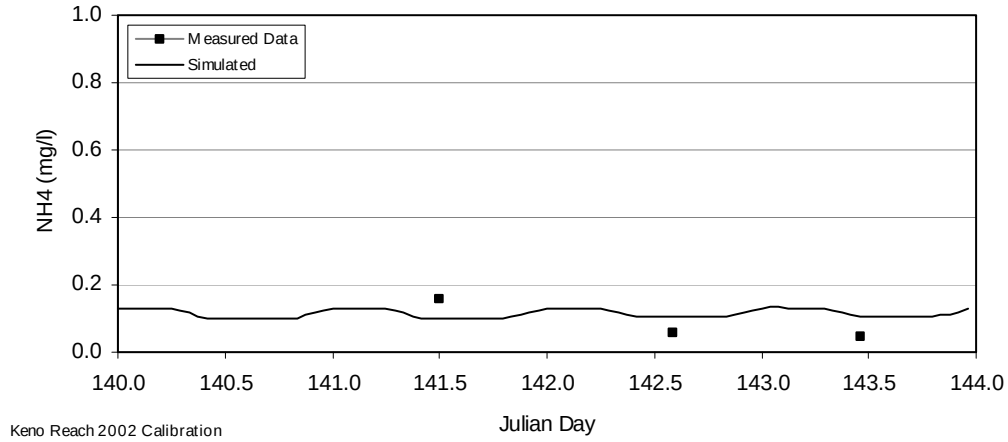


Figure 59. Klamath River, Keno to J.C. Boyle, simulated versus measured ammonia, May 20-23, 2002

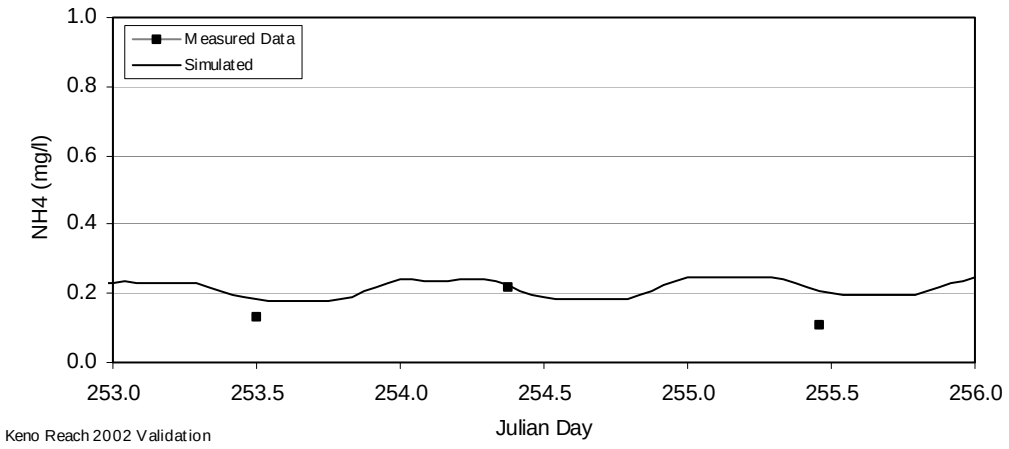


Figure 60. Klamath River, Keno to J.C. Boyle, simulated versus measured ammonia, September 10-12, 2002

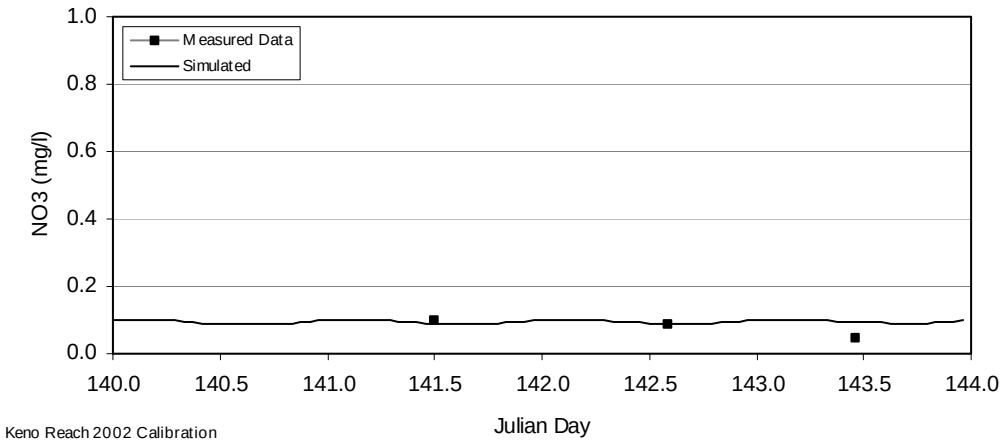


Figure 61. Klamath River, Keno to J.C. Boyle, simulated versus measured nitrate, May 20-23, 2002

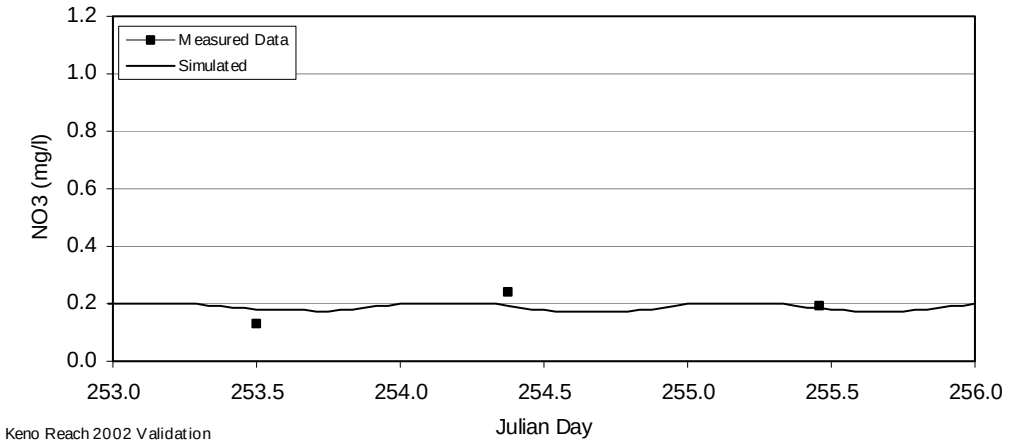


Figure 62. Klamath River, Keno to J.C. Boyle, simulated versus measured nitrate, September 10-12, 2002

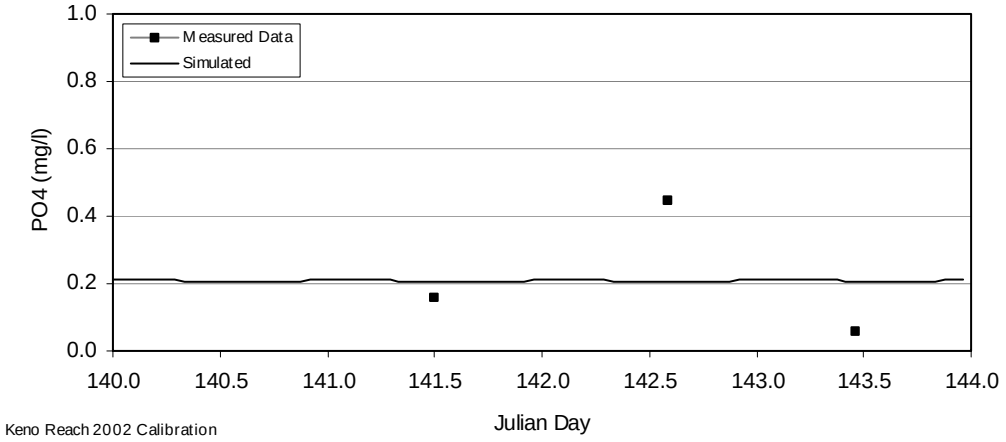


Figure 63. Klamath River, Keno to J.C. Boyle, simulated versus measured orthophosphate, May 20-23, 2002

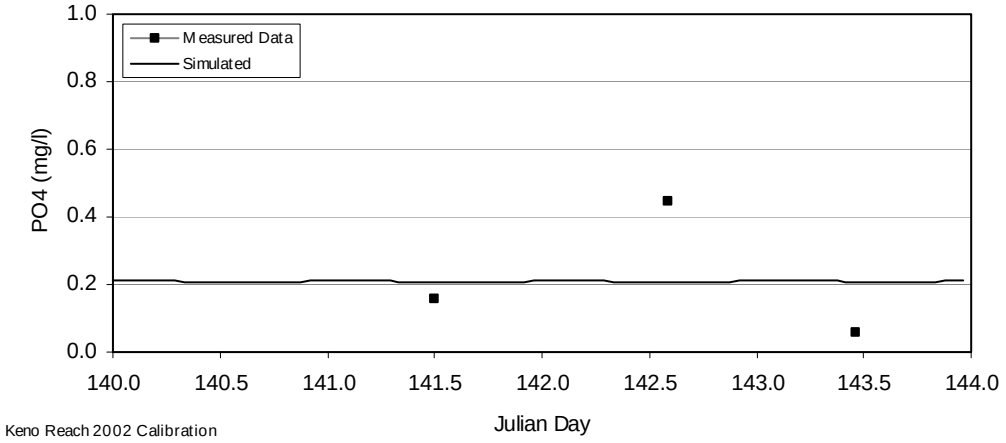


Figure 64. Klamath River, Keno to J.C. Boyle, simulated versus measured orthophosphate, September 10-12, 2002

3.4.2.4 Summary of Parameters

Table 39. RMA-2 and RMA-11 Model , rates, coefficients, constants for the Keno reach

Variable Name	Description, units	Value
	Time step, hr	1.0
	Space step, m	75
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
	Slope Factor	0.90
ELEV	Elevation of site, m	1192
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coefficient a, m hr^{-1} mb^{-1}	0.000015
EVAPB	Evaporative heat flux coefficient b, m hr^{-1} mb^{-1} $(m/h)^{-1}$	0.000010
EXTINC	Light Extinction coefficient, used when algae is not simulated, 1/m	1.5
ALP0	Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.072
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.010
LAMB1	Linear algal self-shading coefficient, phytoplankton, 1/m	n/a
LAMB2	Non-linear algal self shading coefficient, phytoplankton, 1/m	n/a
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.01
RESP	Local respiration rate of algae, phytoplankton, 1/d	0.05
SIG1	Settling rate of algae, phytoplankton, 1/d	0.0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m^{-2} s^{-1}	0.01
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.01
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.001
PREFN	Preference factor for NH3-N, phytoplankton	0.6
ABLP0	Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A	50
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
LAMB1	Linear algal self shading coefficient, bed algae, 1/m	n/a
LAMB2	Non-linear self shading coefficient, bed algae, 1/m	n/a
MUMAX	Maximum specific growth rate, bed algae, 1/d	1.0
RESP	Local respiration rate of algae, bed algae, 1/d	0.60
MORT	Mortality, bed algae, 1/d	0.0
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.01
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.002
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m^{-2} s^{-1}	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.3
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.5
BET3	Rate constant: hydrolysis Org N to NH3-N, 1/d	0.3
BET4	Rate constant: transformation Org P to P-D, 1/d	0.3
KNINH	First order nitrification inhibition coefficient, mg^{-1}	n/a
ALP3	Rate O_2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.6
ALP4	Rate O_2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.6
ABLP3	Rate O_2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.6
ABLP4	Rate O_2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.6
ALP5	Rate O_2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O_2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
K1	Deoxygenation rate constant: BOD, 1/d	0.3
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	3.0
SIG6	BOD settling rate constant, 1/d	0.0

n/a – not applicable

3.5 J.C. Boyle Reservoir

The CE-QUAL-W2 model of J.C. Boyle Reservoir was calibrated for 2000. Although the reservoir has a relatively short residence time and could be calibrated and validated using two periods within a single year, it is proposed to continue testing the model on an independent year for validation. The primary calibration data are monthly profiles and a second year of analysis will provide additional data. Although this reach has not been formally validated, it has been represented under various levels of spatial discretization in CE-QUAL-W2 and results compared with the application of the one-dimensional model WQRRS. Thus, although it is a work in progress, there is a good level of confidence in model results.

Water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) data were collected during field season 2000 just upstream from the dam to support the modeling task (additional profiles were collected in the vicinity of the Highway 66 bridge and conditions were found to be similar to those near the dam).

3.5.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

3.5.1.1 Boundary Conditions

Because no upstream data were available, the upstream boundary conditions were derived from simulated output using the calibrated Keno reach model. Hourly inflow and outflow from J.C. Boyle Reservoir were used, thus peaking operations at J.C. Boyle Powerhouse were reflected in the operations. The accretion / depletion boundary conditions were those defined in model implementation of J.C. Boyle Reservoir.

3.5.1.2 Initial conditions

Initial conditions for the J.C. Boyle Reservoir were assumed to wash out within the first few days of January, due to the short residence time and isothermal conditions of the reservoir.

3.5.2 Results

Calibration was completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from monthly profiles. The nutrient data were primarily derived from field data, which were typically sampled once per month at two depths within the reservoir. All model parameters for the J.C. Boyle Reservoir reach are summarized in Table 42 at the end of this section.

3.5.2.1 Water Temperature

The water temperature was calibrated using the three user specified wind evaporation coefficients available in CE-QUAL-W2. Results are shown in Figure 65 and summary statistics are included in Table 40. J.C. Boyle Reservoir experiences weak, intermittent

stratification. The model does replicate this to some degree. The profile bias ranged from 0.03°C to –1.46°C and the mean absolute error ranged from 0.21°C to 1.46°C. Overall the model is within about 1.5°C of observations. Because J.C. Boyle Reservoir residence time is on the order of a day or two, water temperature is strongly influenced by the temperature of river inflows.

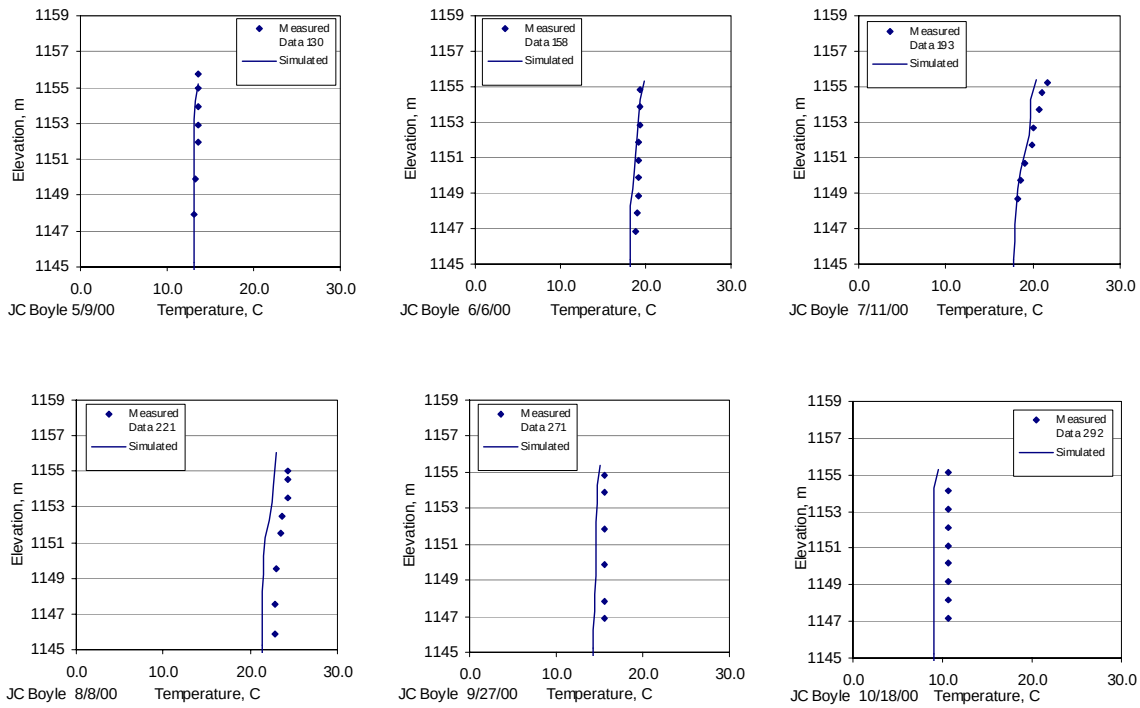


Figure 65. J.C. Boyle Reservoir thermal profiles, simulated versus measured monthly values: 2000

Table 40. J.C. Boyle Reservoir thermal profile summary statistics: simulated versus measured

Date	Mean Bias[a] (°C)	Mean Absolute Error (°C)	Root Mean Squared Error (°C)	n
April 12, 2000	-2.44	2.44	2.45	8
May 9, 2000	-0.29	0.29	0.34	6
June 6, 2000	-0.41	0.47	0.54	9
July 11, 2000	-0.63	0.63	0.79	8
August 8, 2000	-1.53	1.53	1.54	8
September 28, 2000	-0.94	0.94	0.97	6
October 18, 2000	-1.55	1.55	1.56	9

[a] Mean bias = simulated – measured

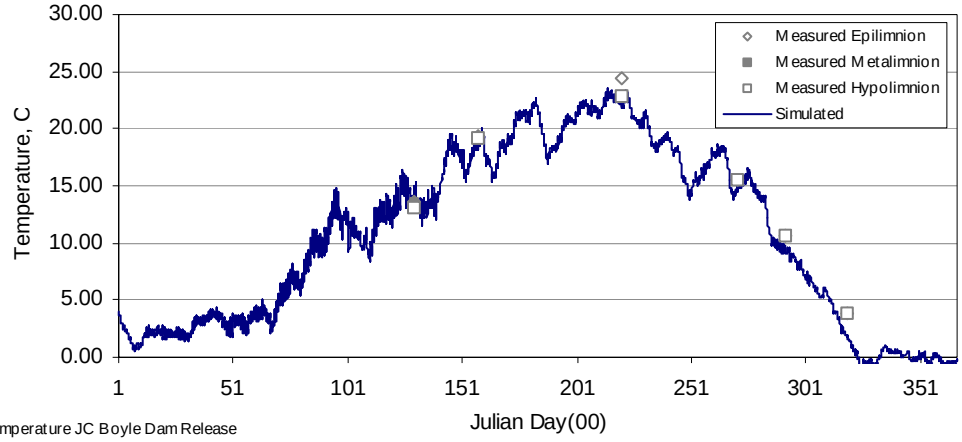


Figure 66. J.C. Boyle Reservoir simulated release temperatures compared with in-pool grab samples near J.C. Boyle Dam

3.5.2.2 Dissolved Oxygen

The dissolved oxygen was calibrated by varying several different parameters, including algal rates, organic matter decay rates and nutrient decay rates. Also zero order SOD was employed in calibrating dissolved oxygen.

Results are shown in Figure 67 and summary statistics are included in Table 41. The profile bias ranged from –1.87 mg/l to 3.75 mg/l while the mean absolute error ranged from 0.30 mg/l to 3.75 mg/l. The model performed well through about mid-June. Thereafter, dissolved oxygen concentrations were over predicted in surface waters. Simulated dissolved oxygen concentration in J.C. Boyle release is compared with in-pool grab samples in Figure 68. Because the reservoir is only weakly stratified and has a short residence time, boundary conditions can play an important role in model performance. Additional simulations using data from subsequent years are planned to improve model representation and to provide a validation step.

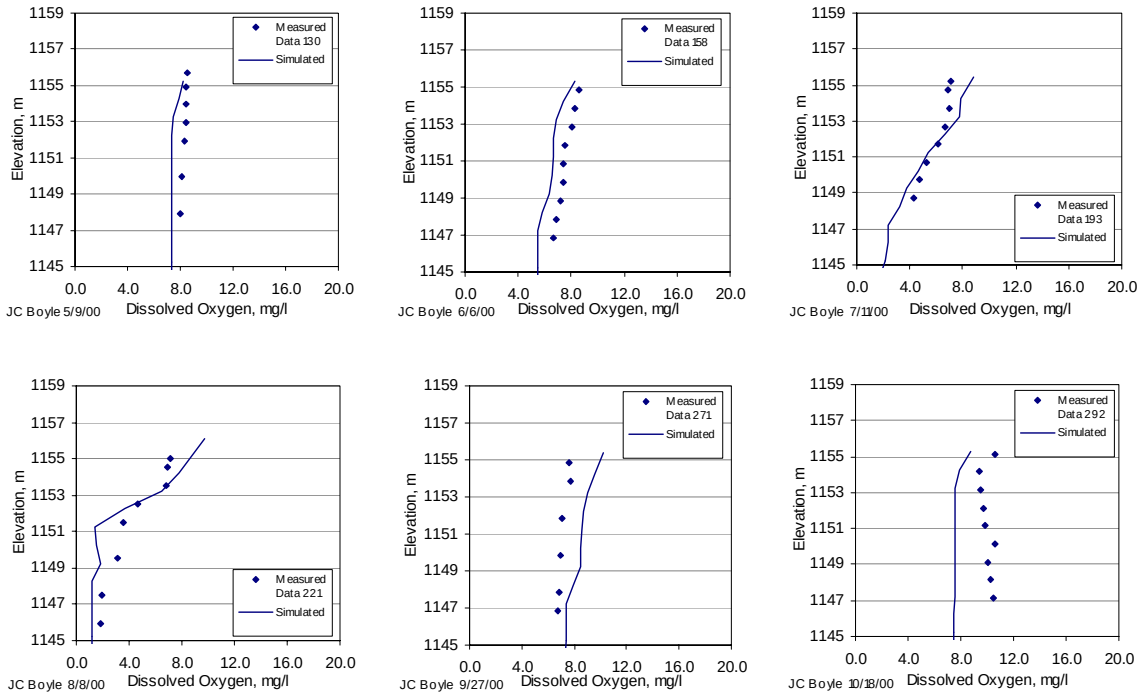


Figure 67. J.C. Boyle Reservoir dissolved oxygen profiles, simulated versus measured monthly values: 2000

Table 41. J.C. Boyle Reservoir dissolved oxygen profile summary statistics: simulated versus measured.

Date	Mean Bias[a] (mg/l)	Mean Absolute Error (mg/l)	Root Mean Squared Error (mg/l)	n
April 12, 2000	0.54	0.54	0.57	8
May 9, 2000	-0.74	0.74	0.78	6
June 6, 2000	-1.01	1.01	1.03	9
July 11, 2000	0.29	0.74	0.88	8
August 8, 2000	-0.27	0.90	1.06	8
September 28, 2000	1.47	1.47	1.57	6
October 18, 2000	-2.33	2.33	2.38	9

[a] Mean bias = simulated – measured

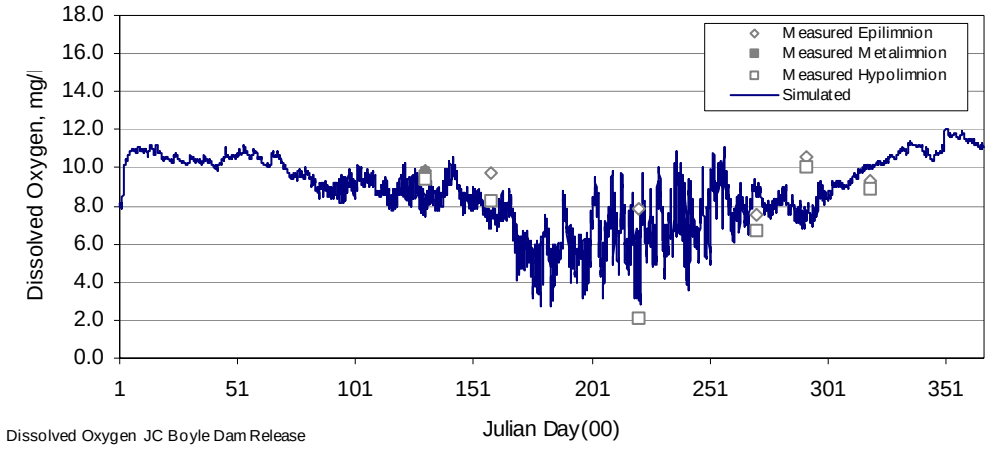


Figure 68. J.C. Boyle Reservoir simulated release dissolved oxygen concentration compared with in-pool grab samples near J.C. Boyle Dam

3.5.2.3 Nutrients

Nutrient concentrations were not actively calibrated in the J.C. Boyle Reservoir reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the DO calibration were not modified, and other parameters were set at default values. Results are presented for orthophosphate, ammonia, nitrate, and chlorophyll a (algae) in Figure 69 through Figure 71, respectively. These results, similar to dissolved oxygen, are impacted by the assumed upstream boundary condition. Additional simulations planned using data from subsequent years to improve model representation.

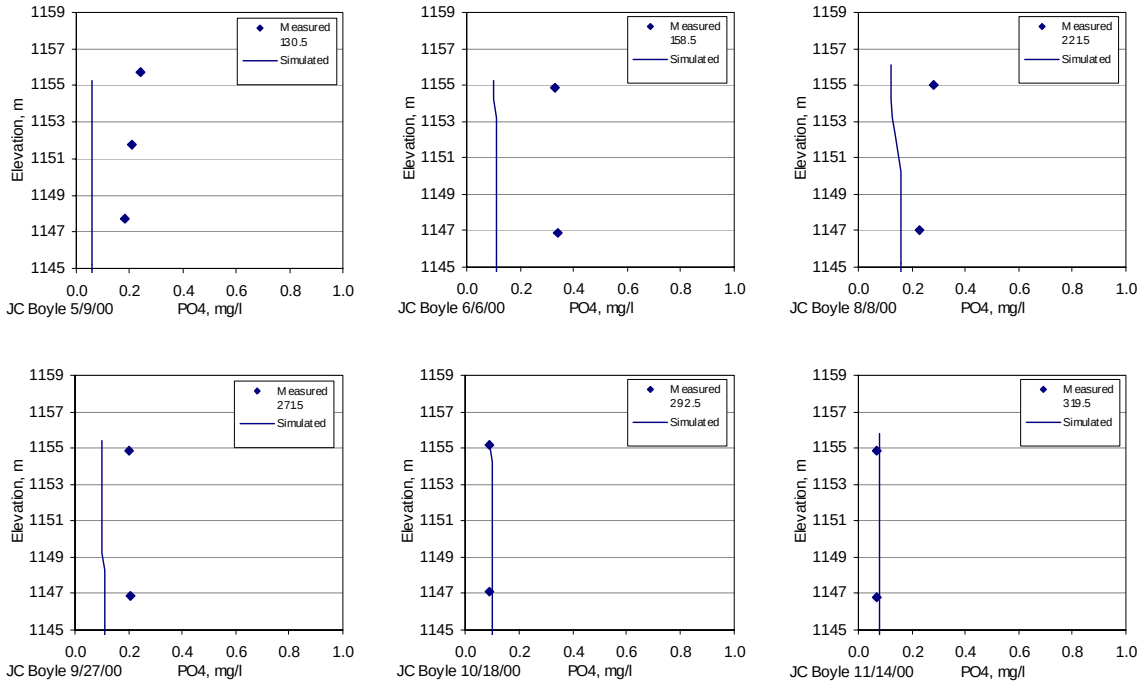


Figure 69. J.C. Boyle Reservoir orthophosphate profiles, simulated versus measured monthly values: 2000

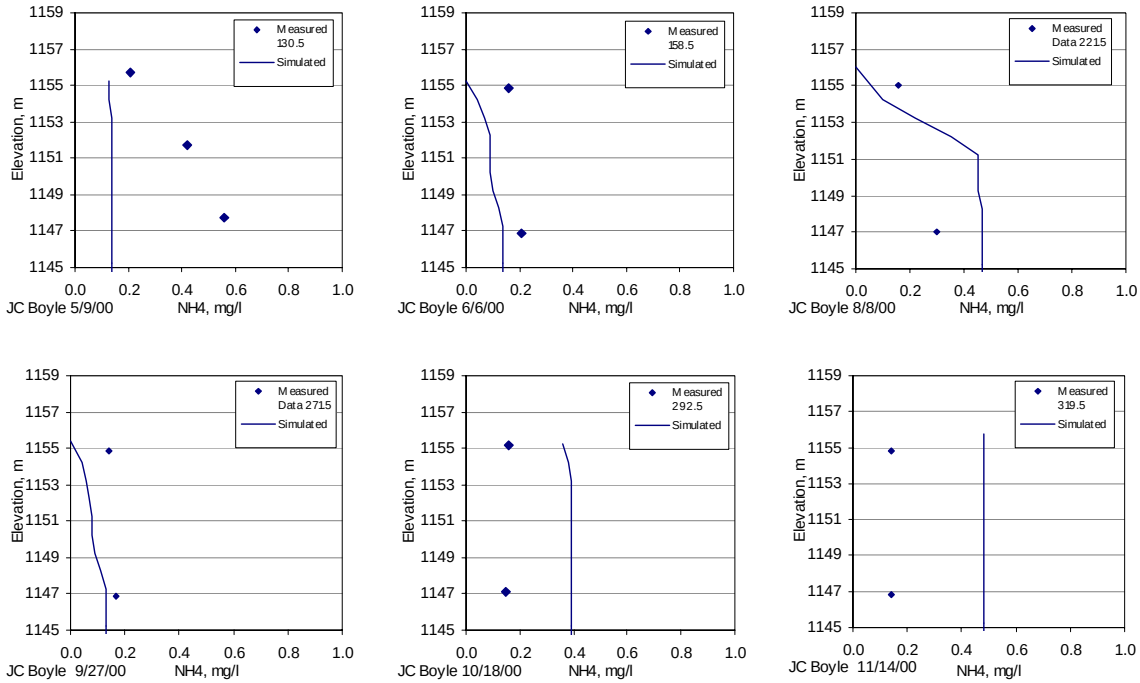


Figure 70. J.C. Boyle Reservoir ammonia profiles, simulated versus measured monthly values: 2000

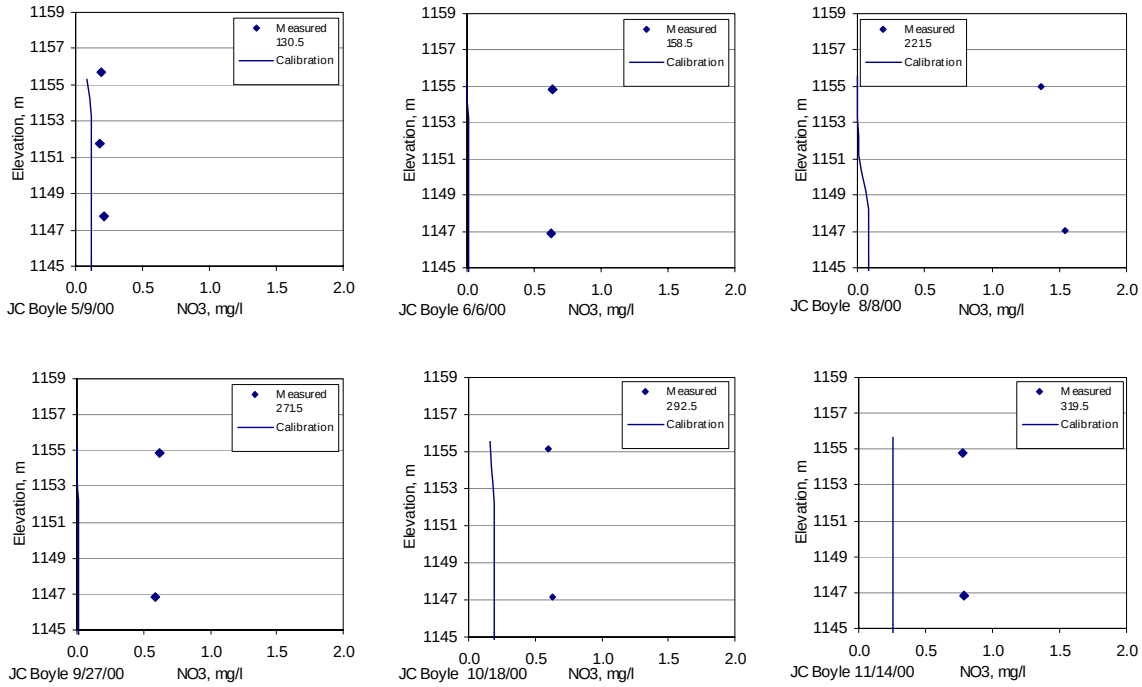


Figure 71. J.C. Boyle Reservoir nitrate profiles, simulated versus measured monthly values: 2000

3.5.2.4 Summary of Parameters

Table 42. Significant control file parameter values for the J.C. Boyle Reservoir EC simulation

Parameter Name	Description	EC J.C. Boyle Value	Default Values
DLT MIN	Minimum timestep, sec	5.0	N/A
DLT MAX	Maximum timestep, sec	500	N/A
SLOPE	Waterbody bottom slope	0.0	N/A
LAT	Latitude, degrees	42.12	N/A
LONG	Longitude, degrees	122.05	N/A
EBOT	Bottom elevation of waterbody, m	1143.75	N/A
AFW	A coefficient in the wind speed formulation	18.0	9.2
WINDH	Wind speed measurement height, m	2.0	N/A
TSED	Sediment (ground) temperature, C	12.0	N/A
FI	Interfacial friction factor	0.04	N/A
TSEDF	Heat lost to sediments that is added back to water column, fraction	0.01	N/A
EXH20	Extinction for pure water, m^{-1}	0.25	0.25 (for full WQ sim)
CGQ10 (Tracer)	Arhennius temperature rate multiplier	0	0
CG0DK (Tracer)	0-order decay rate, 1/day	0	0
CG1DK (Tracer)	1st-order decay rate, 1/day	0	0
CGS (Tracer)	Settling rate, m/day	0	0
CGQ10 (Age)	Arhennius temperature rate multiplier	0	0
CG0DK (Age)	0-order decay rate, 1/day	-1.0	-1.0
CG1DK (Age)	1st-order decay rate, 1/day	0	0
CGS (Age)	Settling rate, m/day	0	0
CGQ10 (Coliform)	Arhennius temperature rate multiplier	1.04	N/A
CG0DK (Coliform)	0-order decay rate, 1/day	0	N/A
CG1DK (Coliform)	1st-order decay rate, 1/day	1.4	N/A
CGS (Coliform)	Settling rate, m/day	1.0	N/A
AG	Maximum algal growth rate, 1/day	3.0	2.0
AT1	Lower temperature for algal growth, C	5.0	5.0
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03	0.001
PARTP	Phosphorus partitioning coefficient for suspended solids	0.001	0.0
NH4REL	Sediment release rate of ammonium, fraction of SOD	0.07	0.001
NH4DK	Ammonium decay rate, 1/day	0.1	0.12
NO3DK	Nitrate decay rate, 1/day	0.1	0.03
NO3S	De-nitrification rate from sediments, m/day	0.0	1.0
CO2REL	Sediment carbon dioxide release rate, fraction of sediment oxygen demand	0.01	0.1
O2AR	Oxygen stoichiometry for algal respiration	1.4	1.1
O2AG	Oxygen stoichiometry for algal primary production	1.5	1.4
SOD	Zero-order sediment oxygen demand for each segment, g O_2 / m^2 day	3.0 (for each segment)	N/A

3.6 Bypass Reach and Peaking Reach

The RMA suite of models for the Klamath River Bypass and Peaking reach was calibrated and validated during May 20 – 23, 2003 and July 15 – 18, 2003 respectively. The Bypass and Peaking Reach extends from J.C. Boyle Dam to the headwaters of Copco Reservoir and encompasses the J.C. Boyle Powerhouse tailrace.

3.6.1 Data

Water quality conditions of water flowing into the reach (boundary conditions at J.C. Boyle Dam and J.C. Boyle Powerhouse return), initial status of the system (initial conditions), and observations in the Klamath River (calibration/validation points at Klamath River above J.C. Boyle Powerhouse tailrace, Stateline and above Copco Reservoir) were required.

3.6.1.1 Boundary Conditions

The boundary condition data was derived from samples collected at J.C. Boyle Dam Reservoir. Water temperature and dissolved oxygen data were available from water quality probes and water temperature loggers at hourly intervals. Grab samples were collected once per day for three days. Due to the inherent variability and infrequent sampling interval of the grab data, the boundary condition values for nutrients, BOD, and algae were assumed to be a constant value for the calibration and validation period, based on the grab sample data from 2002 (Appendix F).

The upstream boundary condition for temperature and dissolved oxygen were obtained from water quality probes during the May and July calibration and validation periods. Sondes were deployed above the J.C. Boyle Dam, but were used to represent temperature and dissolved oxygen in both the direct J.C. Boyle Dam release into the river and the J.C. Boyle Powerhouse tailrace release into the river. Grab samples were also collected above the dam, providing concentrations of nutrients at J.C. Boyle Dam, as well as the boundary condition for the J.C. Boyle Powerhouse tailrace. These boundary conditions were assumed equivalent because they are both drawn from J.C. Boyle Reservoir.

There is a lag time from J.C. Boyle Dam to the powerhouse, but it is well under one hour (approximately 15 minutes at 600 cfs, 8 minutes at 3000 cfs; pers. comm. T. Olson) and is thus neglected.

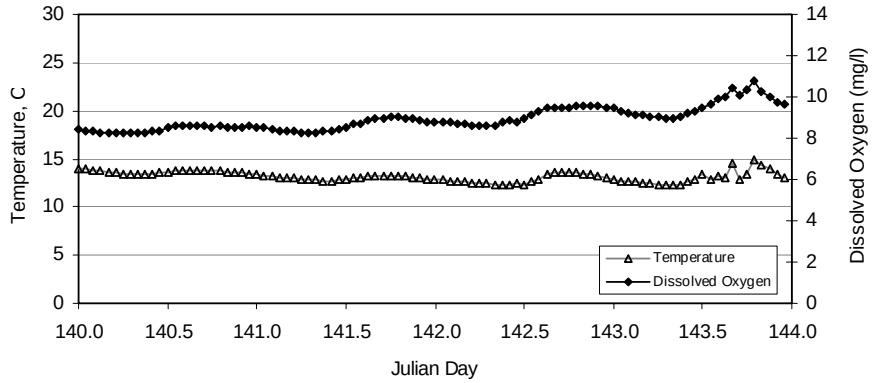
The water quality values for the calibration and validation period are shown in Table 43, Table 44, Figure 72 and Figure 73.

Table 43. Bypass/Peaking Klamath River reach calibration and validation water quality boundary conditions for J.C. Boyle Dam and J.C. Boyle Powerhouse return

Parameter	Units	Dates	
		5/21/02 - 5/23/02	7/16/02 - 7/18/02
BOD	mg/l	3.0	3.0
DO	mg/l	variable	Variable
Org N	mg/l	0.60	1.30
NH_4^+	mg/l	0.10	0.20
NO_2^-	mg/l	0.00	0.00
NO_3^-	mg/l	0.10	0.80
Org P	mg/l	0.20	0.10
PO_4^{3-}	mg/l	0.20	0.30
Algae	mg/l	2.0	22.0
Tw	°C	variable	variable

Table 44. Bypass/Peaking Klamath River reach calibration and validation water quality boundary conditions for the Bypass Reach spring inflow

Parameter	Units	Dates	
		5/21/02 - 5/23/02	7/16/02 - 7/18/02
BOD	mg/l	0.0	0.0
DO	mg/l	9.7	9.7
Org N	mg/l	0.00	0.00
NH_4^+	mg/l	0.00	0.00
NO_2^-	mg/l	0.00	0.00
NO_3^-	mg/l	0.15	0.15
Org P	mg/l	0.00	0.00
PO_4^{3-}	mg/l	0.15	0.15
Algae	mg/l	0.0	0.0
T_w	°C	11.0	11.0



Keno River July 2002 Boundary Conditions

Figure 72. Temperature and dissolved oxygen calibration boundary conditions at both J.C. Boyle Dam and J.C. Boyle Powerhouse

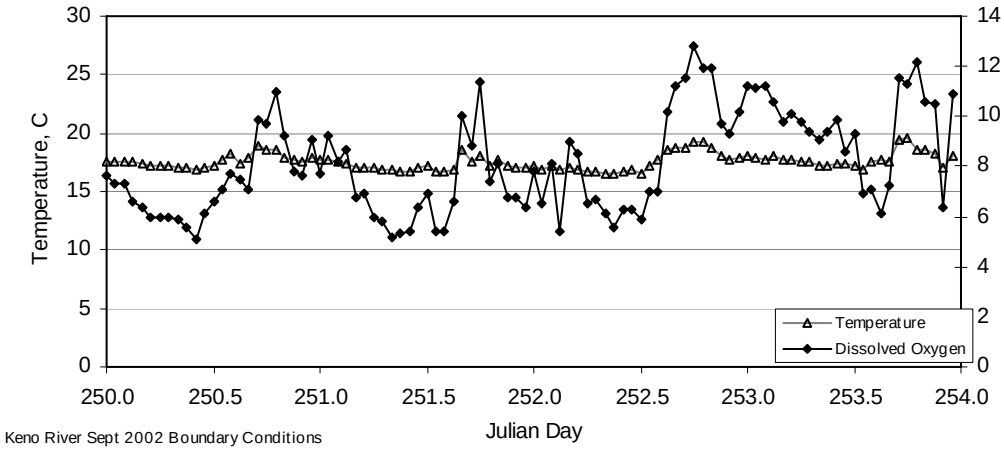


Figure 73. Temperature and dissolved oxygen validation boundary conditions at both J.C. Boyle Dam and J.C. Boyle Powerhouse

3.6.1.2 Initial conditions

The model was run for three days prior to both the calibration and validation periods to provide an initial condition for simulation. The initial bed algae mass was estimated at 5 g/m^2.

3.6.1.3 Calibration and Validation Points

The calibration and validation points for the Bypass / Peaking reach were Klamath River above J.C. Boyle Powerhouse tailrace, Klamath River at Stateline and Klamath River above Copco Reservoir. These data are displayed in the following section with model results.

3.6.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. An exception was at Klamath River above the J.C. Boyle Powerhouse tailrace site during the July (validation) period only temperature was available on an hourly interval. Dissolved oxygen was only available from field data collected once a day, and thus dissolved oxygen summary statistics are not available for that location in July. The nutrient data were primarily derived from field data, which were sampled once per day. All model parameters for the Bypass / Peaking reach are summarized in Table 51 at the end of this section.

3.6.2.1 Water Temperature

Water temperature calibration required varying evaporation heat flux coefficients (presented in Table 51) that govern the mass transfer formulation represented in the numerical model heat budget. No other parameters were varied. The hourly results are

presented graphically in Figure 74 through Figure 79 . Summary statistics for both calibration and validation periods (May 20-23, 2002 and July 15-18, 2002, respectively) are included in Table 45 through Table 47.

At Klamath River above J.C. Boyle Powerhouse tailrace, the phase was well represented while the range was moderated slightly. Hourly bias for the May period (calibration) was 0.14 °C and the mean absolute error was 0.87 °C. Hourly bias for the July period (validation) was –0.23 °C and the mean absolute error was 0.91 °C. Both the calibration and validation simulation results were within 1 °C of observations.

At Klamath River at Stateline, the diurnal phase was approximately reproduced while the diurnal range was well represented. Hourly bias for the May period (calibration) was –0.39 °C and the mean absolute error was 0.67 °C. Hourly bias for the July period (validation) was –0.48 °C and the mean absolute error was 1.11 °C. Both the calibration and validation simulation results were within approximately 1.5 °C of observations.

At Klamath River above Copco Reservoir, the diurnal phase was approximately represented in May, but not represented well in July, while the diurnal range for both periods was well represented. Hourly bias for the May period (calibration) was –0.35 °C and the mean absolute error was 0.61 °C. Hourly bias for the July period (validation) was –0.05 °C and the mean absolute error was 1.10 °C. Both the calibration and validation simulation results were generally within 1.5 °C of observations.

Apparent in both the observed and simulated temperature time series is the influence of peaking operations. During off peak hours, water of a significantly different quality (from the bypass reach) markedly alters water temperature. The timing and magnitude of peaking operations create unique temperature traces at downstream locations. Figure 79 illustrates the thermal response of the Klamath River above Copco and, although shifted slightly in phase, the model replicates such conditions.

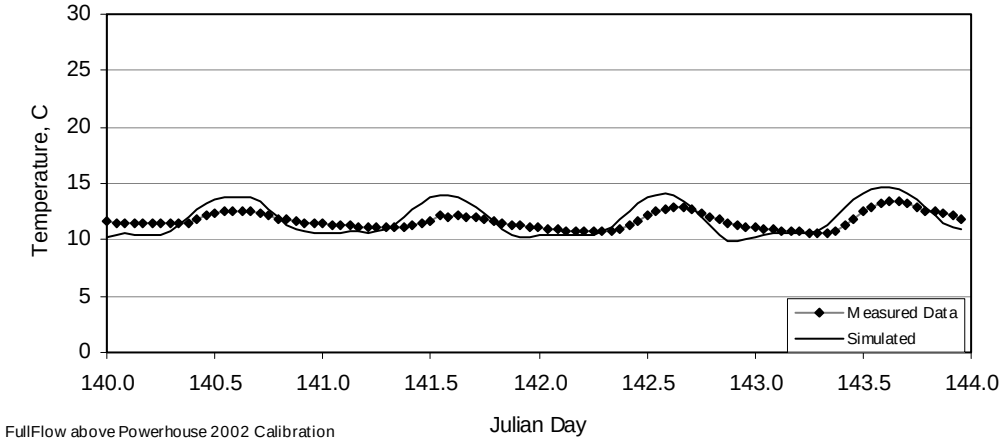


Figure 74. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured water temperature, May 20-23, 2002

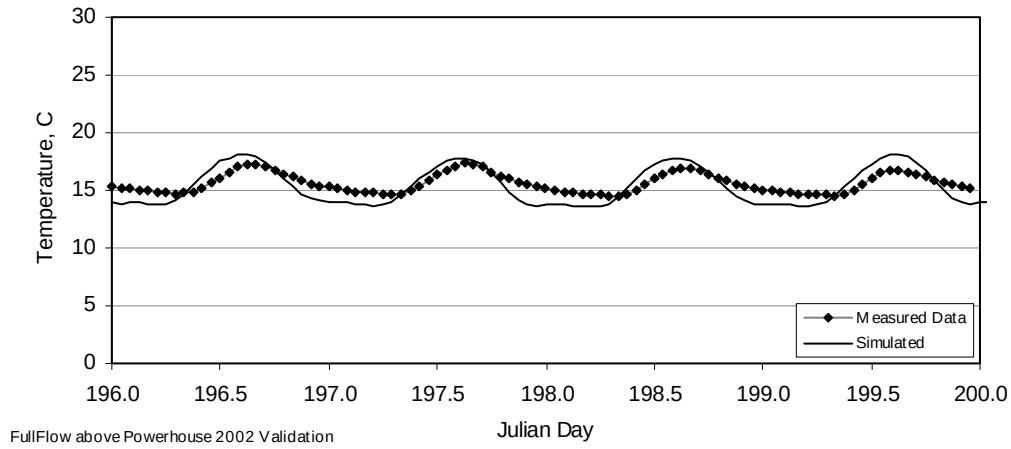


Figure 75. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured water temperature, July 15-18, 2002

Table 45. Klamath River, above J.C. Boyle PH tailrace, hourly and daily calibration and validation period statistics for temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	0.14	-0.23	0.14	-0.23
Mean absolute error (MAE)	mg/l	0.87	0.91	0.18	0.23
Root mean squared error (RMSE)	mg/l	0.99	1.01	0.22	0.27
N	-	96	96	4	4

[a] Mean bias = simulated – measured

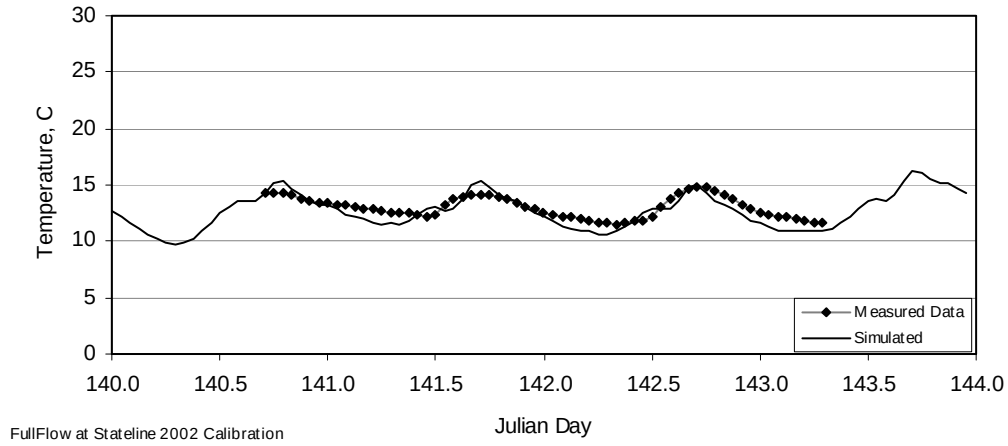


Figure 76. Klamath River, at Stateline, simulated versus measured water temperature, May 20-23, 2002

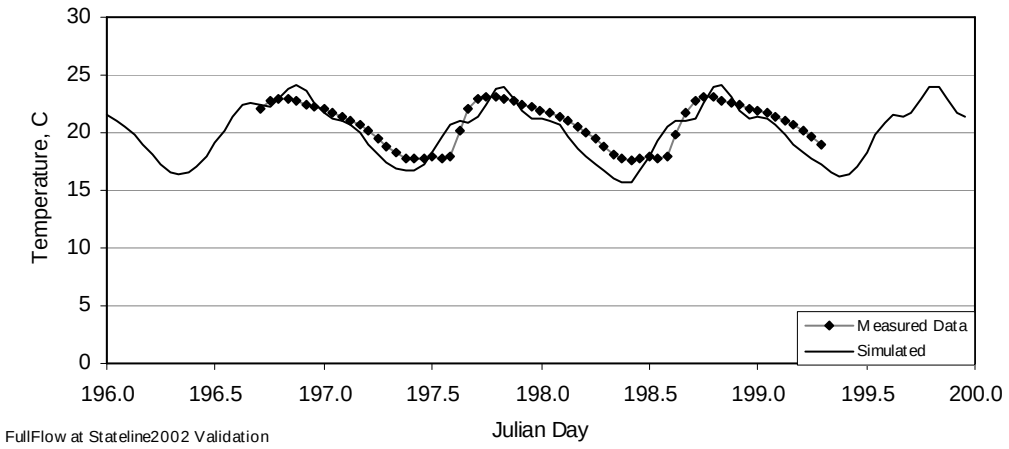


Figure 77. Klamath River, at Stateline, simulated versus measured water temperature, July 15-18, 2002

Table 46. Klamath River, at Stateline, hourly and daily calibration and validation period statistics for temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	-0.39	-0.48	-0.40	-0.49
Mean absolute error (MAE)	mg/l	0.67	1.11	0.40	0.49
Root mean squared error (RMSE)	mg/l	0.77	1.29	0.42	0.51
n	-	63	63	2	2

[a] Mean bias = simulated – measured

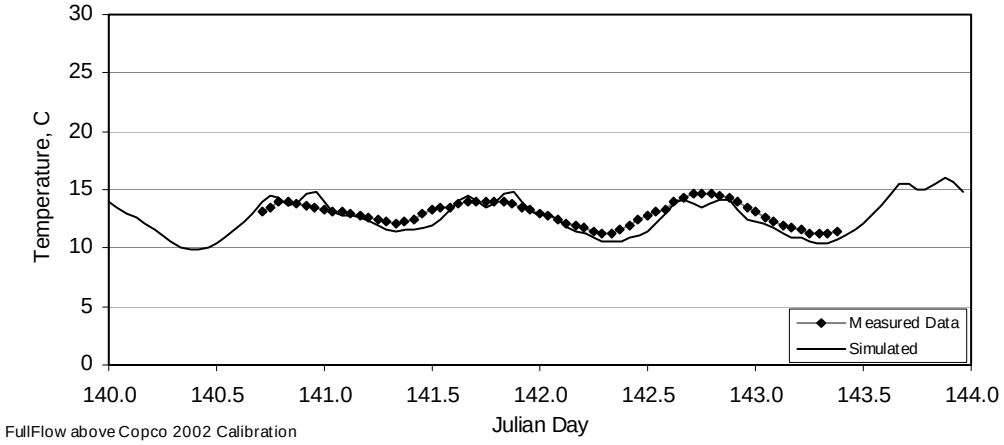


Figure 78. Klamath River, above Copco Reservoir, simulated versus measured water temperature, May 20-23, 2002

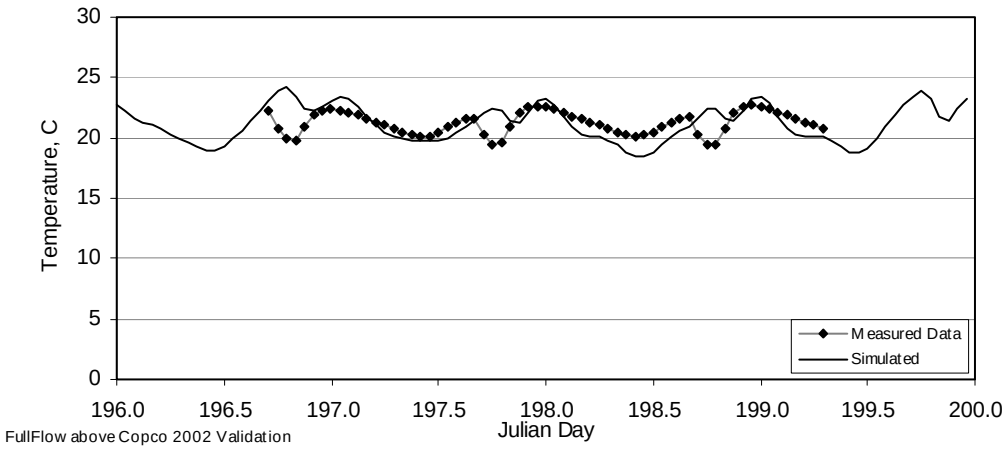


Figure 79. Klamath River, above Copco Reservoir, simulated versus measured water temperature, July 15-18, 2002

Table 47. Klamath River, above Copco Reservoir, hourly and daily calibration and validation period statistics for temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	-0.35	0.05	-0.41	-0.12
Mean absolute error (MAE)	mg/l	0.61	1.10	0.41	0.29
Root mean squared error (RMSE)	mg/l	0.71	1.39	0.46	0.31
n	-	65	63	2	2

[a] Mean bias = simulated – measured

3.6.2.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeling in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from upstream of Keno Dam, growth rates were set to very low numbers in river reaches. The results are presented both graphically, in Figure 80 through Figure 85, and using summary statistics, in Table 48 through

Table 50.

At Klamath River above J.C. Boyle Powerhouse tailrace, the model reproduced dissolved oxygen concentrations and the moderated diurnal signal. For July, the simulated concentrations are very similar to the field data. Hourly bias for the May period (calibration) was –0.07 mg/l and the mean absolute error was 0.28 mg/l. Hourly bias and mean absolute error for the July period (validation) were not available. The calibration and simulation results were within 1 mg/l of observations.

At Klamath River at Stateline, the May phase and range were approximately represented. For July the phase and range were well represented, but the magnitude was over-represented. Hourly bias for the May period (calibration) was 0.37 mg/l and the mean absolute error was 0.39 mg/l. Hourly bias for the July period (validation) was 1.17 mg/l and the mean absolute error was 1.17 mg/l. Both the calibration and validation simulation results were within 1.5 mg/l of observations.

At Klamath River above Copco Reservoir, the overall magnitude was well represented, but the diurnal range was not. In July, both the diurnal phase and range were well represented, as was the magnitude. Hourly bias for the May period (calibration) was 0.00 mg/l and the mean absolute error was 0.59 mg/l. Hourly bias for the July period (validation) was 0.56 mg/l and the mean absolute error was 0.56 mg/l. While the summary statistics of both the calibration and validation indicate the simulation results were within 1 mg/l of observations, a visual inspection of the May graph indicates that the simulation results for that period were within 2 mg/l.

Uncertainty in organic matter and algae inputs may be the cause for elevated simulation values in July at Klamath River at Stateline. Additionally, the distribution of benthic algae and biomass is largely unknown, as are the temporal and spatial variability of light extinction, and could impact model results.

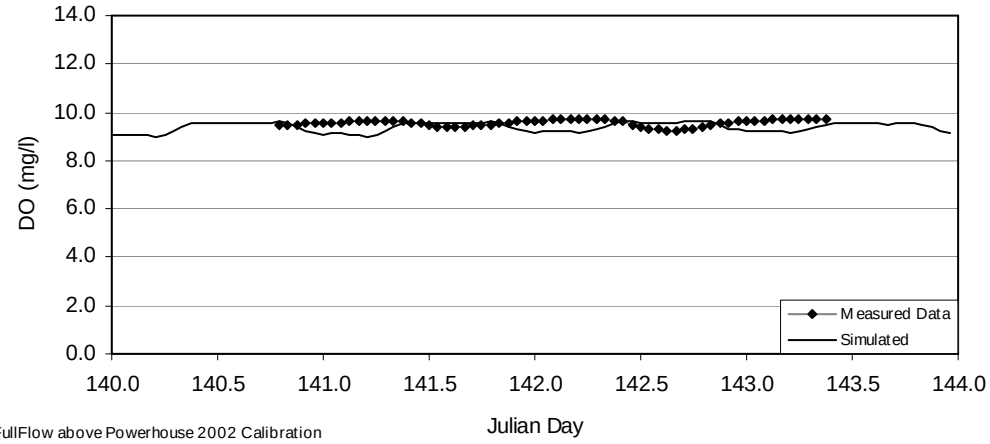


Figure 80. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured dissolved oxygen, May 20-23, 2002

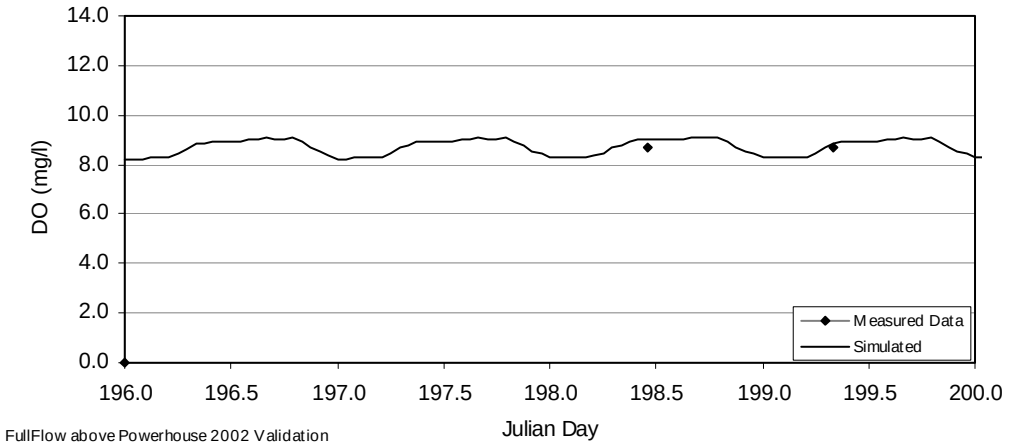


Figure 81. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured dissolved oxygen, July 15-18, 2002

Table 48. Klamath River, above J.C. Boyle PH tailrace, hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	-0.07	n/a	-0.02	n/a
Mean absolute error (MAE)	mg/l	0.28	n/a	0.04	n/a
Root mean squared error (RMSE)	mg/l	0.30	n/a	0.04	n/a
N	-	63	n/a	2	n/a

[a] Mean bias = simulated – measured

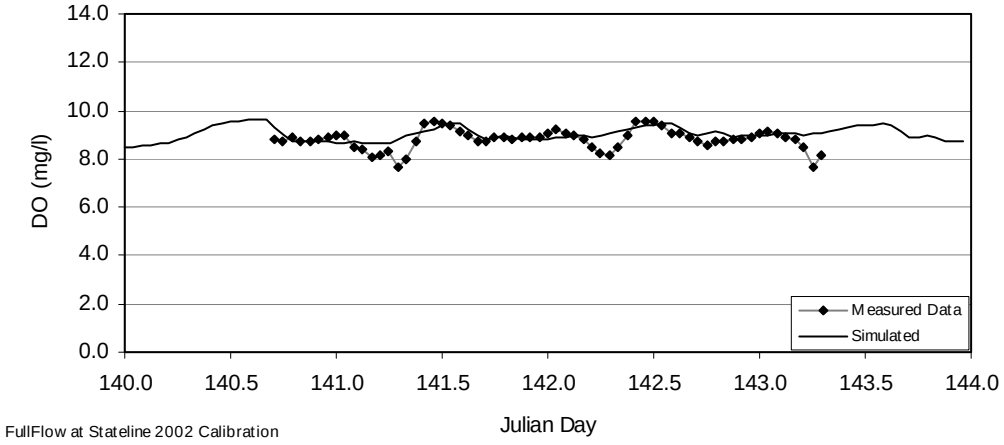


Figure 82. Klamath River, at Stateline, simulated versus measured dissolved oxygen, May 20-23, 2002

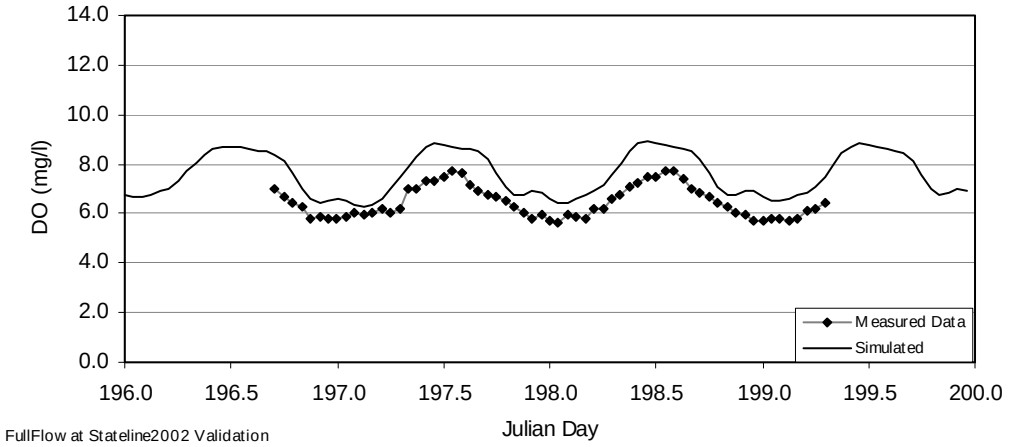


Figure 83. Klamath River, at Stateline, simulated versus measured dissolved oxygen, July 15-18, 2002

Table 49. Klamath River, at Stateline, hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	0.37	1.17	0.36	1.19
Mean absolute error (MAE)	mg/l	0.39	1.17	0.36	1.19
Root mean squared error (RMSE)	mg/l	0.51	1.22	0.36	1.19
n	-	63	63	2	2

[a] Mean bias = simulated – measured

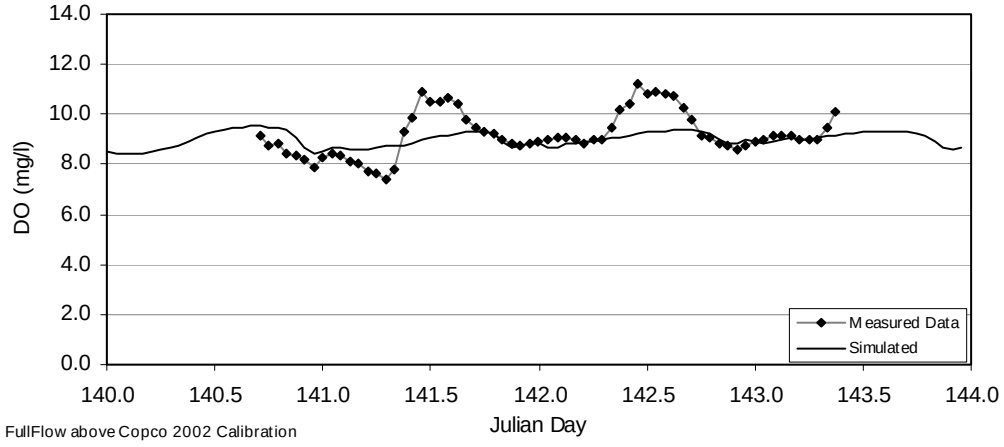


Figure 84. Klamath River, above Copco Reservoir, simulated versus measured dissolved oxygen, May 20-23, 2002

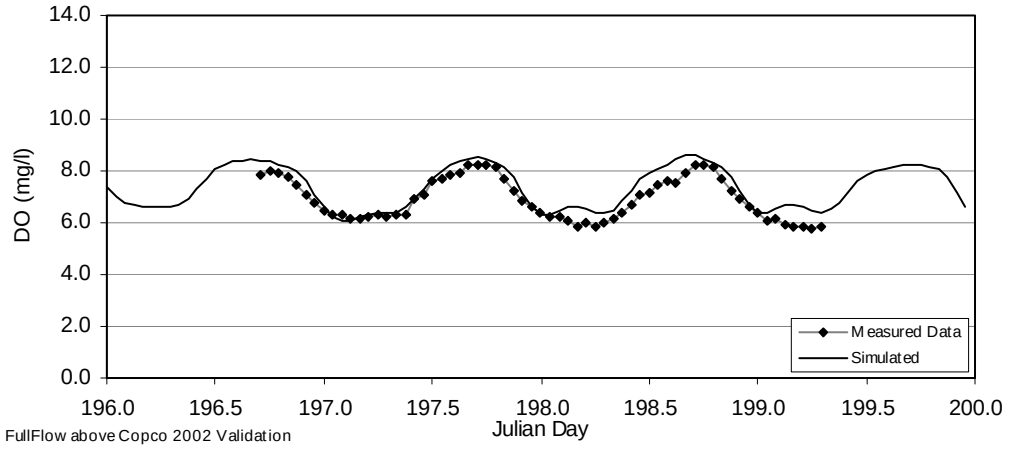


Figure 85. Klamath River, above Copco Reservoir, simulated versus measured dissolved oxygen, July 15-18, 2002

Table 50. Klamath River, above Copco Reservoir, hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	0.00	0.56	-0.13	0.52
Mean absolute error (MAE)	mg/l	0.59	0.56	0.18	0.52
Root mean squared error (RMSE)	mg/l	0.75	0.62	0.22	0.54
n	-	65	63	2	2

[a] Mean bias = simulated – measured

3.6.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Bypass / Peaking reach. That is, values for nutrient interactions (e.g. stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 86 through Figure 103. Simulated concentrations for ammonia, nitrate and orthophosphate were consistent with field observations. Although there is some scatter in the observed data that is not replicated within the model, the variations in water quality in response to peaking operations are well represented for certain constituents (e.g. nitrate, Figure 95 and Figure 101).

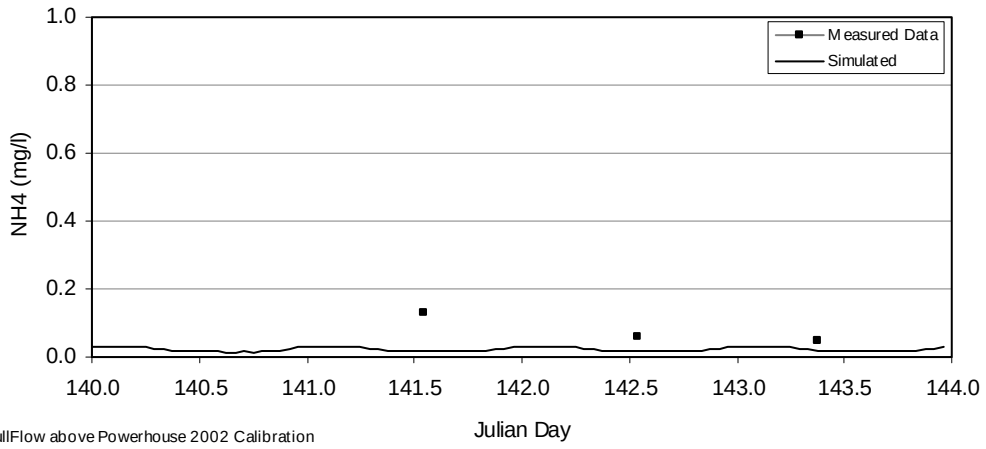


Figure 86. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured ammonia, May 20-23, 2002

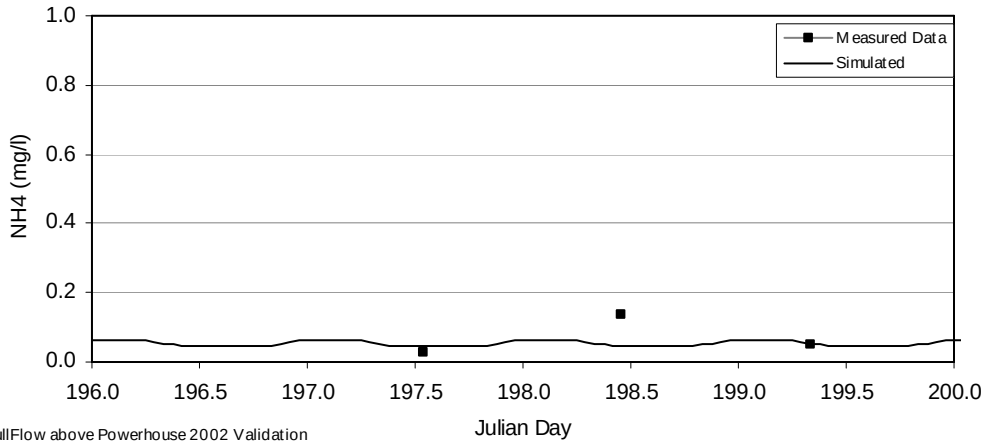


Figure 87. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured ammonia, July 15-18, 2002

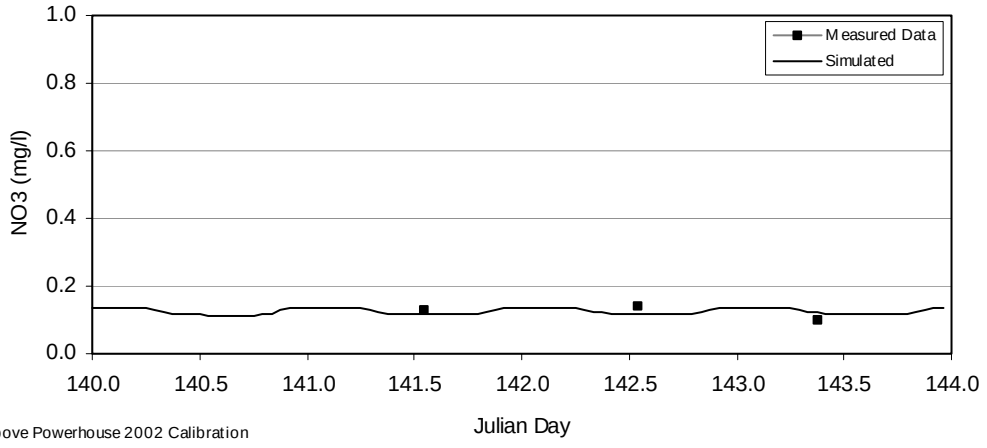


Figure 88. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured nitrate, May 20-23, 2002

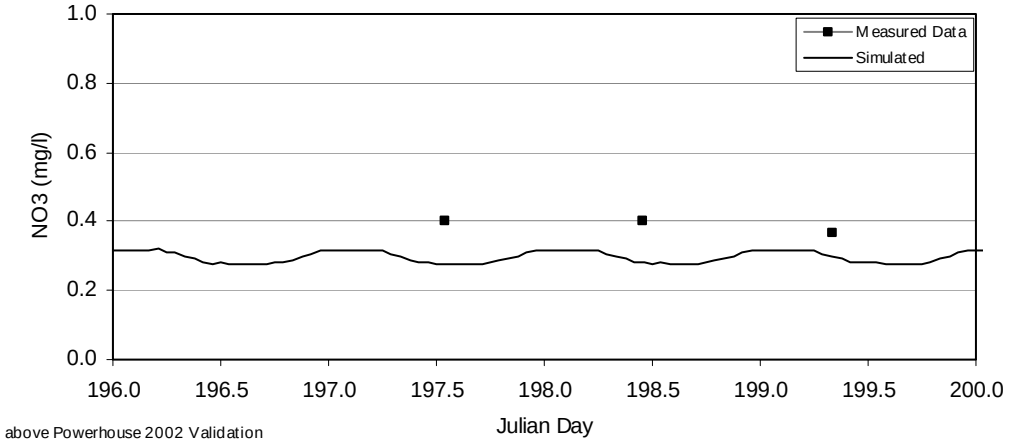


Figure 89. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured nitrate, July 15-18, 2002

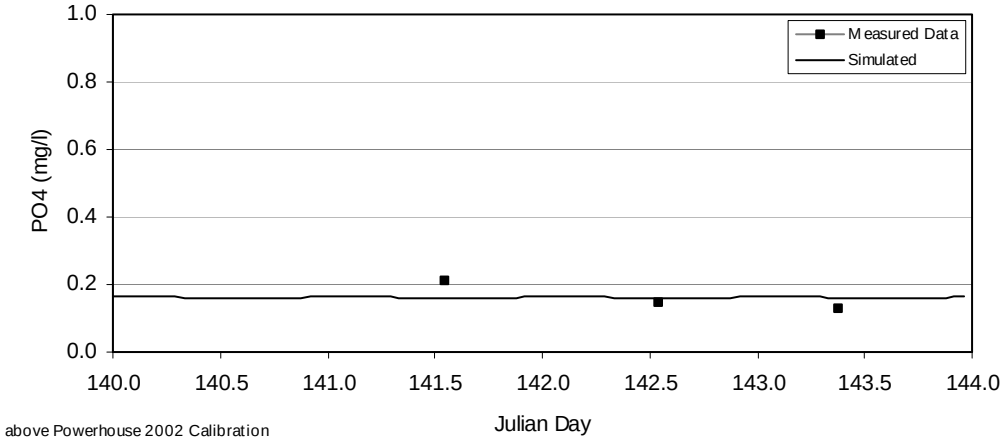


Figure 90. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured orthophosphate, May 20-23, 2002

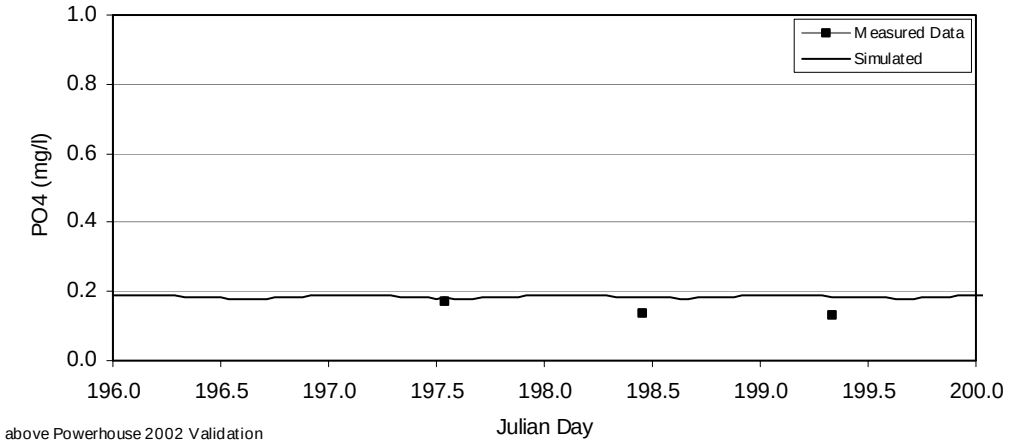


Figure 91. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured orthophosphate, July 15-18, 2002

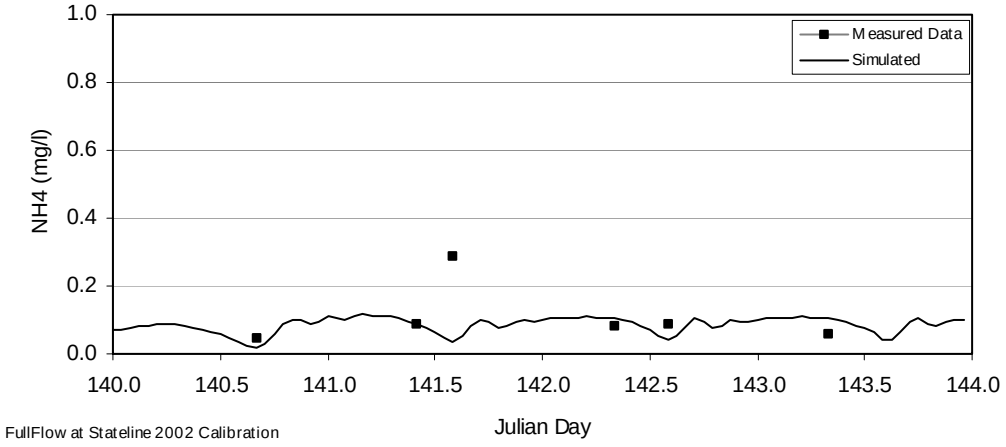


Figure 92. Klamath River, at Stateline, simulated versus measured ammonia, May 20-23, 2002

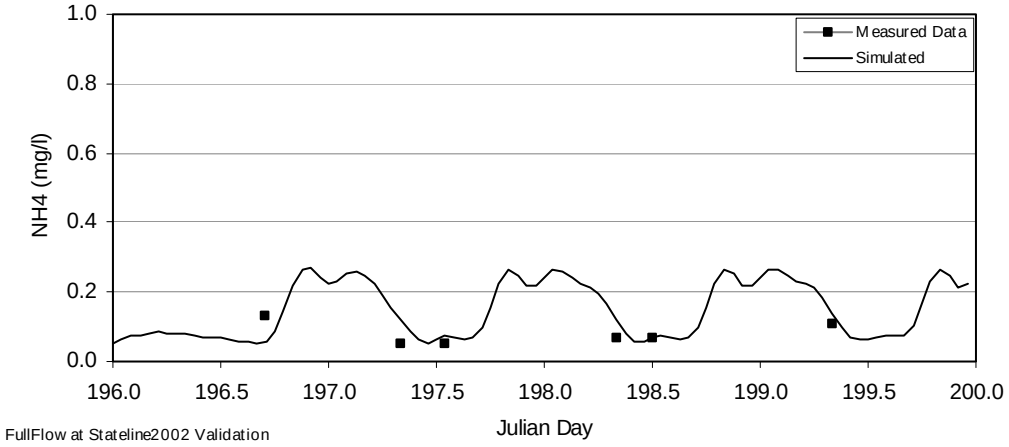


Figure 93. Klamath River, at Stateline, simulated versus measured ammonia, July 15-18, 2002

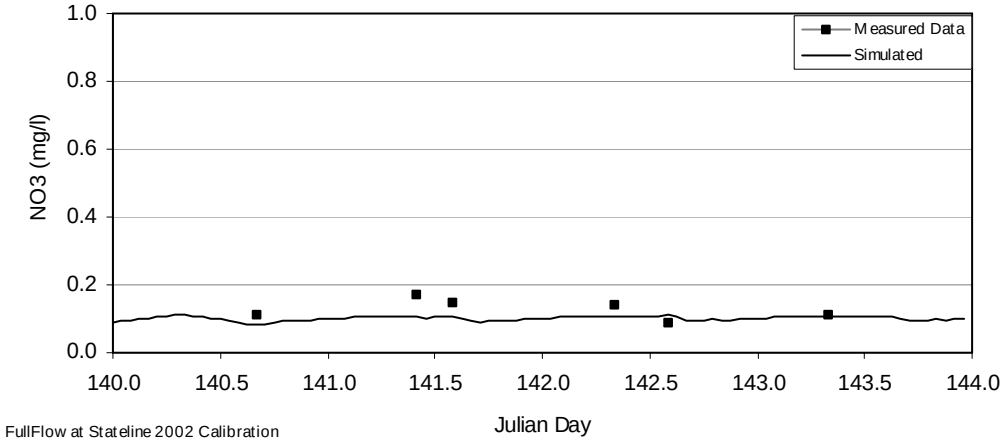


Figure 94. Klamath River, at Stateline, simulated versus measured nitrate, May 20-23, 2002

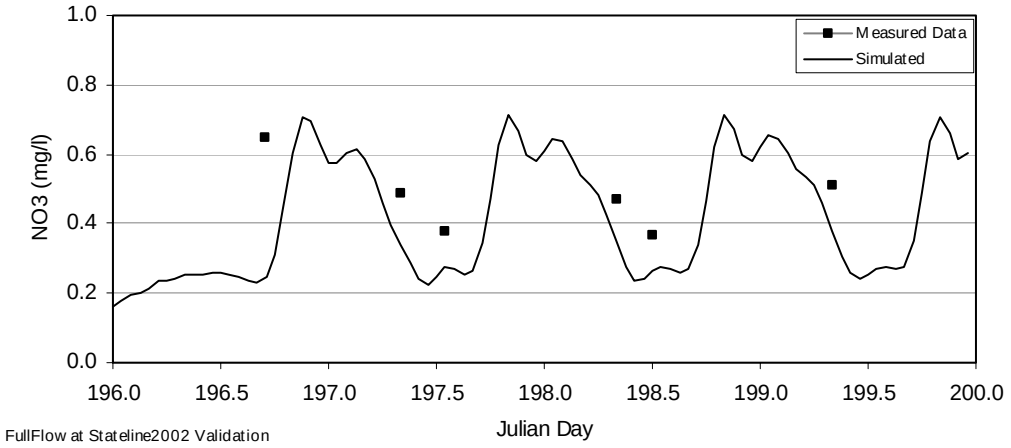


Figure 95. Klamath River, at Stateline, simulated versus measured nitrate, July 15-18, 2002

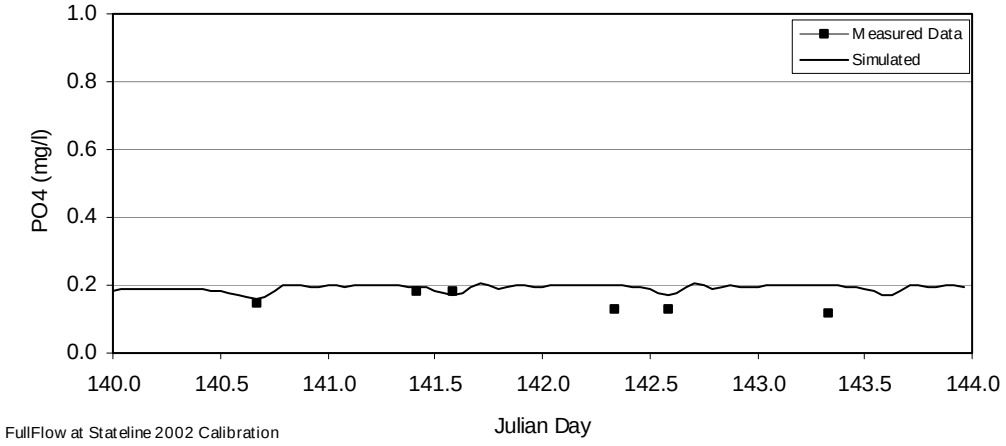


Figure 96. Klamath River, at Stateline, simulated versus measured orthophosphate, May 20-23, 2002

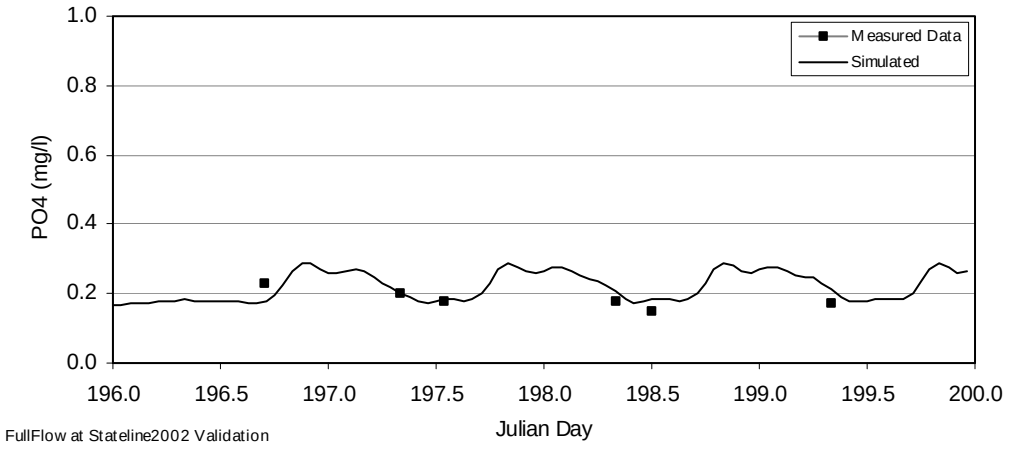


Figure 97. Klamath River, at Stateline, simulated versus measured orthophosphate, July 15-18, 2002

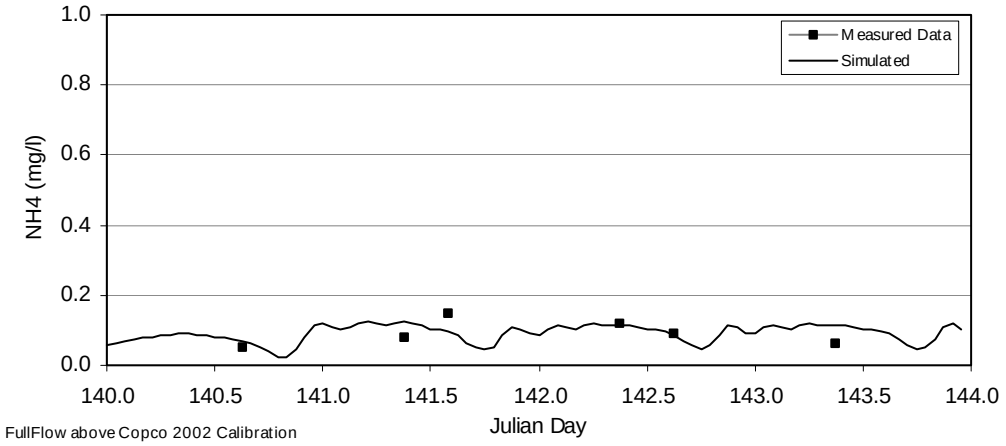


Figure 98. Klamath River, above Copco Reservoir, simulated versus measured ammonia, May 20-23, 2002

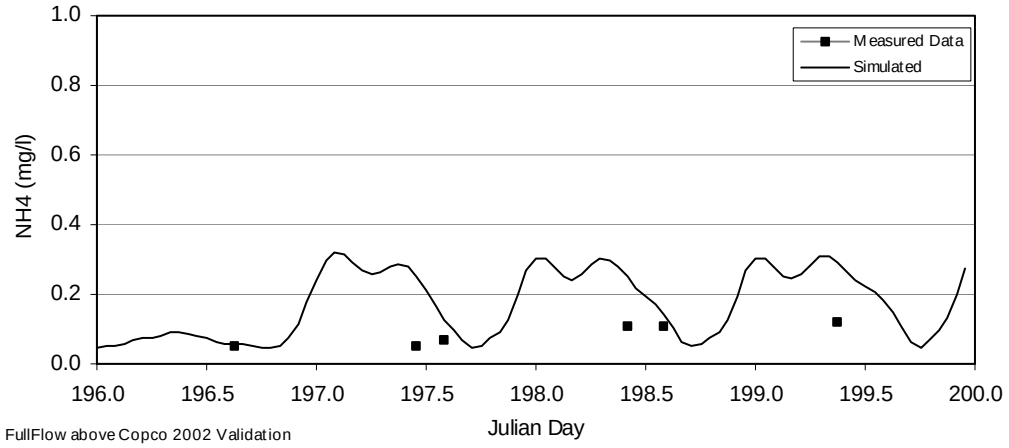


Figure 99. Klamath River, above Copco Reservoir, simulated versus measured ammonia, July 15-18, 2002

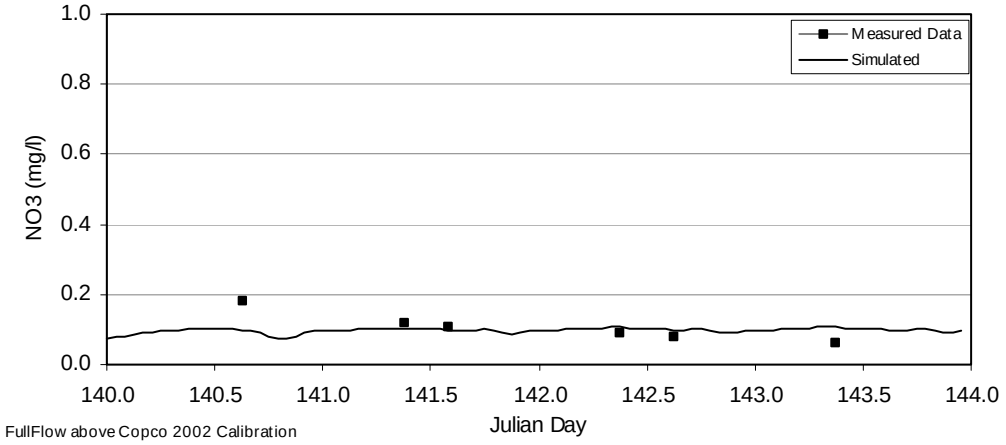


Figure 100. Klamath River, above Copco Reservoir, simulated versus measured nitrate, May 20-23, 2002

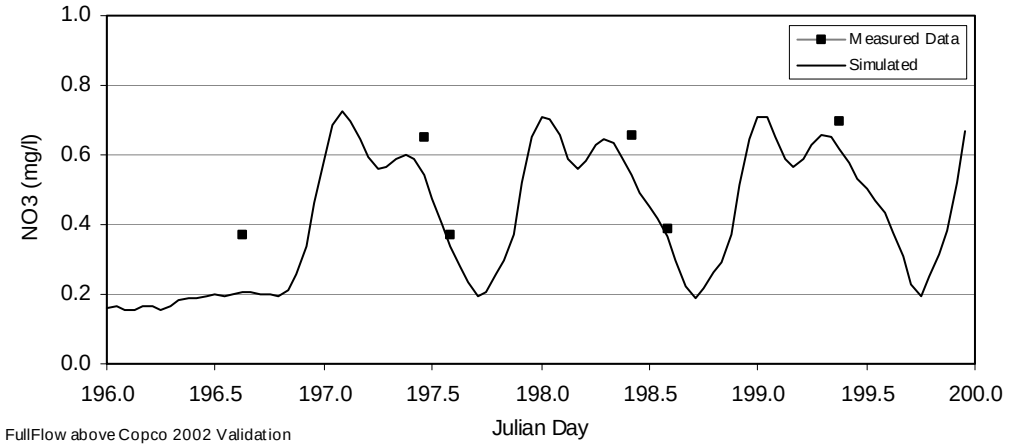


Figure 101. Klamath River, above Copco Reservoir, simulated versus measured nitrate, July 15-18, 2002

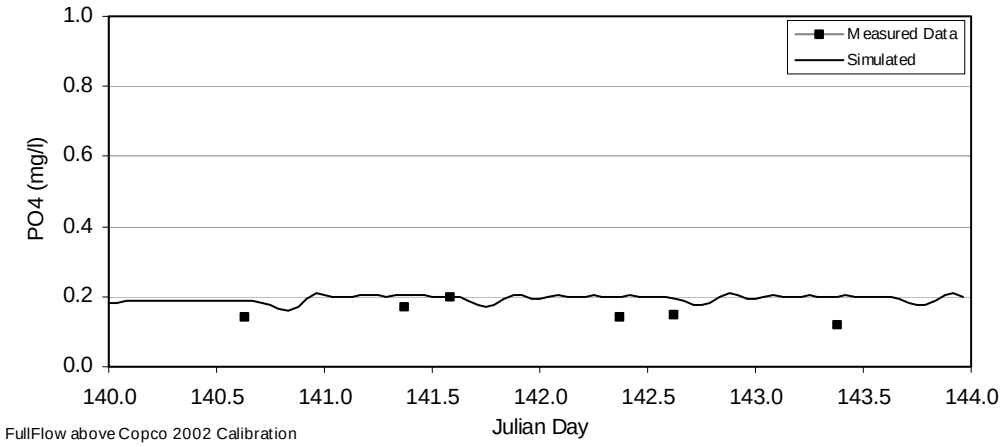


Figure 102. Klamath River, above Copco Reservoir, simulated versus measured orthophosphate, May 20-23, 2002

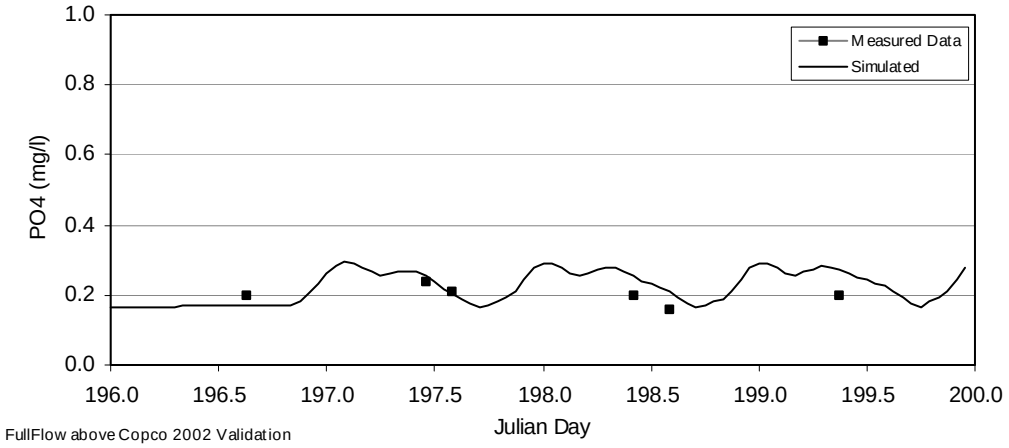


Figure 103. Klamath River, above Copco Reservoir, simulated versus measured orthophosphate, July 15-18, 2002

3.6.2.4 Summary of Parameters

Table 51. RMA-2 and RMA-11 Model rates, coefficients and constants for the Bypass / Peaking reach

Variable Name	Description, units	Value
	Time step, hr	0.25 (RMA-2) 1.0 (RMA-11)
	Space step, m	75
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
	Slope Factor	0.95
ELEV	Elevation of site, m	964.00
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coefficient a, m hr^{-1} mb^{-1}	0.000010
EVAPB	Evaporative heat flux coefficient b, m hr^{-1} mb^{-1} $(m/h)^{-1}$	0.000010
EXTINC	Light Extinction coefficient, used when algae is not simulated, 1/m	1.5
ALP0	Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.072
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.010
LAMB1	Linear algal self-shading coefficient, phytoplankton, 1/m	n/a
LAMB2	Non-linear algal self shading coefficient, phytoplankton, 1/m	n/a
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.01
RESP	Local respiration rate of algae, phytoplankton, 1/d	0.05
SIG1	Settling rate of algae, phytoplankton, 1/d	0.0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m^{-2} s^{-1}	0.01
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.01
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.001
PREFN	Preference factor for NH3-N, phytoplankton	0.6
ABLP0	Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A	50
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
LAMB1	Linear algal self shading coefficient, bed algae, 1/m	n/a
LAMB2	Non-linear self shading coefficient, bed algae, 1/m	n/a
MUMAX	Maximum specific growth rate, bed algae, 1/d	1.0
RESP	Local respiration rate of algae, bed algae, 1/d	0.60
MORT	Mortality, bed algae, 1/d	0.0
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.01
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.002
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m^{-2} s^{-1}	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.3
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.5
BET3	Rate constant: hydrolysis Org N to NH3-N, 1/d	0.3
BET4	Rate constant: transformation Org P to P-D, 1/d	0.3
KNINH	First order nitrification inhibition coefficient, mg^{-1}	n/a
ALP3	Rate O_2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.6
ALP4	Rate O_2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.6
ABLP3	Rate O_2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.6
ABLP4	Rate O_2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.6
ALP5	Rate O_2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O_2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
K1	Deoxygenation rate constant: BOD, 1/d	0.3
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	3.0
SIG6	BOD settling rate constant, 1/d	0.0

n/a – not applicable

3.7 Copco Reservoir

Copco Reservoir reach extends from the headwaters of Copco Reservoir to Copco Dam. Copco Reservoir was modeled using CE-QUAL-W2 and was calibrated at selected dates for 2000.

3.7.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

3.7.1.1 Boundary Conditions

The flow and temperature boundary conditions for the main inflow both passed from the Peaking reach and constituent concentrations were estimated from field data. The accretion / depletion flow for the Copco Reservoir reach is included in the river inflow, and therefore is assumed to have the same temperature and constituent concentrations as the main inflow.

3.7.1.2 Initial conditions

During the winter the Copco Reservoir Can have a residence time of less than 10 days. Thus initial conditions under this short residence time and isothermal conditions are presumed to wash out of the system in a few weeks.

3.7.2 Results

Calibration was completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled once per day. All model parameters for the Copco Reservoir reach are summarized in Table 54, at the end of this section.

3.7.2.1 Water Temperature

The water temperature was calibrated using the three user specified wind evaporation coefficients available in CE-QUAL-W2. Results are shown in Figure 104 and summary statistics are included in Table 52. Copco Reservoir experiences seasonal stratification, and the model replicates these conditions. The profile bias ranged from 0.44°C to –1.11°C and the mean absolute error ranged from 0.45°C to 1.15°C. Overall the model is within about 1.5°C of observations, except at the bottom of the reservoir where simulated data indicate the presence of a cold water pocket not shown in the observations.

Table 52. Copco Reservoir thermal profile summary statistics: simulated versus measured

Date	Mean Bias[a] (°C)	Mean Absolute Error (°C)	Root Mean Squared Error (°C)	n
April 12, 2000	0.32	1.06	1.20	18
May 9, 2000	0.44	0.47	0.66	18
June 6, 2000	0.23	0.46	0.52	18
July 11, 2000	0.10	0.52	0.65	18
August 8, 2000	-0.50	0.83	1.00	17
September 10, 2000	-0.08	0.46	0.62	9
September 27, 2000	-1.11	1.15	1.77	9
October 18, 2000	0.28	0.45	0.54	18

[a] Mean bias = simulated – measured

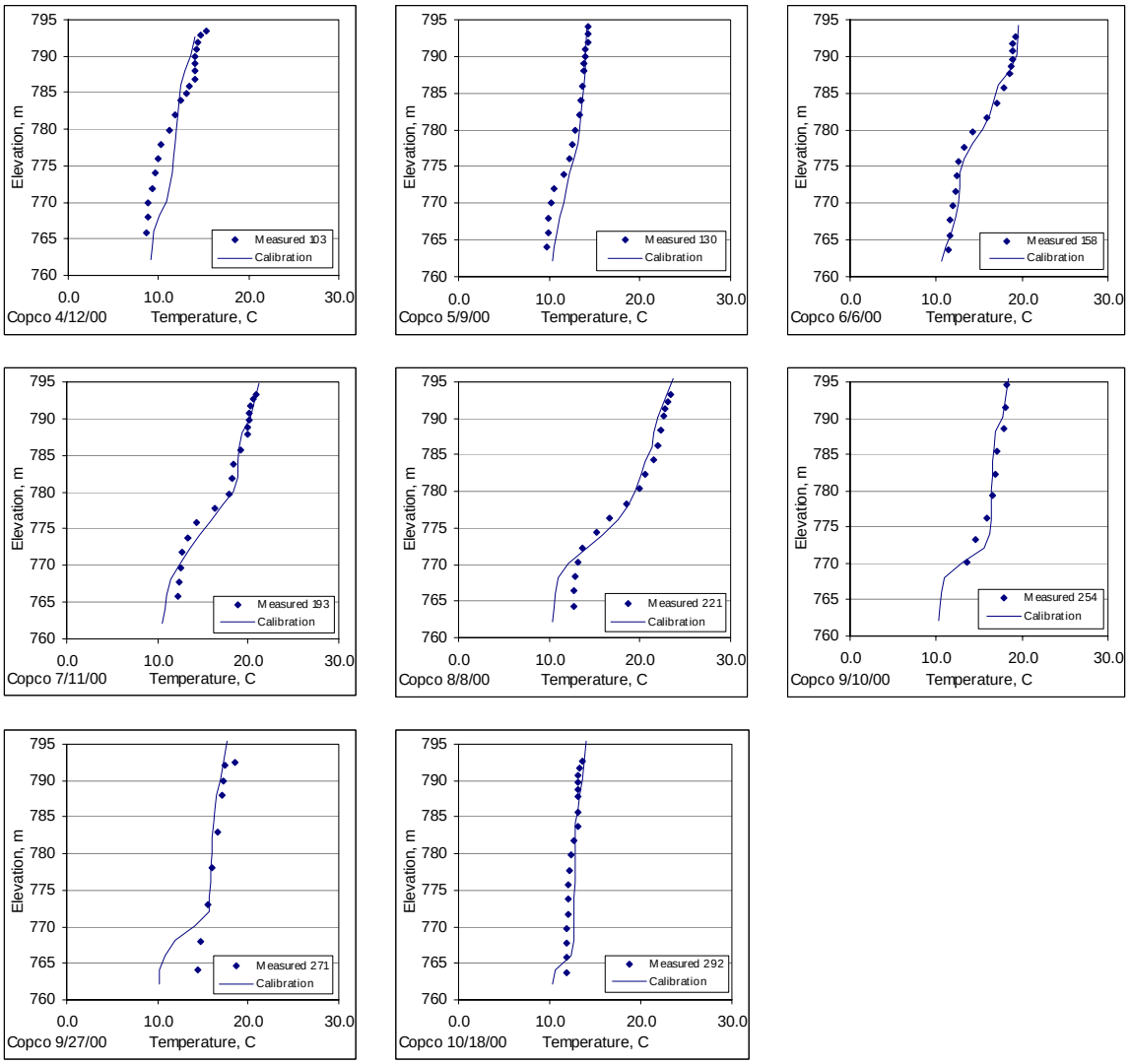


Figure 104. Copco Reservoir thermal profiles, simulated versus measured monthly values: 2000

3.7.2.2 Dissolved Oxygen

The dissolved oxygen was calibrated using several different parameters, including algal rates, organic matter decay rates and nutrient decay rates. Also, zero order SOD was employed in calibrating dissolved oxygen. Results are shown in Figure 105 and summary statistics are included in Table 53. The profile bias ranged from –3.00 mg/l to 5.73 mg/l while the mean absolute error ranged from 0.44 mg/l to 3.00 mg/l.

Conditions are generally well represented, with spring and fall conditions most variable. The October 18 simulated profile suggests that the lake had not attained isothermal condition, while observed data presented in Figure 104 identifies that the lake had turned over.

Table 53. Copco Reservoir dissolved oxygen profile summary statistics: simulated versus measured

Date	Mean Bias[a] (mg/l)	Mean Absolute Error (mg/l)	Root Mean Squared Error (mg/l)	n
April 12, 2000	0.09	0.53	0.64	18
May 9, 2000	1.39	1.40	2.10	18
June 6, 2000	-0.11	0.44	0.61	18
July 11, 2000	-0.61	0.78	1.13	18
August 8, 2000	-1.62	1.62	2.16	17
September 27, 2000	-1.87	1.87	2.29	9
October 18, 2000	-3.00	3.00	4.32	18

[a] Mean bias = simulated – measured

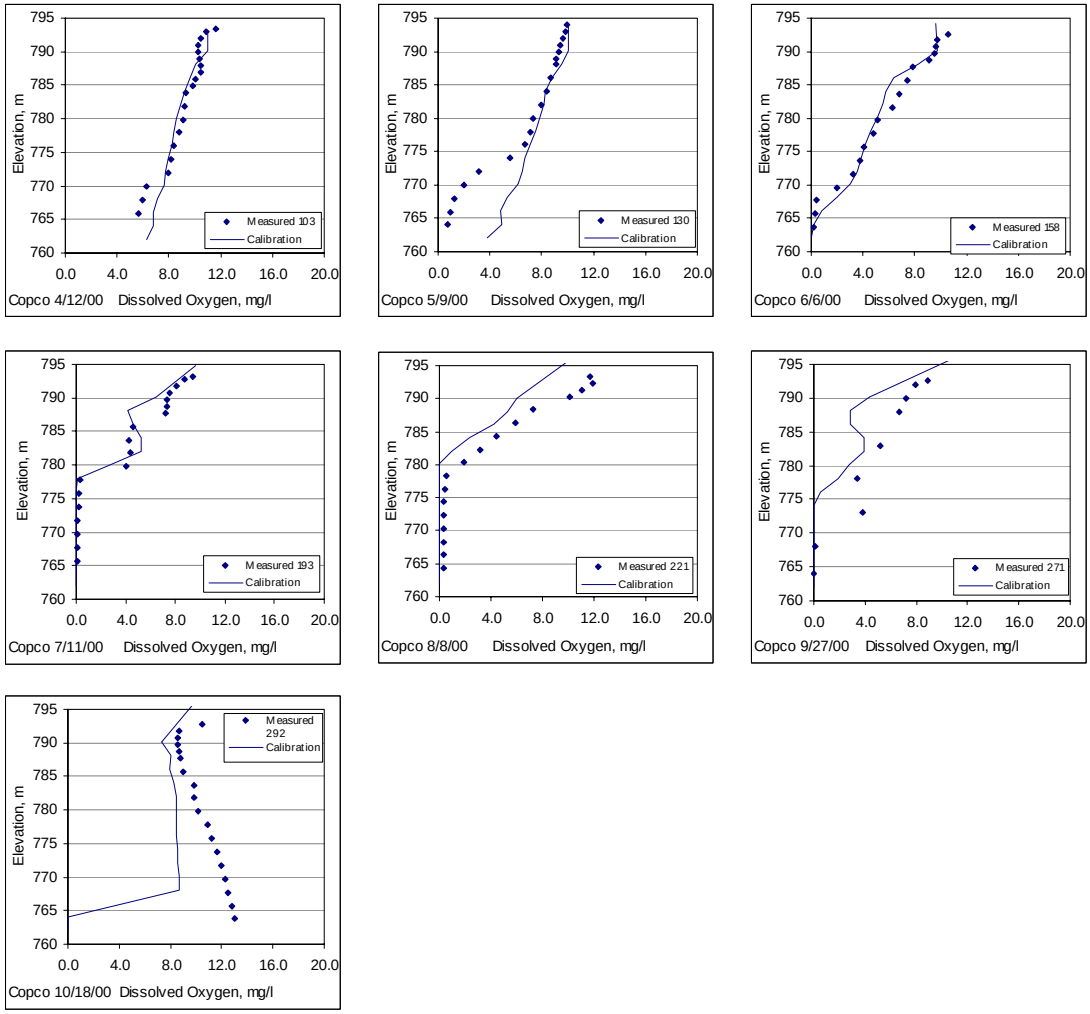


Figure 105. Copco Reservoir dissolved oxygen profiles, simulated versus measured monthly values: 2000

3.7.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Copco Reservoir reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the DO calibration were not modified, and other parameters were set at default values. Graphical results are presented in Figure 106 through Figure 109. Simulated coditions generally follow seasonal trends.

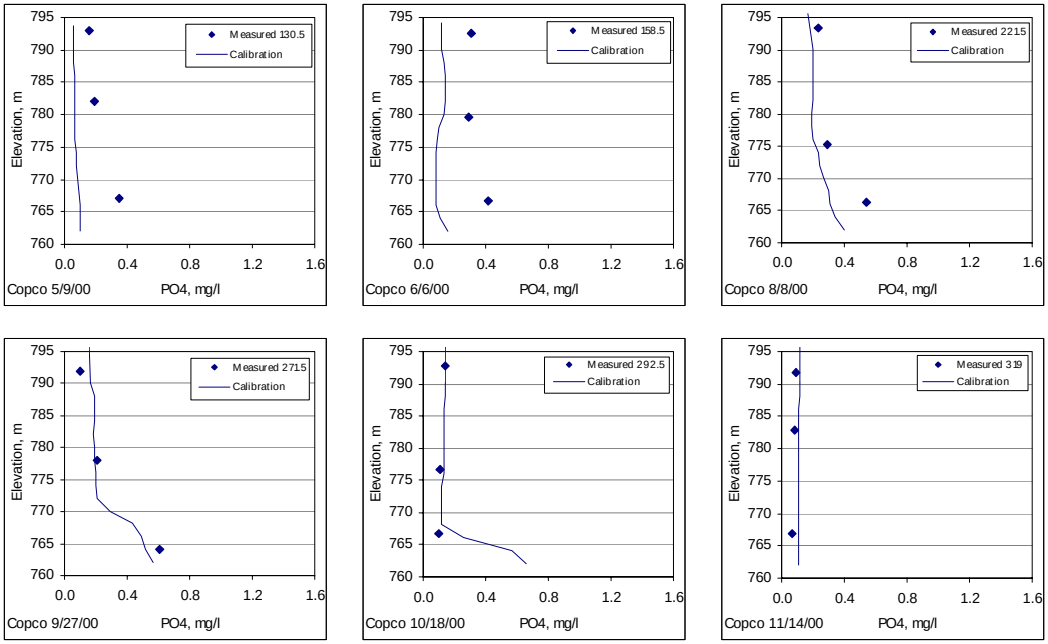


Figure 106. Copco Reservoir phosphate profiles, simulated versus measured monthly values: 2000

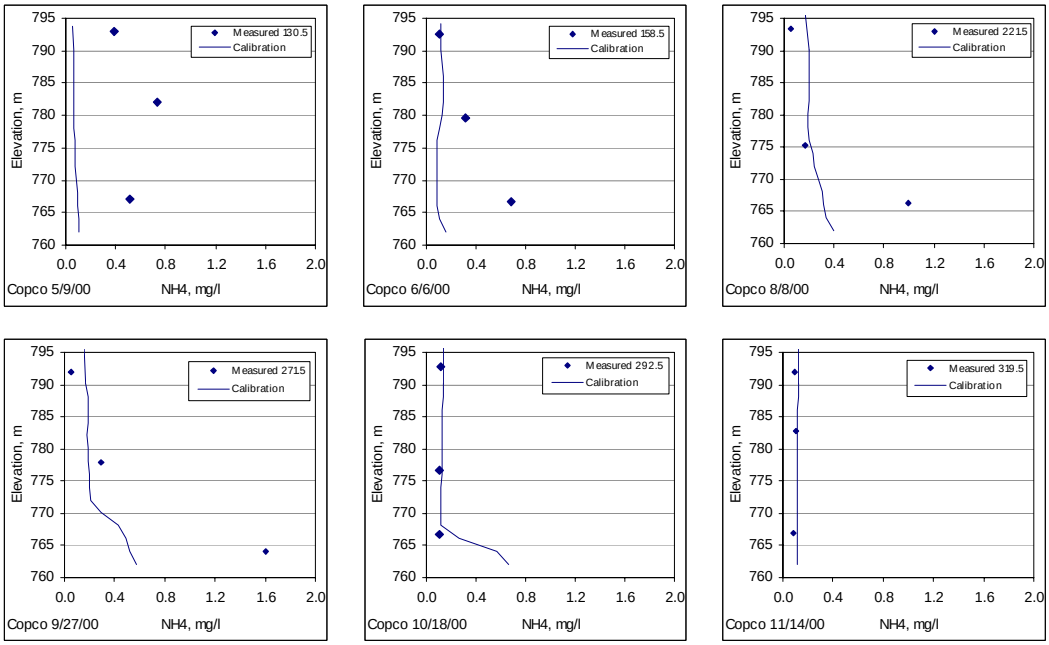


Figure 107. Copco Reservoir ammonia profiles, simulated versus measured monthly values: 2000

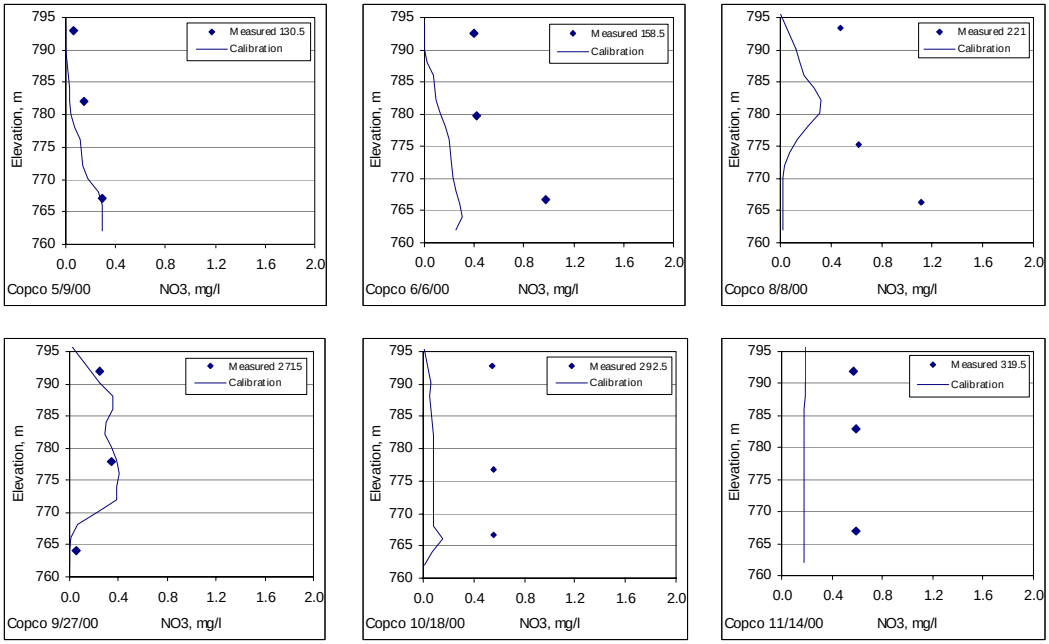


Figure 108. Copco Reservoir nitrate profiles, simulated versus measured monthly values: 2000

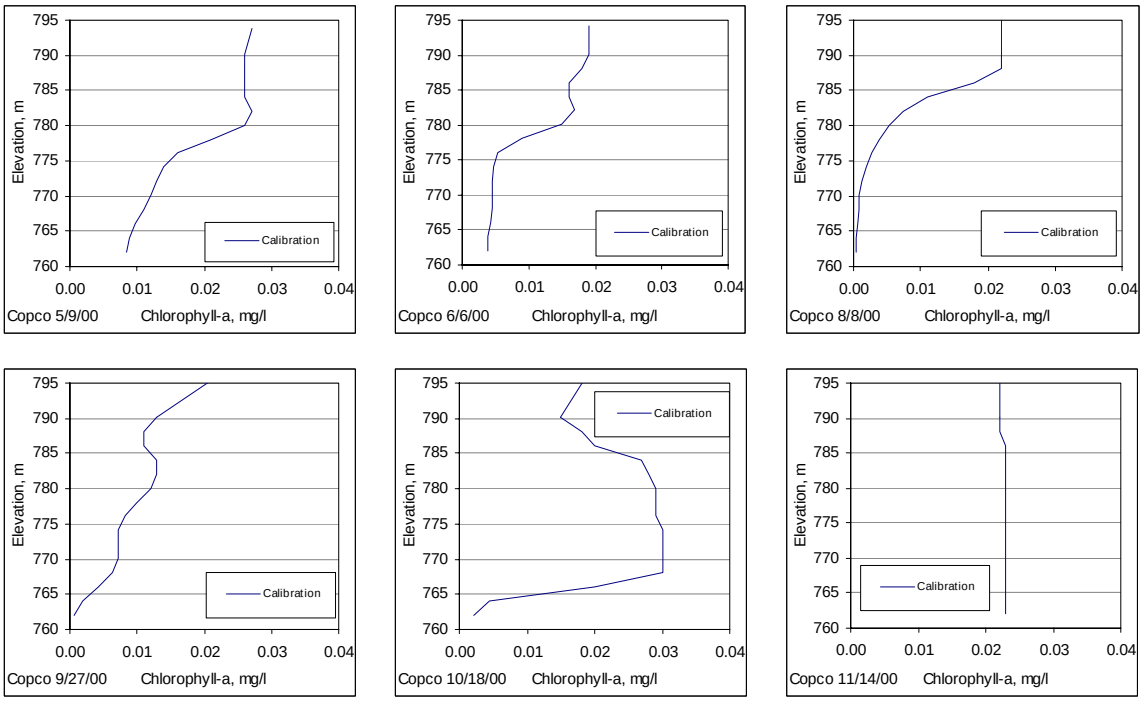


Figure 109. Copco Reservoir chlorophyll-a profiles, simulated concentrations only: 2000

3.7.2.4 Summary of Parameters

Table 54. Significant control file parameters for the Copco Reservoir reach calibration

Parameter Name	Description	EC Copco Value	Default Values
DLT MIN	Minimum timestep, sec	5.0	N/A
DLT MAX	Maximum timestep, sec	500	N/A
SLOPE	Waterbody bottom slope	0.0	N/A
LAT	Latitude, degrees	42.12	N/A
LONG	Longitude, degrees	122.33	N/A
EBOT	Bottom elevation of waterbody, m	761.09	N/A
CFW	C coefficient in the wind speed formulation	1.0	2.0
WINDH	Wind speed measurement height, m	2.0	N/A
CBHE	Coefficient of bottom heat exchange, W/m^2sec	3.0	7.0E-8
TSED	Sediment (ground) Temperature, C	10.0	N/A
FI	Interfacial friction factor	0.04	N/A
TSEDF	Heat lost to sediments that is added back to water column, fraction	0.01	N/A
EXH20	Extinction for pure water, m^{-1}	0.25	0.25 (Full WQ sim)
CGQ10 (Tracer)	Arhennius temperature rate multiplier	0	0
CG0DK (Tracer)	0-order decay rate, 1/day	0	0
CG1DK (Tracer)	1st-order decay rate, 1/day	0	0
CGS (Tracer)	Settling rate, m/day	0	0
CGQ10 (Age)	Arhennius temperature rate multiplier	0	0
CG0DK (Age)	0-order decay rate, 1/day	-1.0	-1.0
CG1DK (Age)	1st-order decay rate, 1/day	0	0
CGS (Age)	Settling rate, m/day	0	0
CGQ10 (Coliform)	Arhennius temperature rate multiplier	1.04	N/A
CG0DK (Coliform)	0-order decay rate, 1/day	0	N/A
CG1DK (Coliform)	1st-order decay rate, 1/day	1.4	N/A
CGS (Coliform)	Settling rate, m/day	1.0	N/A
AG	Maximum algal growth rate, 1/day	3.0	2.0
AT1	Lower temperature for algal growth, C	5.0	5.0
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03	0.001
PARTP	Phosphorus partitioning coefficient for suspended solids	0.001	0.0
NH4REL	Sediment release rate of ammonium, fraction of SOD	0.07	0.001
NH4DK	Ammonium decay rate, 1/day	0.1	0.12
NO3DK	Nitrate decay rate, 1/day	0.1	0.03
NO3S	De-nitrification rate from sediments, m/day	0.0	1.0
CO2REL	Sediment carbon dioxide release rate, fraction of sediment oxygen demand	0.01	0.1
O2AR	Oxygen stoichiometry for algal respiration	1.4	1.1
O2AG	Oxygen stoichiometry for algal primary production	1.5	1.4
SOD	Zero-order sediment oxygen demand for each segment, g O_2 / m^2 day	2.0 (for each segment)	N/A

3.8 Iron Gate Reservoir

Iron Gate Reservoir was modeled using CE-QUAL-W2. Calibration occurred at selected dates in 2000. Validation has not occurred. Iron Gate Reservoir reach extends from the headwaters of Iron Gate Reservoir to Iron Gate Dam.

3.8.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

3.8.1.1 Boundary Conditions

The boundary condition information for Iron Gate Reservoir is passed from the Copco Reservoir reach simulation. The accretion / depletion, located at Jenny Creek, has the same concentrations as presented in the model implementation section.

3.8.1.2 Initial conditions

The residence time for Iron Gate Reservoir is approximately 10 days in the winter. Thus initial conditions under this short residence time and isothermal conditions are presumed to wash out of the system in a few weeks.

3.8.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled once per day. All model parameters for the Iron Gate Reservoir reach are summarized in Table 57, at the end of this section.

3.8.2.1 Water Temperature

The water temperature was calibrated using the three user specified wind evaporation coefficients available in CE-QUAL-W2. Results are shown in Figure 110 and summary statistics are included in Table 55. Iron Gate Reservoir experiences seasonal stratification and the model replicates this stratification. The profile bias ranged from –1.06°C to 1.42°C and the mean absolute error ranged from 0.46°C to 1.42°C. Overall the model is within about 2°C of observations.

Table 55. Iron Gate Reservoir thermal profile summary statistics: simulated versus measured

Date	Mean Bias[a] (°C)	Mean Absolute Error (°C)	Root Mean Squared Error (°C)	n
April 12, 2000	0.24	1.16	1.28	26
May 9, 2000	1.06	1.06	1.22	24
June 6, 2000	1.42	1.42	1.70	23
July 11, 2000	0.26	0.46	0.50	23
August 8, 2000	0.53	0.75	0.91	23
September 10, 2000	0.34	0.93	1.21	12
September 27, 2000	-0.80	0.91	1.26	19
October 18, 2000	-1.06	1.06	1.31	22

[a] Mean bias = simulated – measured

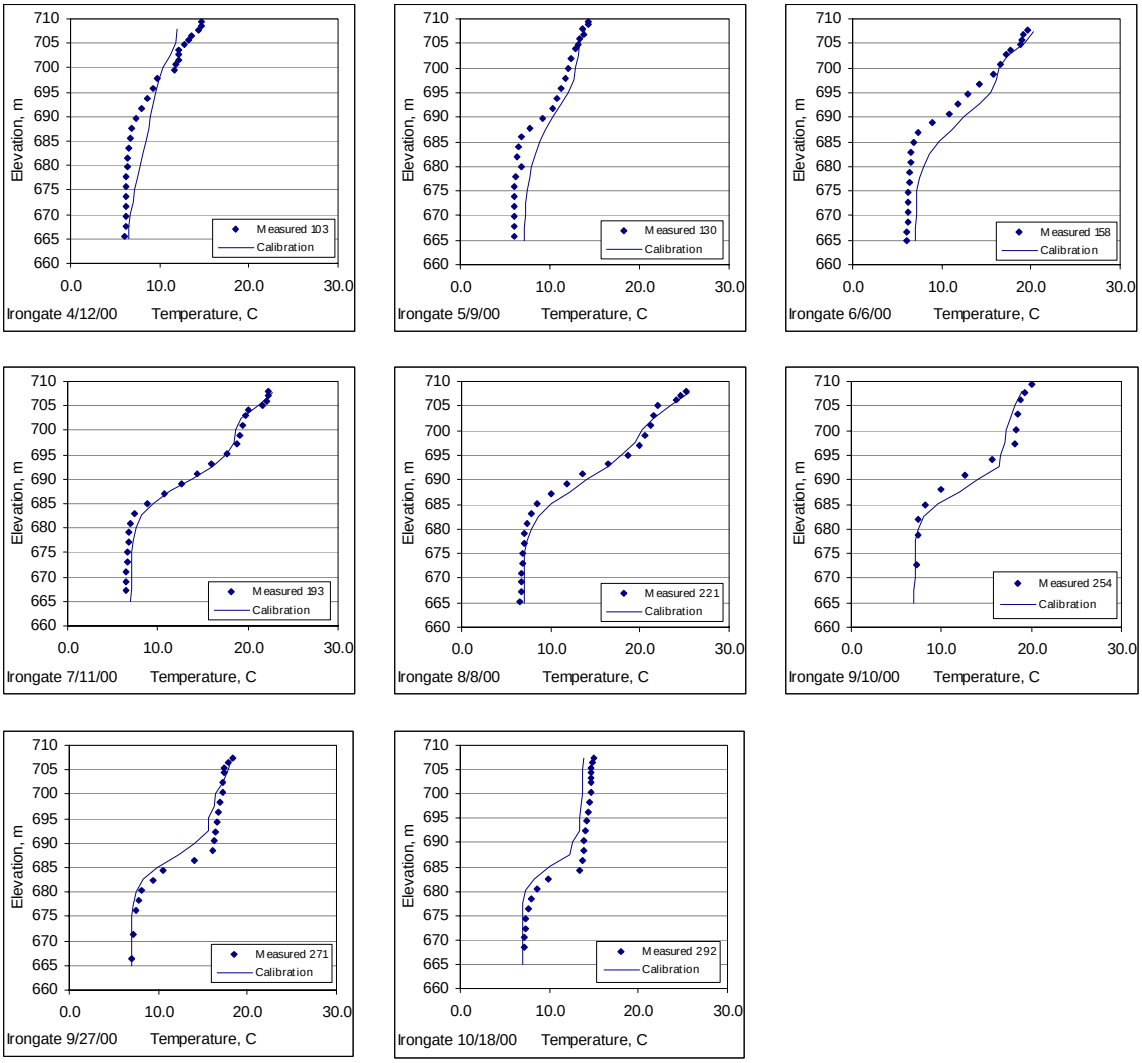


Figure 110. Iron Gate Reservoir thermal profiles, simulated versus measured monthly values: 2000

3.8.2.2 Dissolved Oxygen

The dissolved oxygen was calibrated using several different parameters, including algal rates, organic matter decay rates and nutrient decay rates. A zero order SOD representation was employed in calibrating dissolved oxygen. Results are shown in Figure 111 and summary statistics are included in Table 56. Iron Gate Reservoir dissolved oxygen concentrations experience significant seasonal deviations from saturated conditions. The seasonal anoxia in timing and extent is well represented in simulated results, with the exception of October when anoxia persists longer than the last observed data suggest. The profile bias ranged from –1.12 mg/l to 3.20 mg/l and the mean absolute error ranged from 0.94 mg/l to 3.20 mg/l. Overall the model is within about 5 mg/l of observations.

Table 56. Iron Gate Reservoir dissolved oxygen profile summary statistics: simulated versus measured

Date	Mean Bias[a] (mg/l)	Mean Absolute Error (mg/l)	Root Mean Squared Error (mg/l)	n
April 12, 2000	-1.12	1.51	1.74	26
May 9, 2000	0.54	0.94	1.07	24
June 6, 2000	0.17	0.94	1.09	23
July 11, 2000	0.02	1.00	1.26	23
August 8, 2000	0.25	1.77	2.38	23
September 10, 2000	3.20	3.20	4.61	12
September 27, 2000	1.00	1.40	2.15	19
October 18, 2000	0.66	2.53	2.81	22

[a] Mean bias = simulated – measured

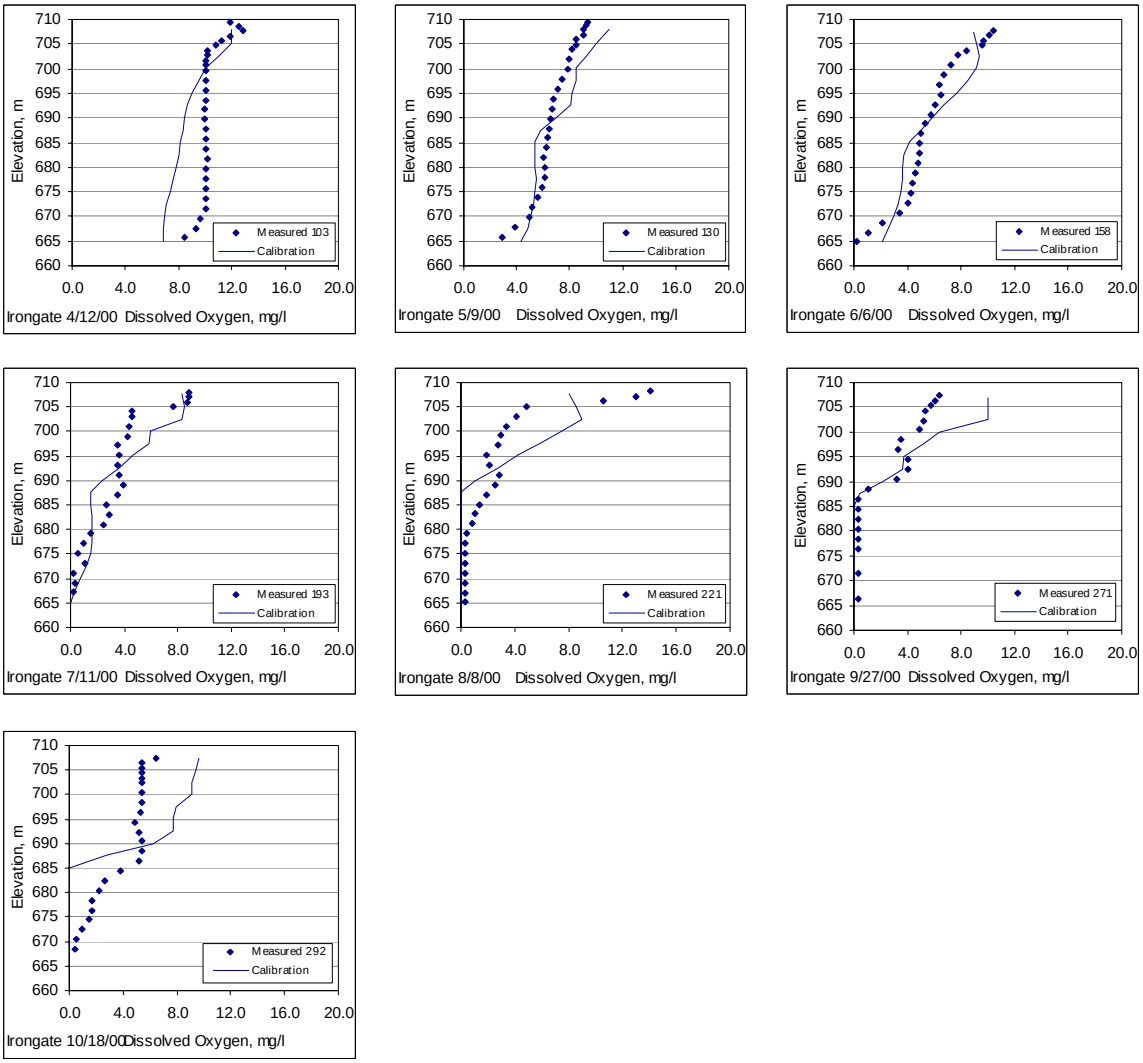


Figure 111. Iron Gate Reservoir dissolved oxygen profiles, simulated versus measured monthly values: 2000

3.8.2.3 Nutrients

Nutrient concentrations were not actively calibrated in the Iron Gate Reservoir reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the DO calibration were not modified, and other parameters were set at default values.

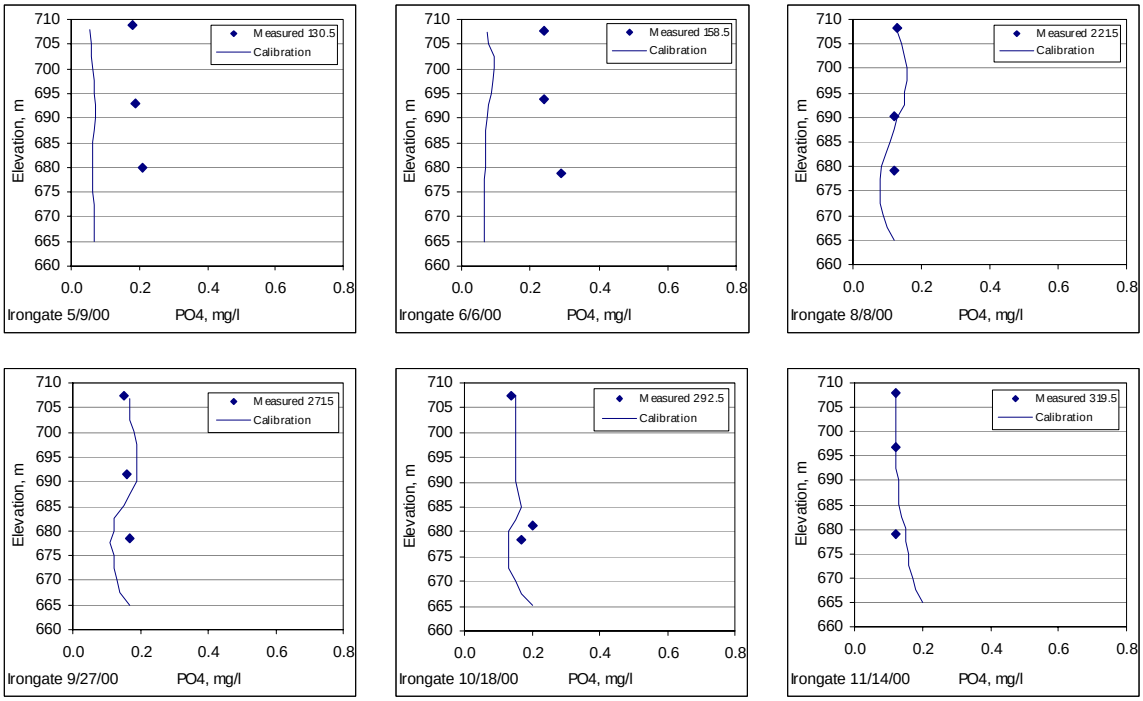


Figure 112. Iron Gate Reservoir phosphate profiles, simulated versus measured monthly values: 2000

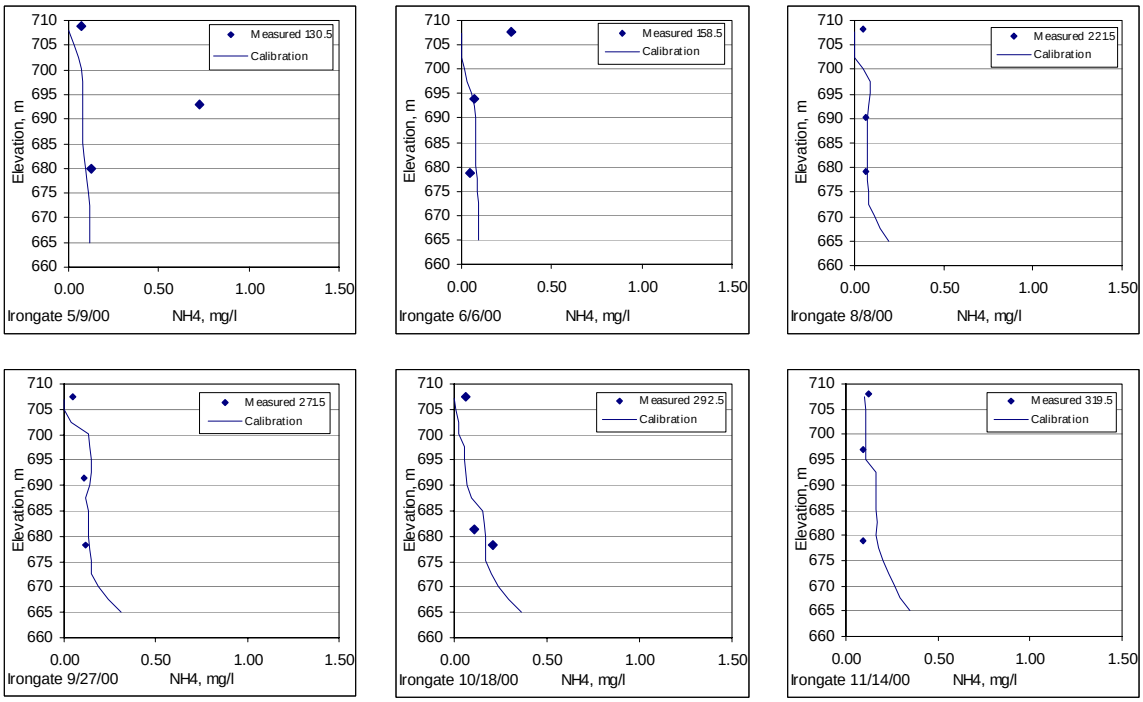


Figure 113. Iron Gate Reservoir ammonia profiles, simulated versus measured monthly values: 2000

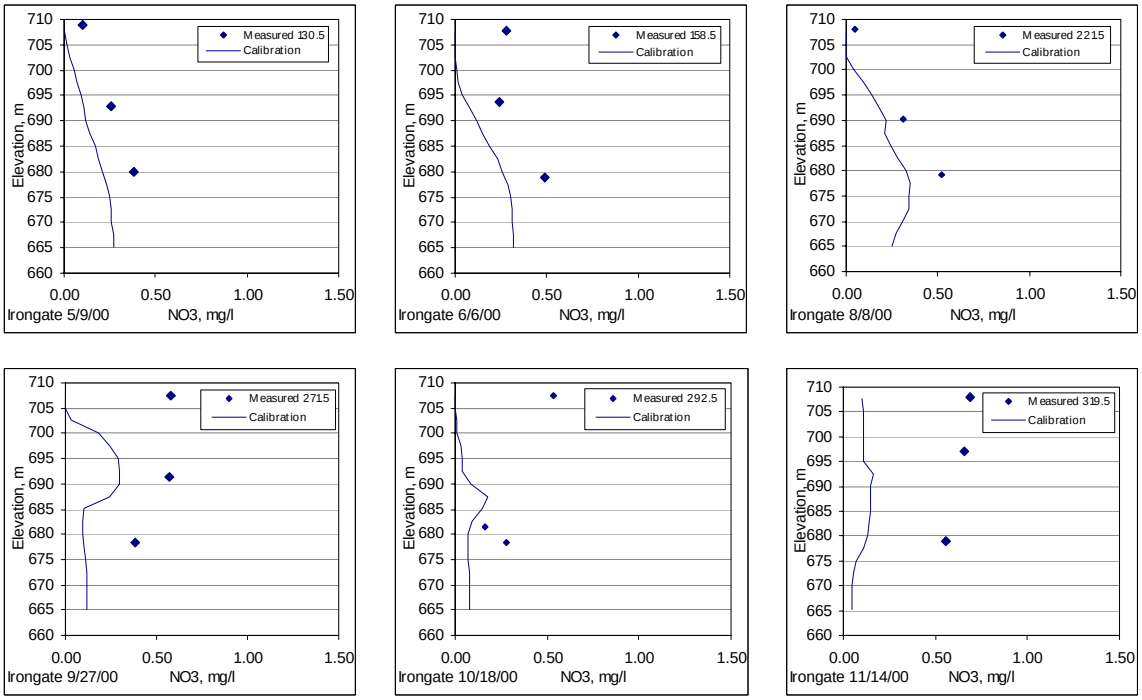


Figure 114. Iron Gate Reservoir nitrate profiles, simulated versus measured monthly values: 2000

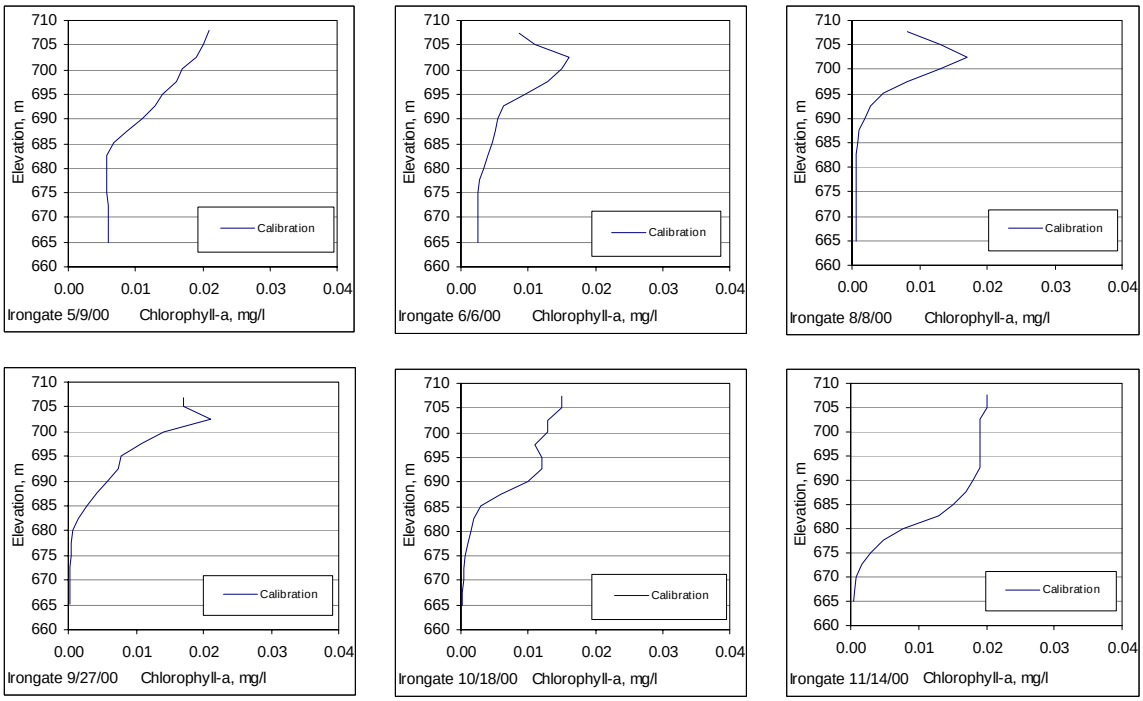


Figure 115. Iron Gate Reservoir chlorophyll-a profiles, simulated concentrations only: 2000

3.8.2.4 Summary of Parameters

Table 57. Significant control file parameters in the Iron Gate Reservoir calibration

Parameter Name	Description	EC Iron Gate Value	Default Value
DLT MIN	Minimum timestep, sec	5.0	N/A
DLT MAX	Maximum timestep, sec	500	N/A
SLOPE	Waterbody bottom slope	0.0	N/A
LAT	Latitude, degrees	42.97	N/A
LONG	Longitude, degrees	122.42	N/A
EBOT	Bottom elevation of waterbody, m	663.78	N/A
AFW	A coefficient in the wind speed formulation	6.0	
CFW	C coefficient in the wind speed formulation	1.0	2.0
WINDH	Wind speed measurement height, m	2.0	N/A
CBHE	Coefficient of bottom heat exchange, W/m^2sec	17.14	7.0-8
TSED	Sediment (ground) Temperature, C	7.0	N/A
FI	Interfacial friction factor	0.04	N/A
TSEDF	Heat lost to sediments that is added back to water column, fraction	0.01	N/A
EXH20	Extinction for pure water, m^{-1}	0.25	0.25 (for Full WQ sim)
CGQ10 (CG1)	Arhennius temperature rate multiplier	0	0
CG0DK (CG1)	0-order decay rate, 1/day	0	0
CG1DK (CG1)	1st-order decay rate, 1/day	0	0
CGS (CG1)	Settling rate, m/day	0	0
CGQ10 (CG2)	Arhennius temperature rate multiplier	0	0
CG0DK (CG2)	0-order decay rate, 1/day	-1.0	-1.0
CG1DK (CG2)	1st-order decay rate, 1/day	0	0
CGS (CG2)	Settling rate, m/day	0	0
CGQ10 (CG3)	Arhennius temperature rate multiplier	1.04	N/A
CG0DK (CG3)	0-order decay rate, 1/day	0	N/A
CG1DK (CG3)	1st-order decay rate, 1/day	1.4	N/A
CGS (CG3)	Settling rate, m/day	1.0	N/A
AG	Maximum algal growth rate, 1/day	3.0	2.0
AT1	Lower temperature for algal growth, C	5.0	5.0
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03	0.001
PARTP	Phosphorus partitioning coefficient for suspended solids	0.001	0.0
NH4REL	Sediment release rate of ammonium, fraction of SOD	0.07	0.001
NH4DK	Ammonium decay rate, 1/day	0.1	0.12
NO3DK	Nitrate decay rate, 1/day	0.1	0.03
NO3S	De-nitrification rate from sediments, m/day	0.0	1.0
CO2REL	Sediment carbon dioxide release rate, fraction of sediment oxygen demand	0.01	0.1
O2AR	Oxygen stoichiometry for algal respiration	1.4	1.1
O2AG	Oxygen stoichiometry for algal primary production	1.5	1.4
SOD	Zero-order sediment oxygen demand for each segment, g O_2 / m^2 day	3.0 (for each segment)	N/A

3.9 Iron Gate Dam to Turwar

The RMA suite of models for the Klamath River from Iron Gate Dam (RM 190) to Seiad Valley (RM 129) was initially calibrated for June 5-7, 2000 (Julian Day 157-159) and August 7-9, 2000 (JD 220-222), respectively. To calibrate the lower river and further test the model, field data was collected from 12 locations between Iron Gate Dam and Turwar, including major tributaries, in 2003. Field data was collected June 9-12, 2003 (JD 160-164) and August 18-21, 2003 (JD 230-234). The 2003 period was used as the final calibration data set; however, 2000 results are included to illustrate model performance over a wider range of conditions. The 2000 data are presented in less detail following the 2003 results.

3.9.1 Data: 2003

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and observations in the Klamath River at several points were required (calibration / validation points).

3.9.1.1 Boundary Conditions: 2003

Boundary conditions were required for all inflows into the reach, including the main inflow from Iron Gate Dam and twenty of the twenty-three tributaries modeled in the reach (three tributaries were not assigned temperature, dissolved oxygen or constituent concentrations due to their relatively small size, especially in summer: Willow, Cottonwood, and Humbug Creeks). Flow, temperature, dissolved oxygen and other water quality conditions for the 2003 period are presented below.

Flow

The Iron Gate Dam to Turwar reach includes 23 inflows in addition to the headwater boundary condition at Iron Gate Dam. Measured gage flow at Klamath River below Iron Gate Dam (USGS gage 11516530) during the 2003 recalibration periods was used to designate flow from Iron Gate Dam (presented in Figure 116).

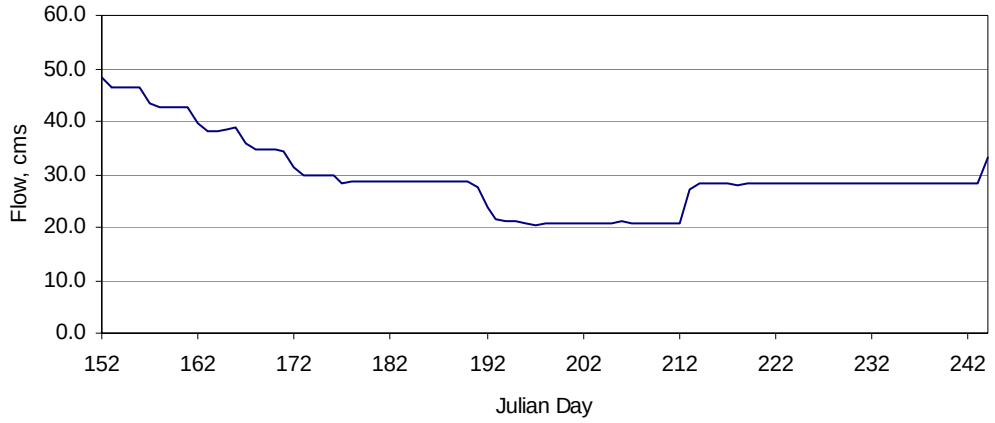


Figure 116. Gauged flow at Klamath River below Iron Gate Dam for Iron Gate to Turwar reach model 2003 calibration

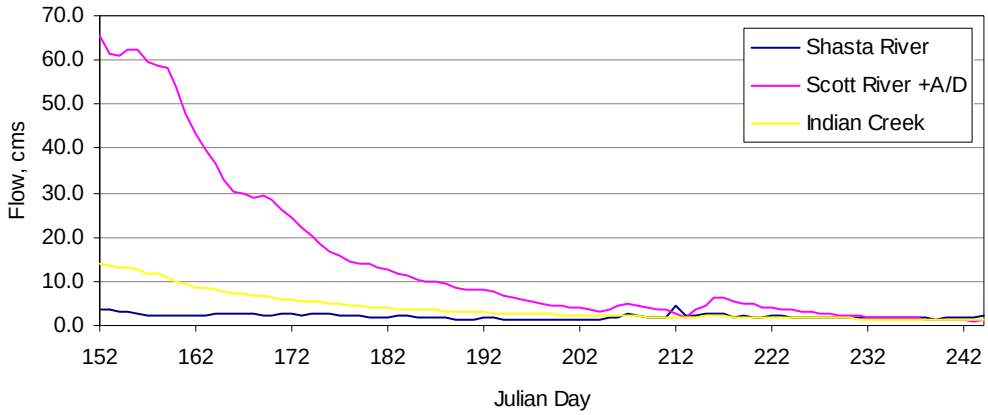
There are 23 tributary flows in the IG-Turwar reach. Tributary contributions were assigned daily data based on USGS gages or daily average calculated flows based on

accretion calculations. Table 17 summarizes the locations, model node and element information, and type of record employed.

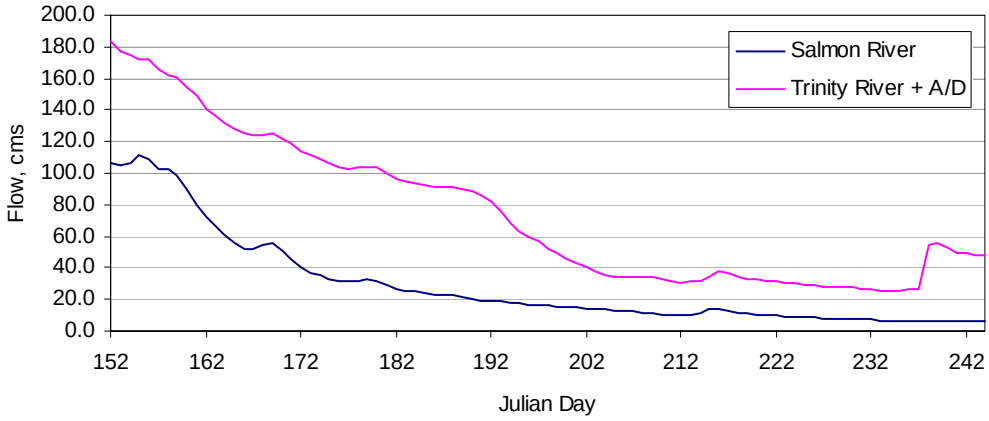
Table 58. Element flow information for the IG-Turwar EC simulation

Location	Node	Element	Flow Type
Bogus Creek	7	4	Daily average
Willow Creek	55	28	Daily average
Cottonwood Creek	86	43	Daily average
Shasta River	144	72	Daily measured
Humbug Creek	204	102	Daily average
Beaver Creek	319	160	Daily average
Horse Creek	468	234	Daily average
Scott River (+ A/D)	513	257	Daily calculated
Grider Creek	656	328	Daily average
Thompson Creek	735	368	Daily average
Indian Creek	906	453	Daily measured
Elk Creek	925	463	Daily average
Clear Creek	1000	500	Daily average
Ukonom Creek	1098	549	Daily average
Dillon Creek	1162	581	Daily average
Salmon River	1357	679	Daily measured
Camp Creek	1466	733	Daily average
Red Cap Creek	1511	756	Daily average
Bluff Creek	1547	774	Daily average
Trinity River (+ A/D)	1609	805	Daily calculated
Pine Creek	1644	822	Daily average
Tectah Creek	1850	925	Daily average
Blue Creek	1908	954	Daily average

The Shasta River daily flows were from USGS gage 11517500. The Scott + A/D daily flows were calculated from USGS gage 11519500 (Scott River daily flows) and A/D described below. The daily Indian Creek flows were from USGS gage 11521500. The Salmon River daily flows were from USGS gage 11522500. The Trinity + A/D daily flows were calculated from USGS gage 11530000 (Trinity River daily flows) and the A/D described below. For input into the water quality input file for RMA-11, the daily average flows were disaggregated to hourly flows using linear interpolation. Daily A/D flows were calculated as those for implementation of the reach, but were not averaged over 7 days. Weekly A/D flows were also calculated for use in the water quality input file for RMA-11. The daily inflows for the gauged tributaries are presented in Figure 117. The daily inflows for the minor tributaries are presented in Figure 118. The weekly inflows for the minor tributaries are presented in Table 59.

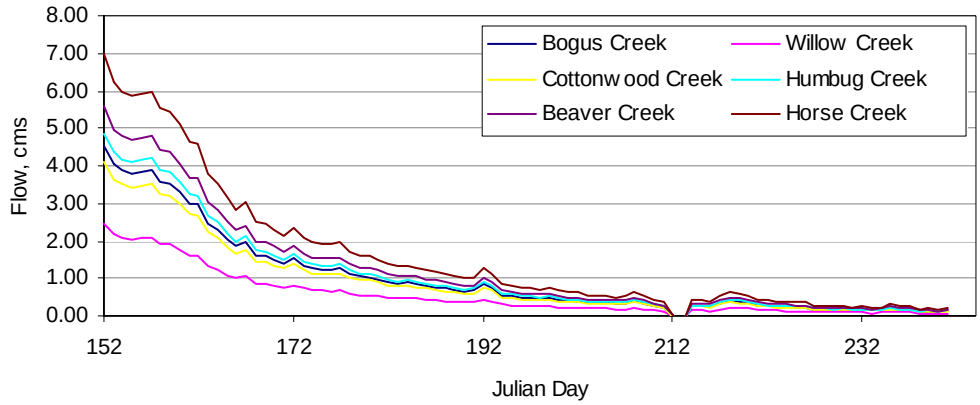


(a)

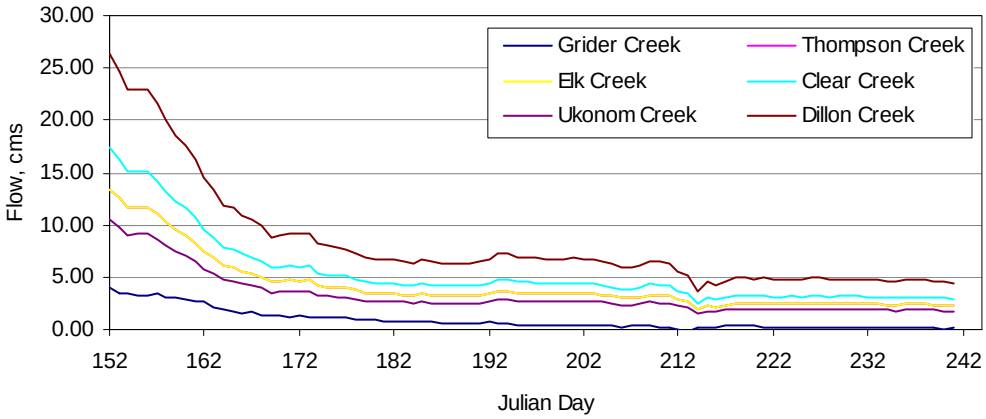


(b)

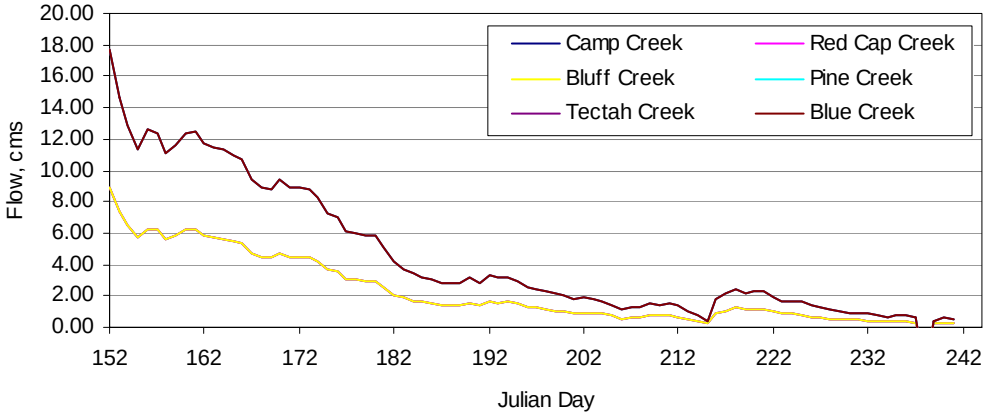
Figure 117. Gauged tributary inflows for Iron Gate to Turwar reach model 2003 calibration: (a) Shasta River, Scott River and Indian Creek; (b) Salmon River and Trinity River



(a)



(b)



(c)

Figure 118. Minor tributary inflows for Iron Gate to Turwar 2003 calibration: (a) above Scott River; (b) between the Scott and the Salmon Rivers; (c) between the Salmon River and the mouth of the Klamath River.

Table 59. Weekly average minor tributary inflows for Iron Gate to Turwar reach model, for use in the water quality input files for RMA-11

	Flow, cms												
Julian Day	**152**	**158**	**165**	**172**	**179**	**186**	**193**	**200**	**207**	**214**	**221**	**228**	**235**
Bogus Creek	3.94	3.94	2.80	1.64	1.22	0.90	0.73	0.49	0.36	0.19	0.32	0.23	0.17
Beaver Creek	4.85	4.85	3.45	2.02	1.50	1.11	0.90	0.60	0.45	0.24	0.40	0.28	0.21
Horse Creek	6.07	6.07	4.32	2.52	1.88	1.39	1.12	0.75	0.56	0.30	0.50	0.35	0.26
Grider Creek	3.42	3.42	2.43	1.42	1.06	0.78	0.63	0.42	0.31	0.17	0.28	0.20	0.14
Thompson Creek	11.77	11.77	7.57	4.94	4.02	3.37	3.34	3.49	3.27	2.91	2.41	2.44	2.42
Indian Creek	12.78	12.78	9.03	6.62	5.06	3.84	3.16	2.67	2.22	1.93	2.05	1.76	1.55
Elk Creek	11.77	11.77	7.57	4.94	4.02	3.37	3.34	3.49	3.27	2.91	2.41	2.44	2.42
Clear Creek	15.18	15.18	9.76	6.37	5.18	4.34	4.31	4.50	4.21	3.75	3.10	3.15	3.12
Ukonom Creek	9.15	9.15	5.89	3.84	3.12	2.62	2.60	2.71	2.54	2.26	1.87	1.90	1.88
Dillon Creek	23.05	23.05	14.83	9.67	7.86	6.59	6.54	6.83	6.40	5.69	4.71	4.79	4.74
Camp Creek	6.63	6.63	5.86	4.67	3.54	2.05	1.49	1.27	0.79	0.63	0.97	0.76	0.41
Red Cap Creek	6.63	6.63	5.86	4.67	3.54	2.05	1.49	1.27	0.79	0.63	0.97	0.76	0.41
Bluff Creek	6.63	6.63	5.86	4.67	3.54	2.05	1.49	1.27	0.79	0.63	0.97	0.76	0.41
Pine Creek	13.22	13.22	11.67	9.30	7.06	4.09	2.97	2.53	1.57	1.26	1.94	1.51	0.83
Tectah Creek	13.22	13.22	11.67	9.30	7.06	4.09	2.97	2.53	1.57	1.26	1.94	1.51	0.83
Blue Creek	13.22	13.22	11.67	9.30	7.06	4.09	2.97	2.53	1.57	1.26	1.94	1.51	0.83

The downstream boundary for the Iron Gate to Turwar reach was not altered from the downstream boundary used in implementation of the reach.

Temperature

Inflow temperatures for the upstream boundary condition were the hourly and half-hourly temperatures recorded by sondes deployed below Iron Gate Dam in June and August (shown in Figure 119 and Figure 120). The first full day of data is repeated for the four days previous to deployment to provide main inflow temperatures for the “warm up” period of the model. The source of records and final model inputs for major and minor tributaries are outlined below.

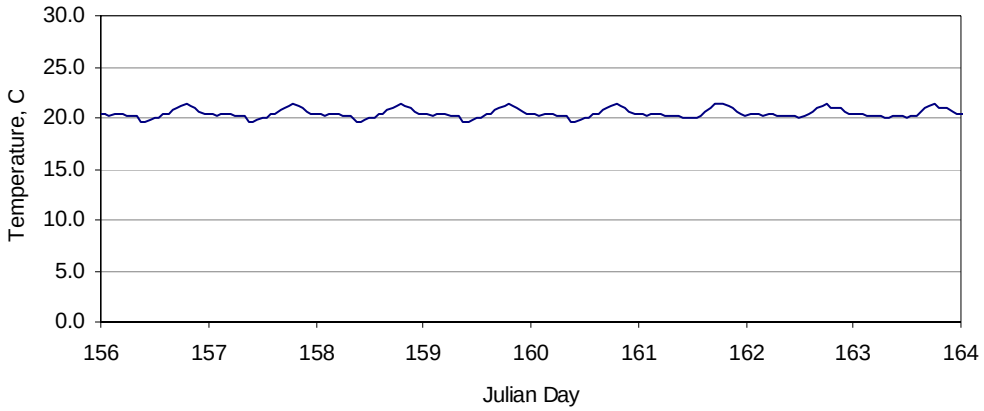


Figure 119. Main inflow temperatures for Iron Gate to Turwar reach model (June 2003)

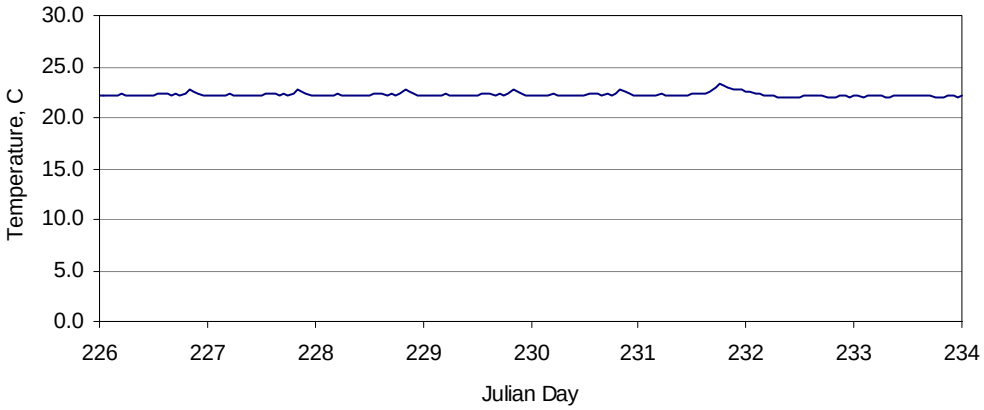


Figure 120. Main inflow temperatures for Iron Gate to Turwar reach model (August 2003)

Major Tributaries

Sonde data collected in June and August in the Shasta River, Scott River, Salmon River and Trinity River provided hourly temperatures for recalibration of the Iron Gate Dam to Turwar reach (presented in Figure 121 through Figure 122). To provide data for the four days of model simulation that occur prior to the deployment of the sondes, the first day temperatures are repeated until the time of deployment for all major tributaries. The Scott River had some missing data due to deployment difficulties in June. The following day's temperatures were used to fill in the missing temperatures. The simulation periods last until midnight of the last day of deployment, although many of the sondes were not deployed at that point in time. If there was missing data, the temperatures were filled in with the last recorded temperature for the particular hour of the day until midnight was reached.

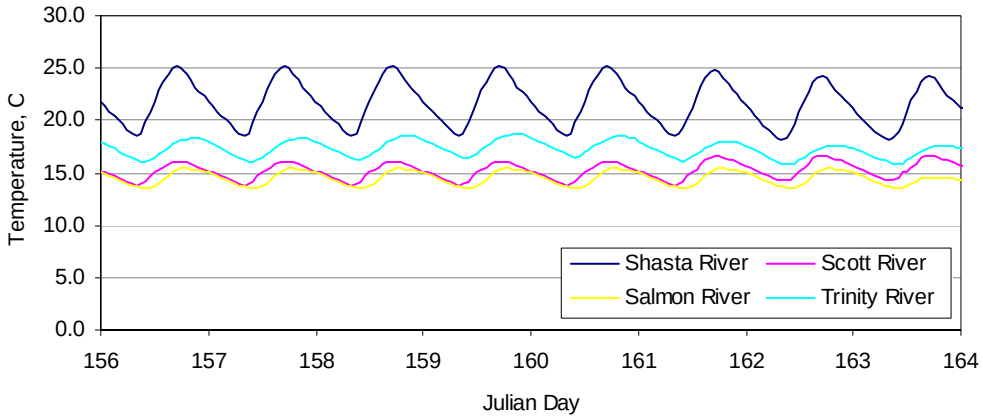


Figure 121. Major tributary inflow temperatures for Iron Gate to Turwar reach model 2003 calibration (June 2003)

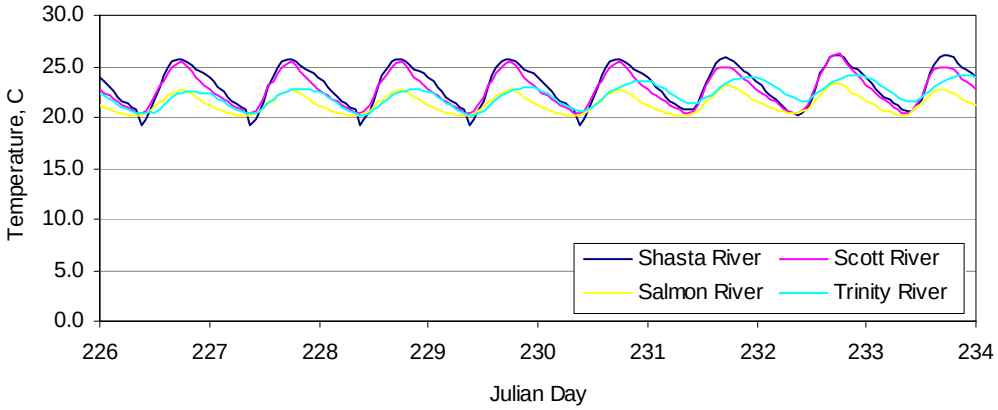


Figure 122. Major tributary inflow temperatures for Iron Gate to Turwar reach model 2003 calibration (August 2003)

Minor Tributaries

The minor tributary temperatures used for the 2003 calibration of the Iron Gate to Turwar reach were those used for the 2000 calibration and are presented in the main model documentation. The monthly average temperatures used in the previous calibration were disaggregated to weekly averages using linear interpolation for use in the 2003 calibration. The weekly average temperatures are presented in Table 60.

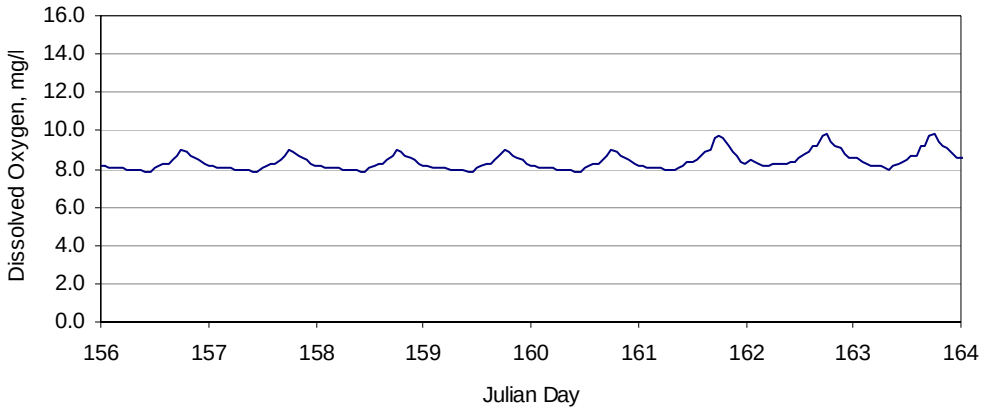
Table 60. Minor tributary inflow temperatures for Iron Gate to Turwar reach 2003 model calibration

	Temperature, °C												
Julian Day	**152**	**158**	**165**	**172**	**179**	**186**	**193**	**200**	**207**	**214**	**221**	**228**	**235**
Bogus Creek	12.60	12.66	12.74	12.98	13.28	13.58	13.89	14.10	14.20	14.30	14.40	14.50	14.03
Beaver Creek	9.96	10.44	11.00	11.64	12.31	12.98	13.65	14.18	14.52	14.86	15.21	15.55	15.27
Horse Creek	9.92	10.39	10.93	11.43	11.91	12.38	12.86	13.22	13.44	13.65	13.87	14.08	13.98
Grider Creek	9.92	10.39	10.93	11.96	13.18	14.40	15.61	16.36	16.47	16.59	16.70	16.82	16.17
Thompson Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56
Indian Creek	10.22	10.78	11.42	12.49	13.72	14.95	16.18	17.03	17.37	17.72	18.06	18.41	17.80
Elk Creek	9.92	10.39	10.93	12.18	13.70	15.23	16.75	17.67	17.79	17.91	18.03	18.15	17.43
Clear Creek	10.41	11.03	11.75	12.60	13.49	14.38	15.27	15.93	16.27	16.61	16.95	17.29	16.79
Ukonom Creek	9.48	9.97	10.55	11.10	11.65	12.19	12.74	13.14	13.34	13.54	13.75	13.95	13.59
Dillon Creek	14.02	14.61	15.29	16.28	17.38	18.48	19.58	20.05	19.68	19.32	18.95	18.58	18.21
Camp Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56
Red Cap Creek	14.02	14.61	15.29	16.29	17.41	18.54	19.66	20.21	20.00	19.79	19.58	19.37	18.75
Bluff Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56
Pine Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56
Tectah Creek	11.31	11.79	12.35	12.71	13.00	13.28	13.57	13.77	13.85	13.93	14.02	14.10	14.19
Blue Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56

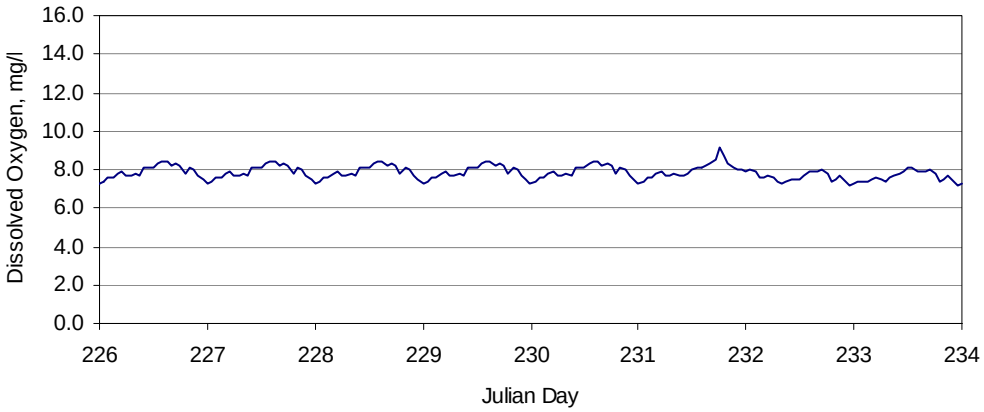
Constituent Concentrations

Constituent concentrations for the tributary inflows between Iron Gate Dam and the Pacific Ocean were assigned for all streams identified in Table 17 with the exception of Willow, Cottonwood, and Humbug Creeks. There was no data available for these tributaries and they contribute only minor flow in the summer months.

Dissolved oxygen concentrations were recorded by sonde below Iron Gate Dam. The first four days of model data are the first day of recorded data repeated to provide dissolved oxygen concentrations for the main inflow during the “warm up” period of the model. The model input dissolved oxygen concentrations are presented in Figure 123.



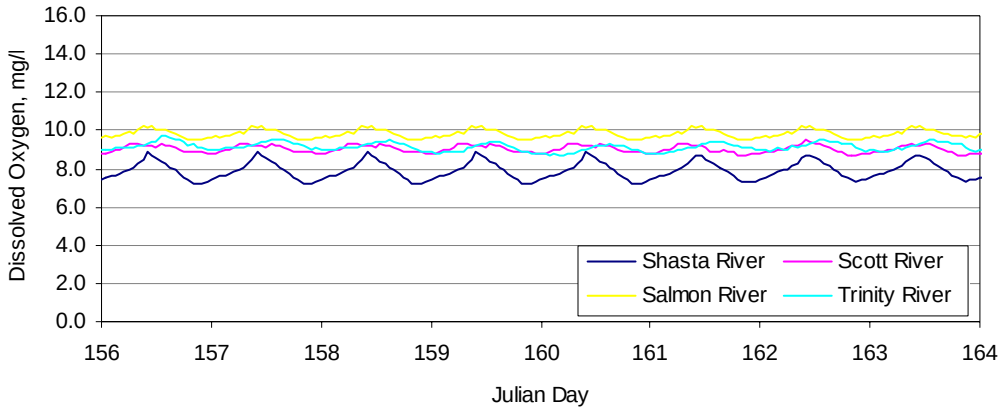
(a)



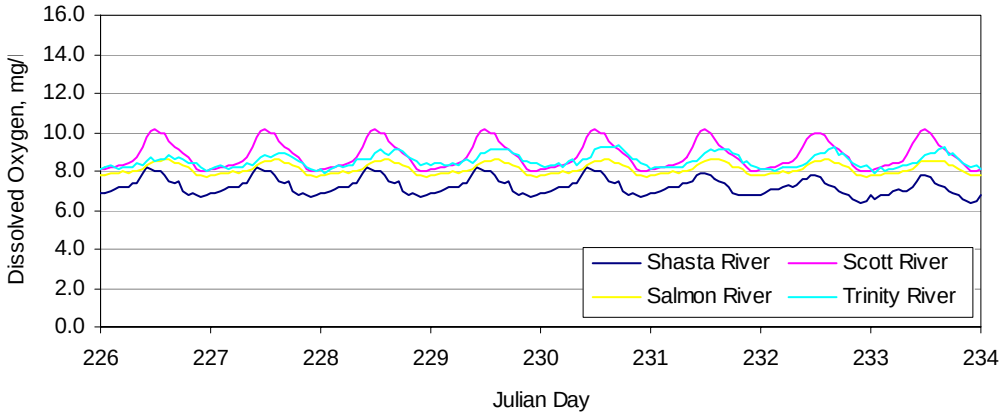
(b)

Figure 123. Klamath River below Iron Gate Dam dissolved oxygen concentrations for: (a) June 2003; (b) August 2003

Dissolved oxygen concentrations for the 2003 were those recorded by sondes for the major tributaries on the hourly (Shasta, Scott, Salmon, and Trinity Rivers) or those calculated in model implementation for the minor tributaries (all remaining tributaries). The dissolved oxygen concentrations recorded by sonde were adjusted for biofouling when appropriate (as discussed in Technical Memorandum 6). The calculated monthly average dissolved oxygen concentrations were disaggregated to weekly averages by linear interpolation. Hourly dissolved oxygen concentrations are presented in Figure 124. Weekly average dissolved oxygen concentrations are presented in Table 61.



(a)



(b)

Figure 124. Major tributary dissolved oxygen concentrations for Iron Gate to Turwar reach model calibration: (a) June 2003; (b) August 2003

Table 61. Minor tributary inflow dissolved oxygen concentrations for Iron Gate to Turwar reach model

	Dissolved Oxygen, mg/l												
Julian Day	**152**	**158**	**165**	**172**	**179**	**186**	**193**	**200**	**207**	**214**	**221**	**228**	**235**
Bogus Creek	10.02	10.01	9.99	9.94	9.87	9.81	9.74	9.69	9.67	9.65	9.63	9.61	9.71
Beaver Creek	10.66	10.54	10.40	10.25	10.10	9.95	9.80	9.68	9.61	9.53	9.46	9.39	9.45
Horse Creek	10.68	10.56	10.42	10.30	10.19	10.08	9.97	9.89	9.84	9.79	9.75	9.70	9.72
Grider Creek	10.68	10.56	10.42	10.19	9.92	9.66	9.39	9.23	9.21	9.19	9.16	9.14	9.27
Thompson Creek	10.39	10.24	10.08	9.99	9.92	9.86	9.80	9.73	9.67	9.60	9.54	9.47	9.52
Indian Creek	10.97	10.82	10.66	10.42	10.15	9.88	9.60	9.42	9.35	9.29	9.22	9.15	9.27
Elk Creek	11.04	10.92	10.78	10.50	10.16	9.83	9.49	9.29	9.27	9.25	9.22	9.20	9.35
Clear Creek	10.92	10.76	10.57	10.38	10.18	9.98	9.78	9.64	9.57	9.51	9.44	9.37	9.47
Ukonom Creek	11.16	11.03	10.87	10.74	10.61	10.48	10.34	10.25	10.20	10.15	10.11	10.06	10.14
Dillon Creek	10.05	9.92	9.77	9.58	9.37	9.16	8.95	8.86	8.92	8.99	9.05	9.12	9.19
Camp Creek	10.39	10.24	10.08	9.99	9.92	9.86	9.80	9.73	9.67	9.60	9.54	9.47	9.52
Red Cap Creek	10.05	9.92	9.77	9.58	9.36	9.15	8.93	8.83	8.86	8.90	8.94	8.98	9.10
Bluff Creek	10.39	10.24	10.08	9.99	9.92	9.86	9.80	9.73	9.67	9.60	9.54	9.47	9.52
Pine Creek	10.63	10.48	10.31	10.21	10.15	10.08	10.02	9.95	9.89	9.82	9.76	9.69	9.74
Tectah Creek	10.93	10.81	10.67	10.58	10.52	10.45	10.39	10.34	10.32	10.30	10.28	10.26	10.24
Blue Creek	10.63	10.48	10.31	10.21	10.15	10.08	10.02	9.95	9.89	9.82	9.76	9.69	9.74

Other constituent concentrations for the main inflow and major tributaries were either based on grab samples taken during the summer of 2003 or were those concentrations used in the previous calibration effort. Concentrations based on 2003 grab samples are presented in Table 62 and Table 63.

Table 62. Main inflow and major tributary constituent concentrations based on 2003 grab sample data, June 2003

	Ammonia as N	Nitrate as N	Ortho Phosphate as P	Organic Nitrogen	Organic Phosphorus	Algae	BOD
Site Name	**mg/L**	**mg/L**	**mg/L**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
KR below Iron Gate Dam	0.10	0.15	0.08	0.93	0.06	0.28	2
Shasta River	0.10	0.01	0.17	1.01	0.04	0.02	2
Scott River	0.10	0.11	0.05	0.79	0.00	0.03	2
Salmon River	0.10	0.01	0.05	0.86	0.00	0.00	2
Trinity River	0.10	0.01	0.05	0.84	0.00	0.02	2

Table 63. Main inflow and major tributary constituent concentrations based on 2003 grab sample data, August 2003

Site Name	Ammonia as N	Nitrate as N	Ortho Phosphate as P	Organic Nitrogen	Organic Phosphorus	Algae	BOD
	mg/L	mg/L	mg/L	mg/l	mg/l	mg/l	mg/l
KR below Iron Gate Dam	0.10	0.27	0.12	0.65	0.02	0.30	5
Shasta River	0.10	0.01	0.20	0.45	0.00	0.02	2
Scott River	0.10	0.14	0.05	0.40	0.00	0.03	2
Salmon River	0.10	0.01	0.05	0.40	0.00	0.00	2
Trinity River	0.10	0.01	0.05	0.40	0.00	0.02	2

Other constituent concentrations for minor tributaries were those used for model implementation and the previous calibration effort and are presented in the main model documentation.

3.9.1.2 Initial Conditions

The model was run for four days prior for the 2003 period (approximate travel time to mouth) to provide an initial condition for simulations. The initial bed algae mass was estimated at 5 g/m^2. Where field data were unavailable, the conditions of the first day of available field data were applied.

3.9.1.3 Meteorological Data

The meteorological data for the 2003 calibration was processed in the same manner as identified above under model implementation, using 2003 meteorological data from the KLFO station in Klamath Falls, Oregon.

3.9.2 Model Output Locations: 2003

The calibration locations for the Iron Gate to Turwar reach are presented in Table 64. There was additional temperature and dissolved oxygen collected from deployed sondes during June at Klamath River at Aikens Hole, but that data was not used for formal calibration of the reach. The recorded data are presented in the following section with model results.

All water quality probes and grab samples were collected from near-shore areas and although all efforts were made to identify locations that were deemed consistent with overall main stem conditions (e.g., areas that readily exchanged water with main flow in the river), several factors could result in potential deviation main stem conditions. The primary factor is probably the rapidly descending hydrographs in the June sampling periods which changed local conditions at some sampling locations and required successive re-deployment of water quality probes as water levels fell.

Table 64. Calibration and other data gathering locations in the Klamath River for 2003

Site	River Mile	Elevation, ft	Node	Location Type
Klamath River above Shasta River	177.46	2002.0	141	Cal / Val
Klamath River above Scott River	143.61	1560.0	369	Cal / Val
Klamath River at Seiad Valley	129.04	1320.0	672	Cal / Val
Klamath River at Clear Creek	99.00	937.0	994	Cal / Val
Klamath River above Salmon River	67.05	491.2	1354	Cal / Val
Klamath River at Aikens Hole	50.00	310.0	1545	Additional Information
Klamath River above Trinity River	43.50	302.0	1609	Cal / Val
Klamath River at Martins Ferry / Tully Creek	39.50	273.0	1649	Cal / Val
Klamath River at Blue Creek	16.95	100.0	1901	Cal / Val
Klamath River at Turwar	5.63	6.0	1974	Cal / Val

3.9.3 Results 2003

3.9.3.1 Water Temperature

Mean absolute error was less than 1.0°C for all sites for both June and August conditions with the exception of Klamath River above Salmon River in June (MAE = 1.44°C). Tabulated statistics illustrate that simulated results on a daily basis were within 1.0°C of observations, with the exception of the above noted site. Further, observation of the diurnal phase and amplitude were generally well represented at the individual locations.

Summary statistics include bias (average error), mean absolute error, and root mean square error. The error is computed as simulated values minus measured values, and the summary statistics are determined based on the period of available data. Daily statistics are calculated based on whole days, while hourly statistics utilize portions of days when data is available. The statistics represent performance over the period observed data.

The hourly results are presented graphically in Figure 125 through Figure 140. Summary statistics are included in Table 69. Representation of diurnal phase as well as diurnal range was a calibration objective.

At Klamath River above Shasta River, the diurnal phase for both June and August was well represented, as well as the shape of the diurnal temperature trace. The maximum and minimum daily temperatures closely matched observed temperatures. Hourly bias for the June period was –0.40°C with a mean absolute error of 0.47 °C. Hourly bias for the August period was 0.81°C with a mean absolute error of 0.81°C.

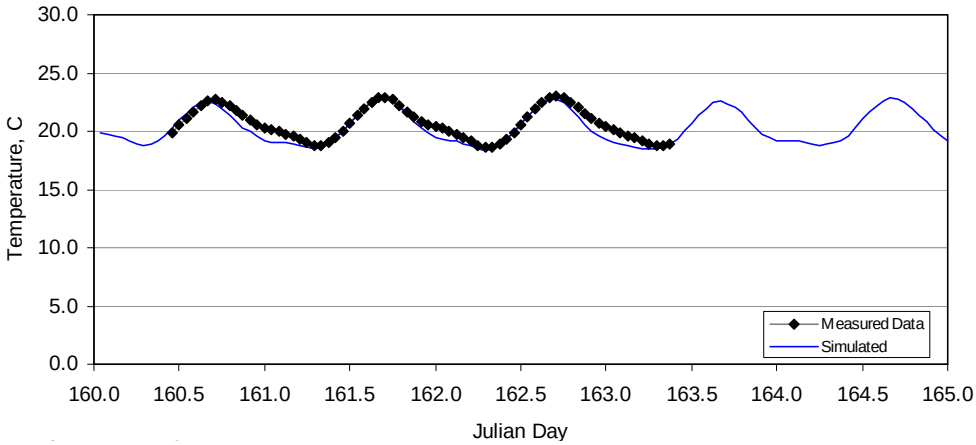


Figure 125. Klamath River ab Shasta River simulated versus measured water temperature, June 9-12, 2003

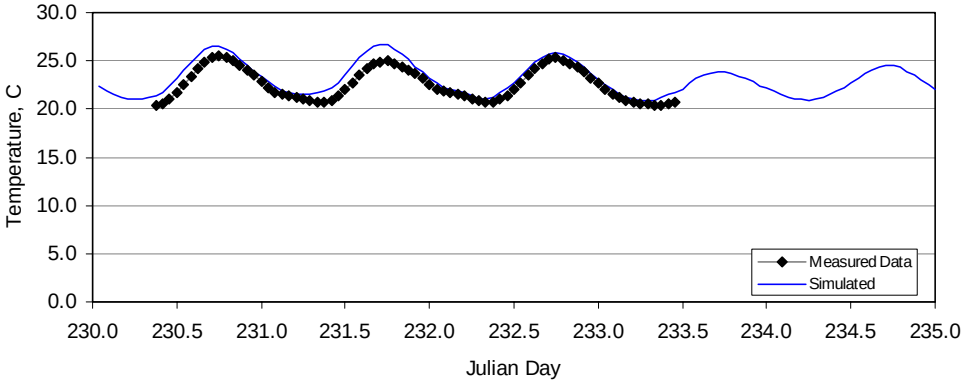


Figure 126. Klamath River ab Shasta River simulated versus measured water temperature, August 18-21, 2003

At Klamath River above Scott River, the diurnal phase and range for both June and August periods was well represented. Hourly bias for the June period was -0.11°C with a mean absolute error of 0.51°C. Hourly bias for the August period was 0.91°C with a mean absolute error of 0.91°C.

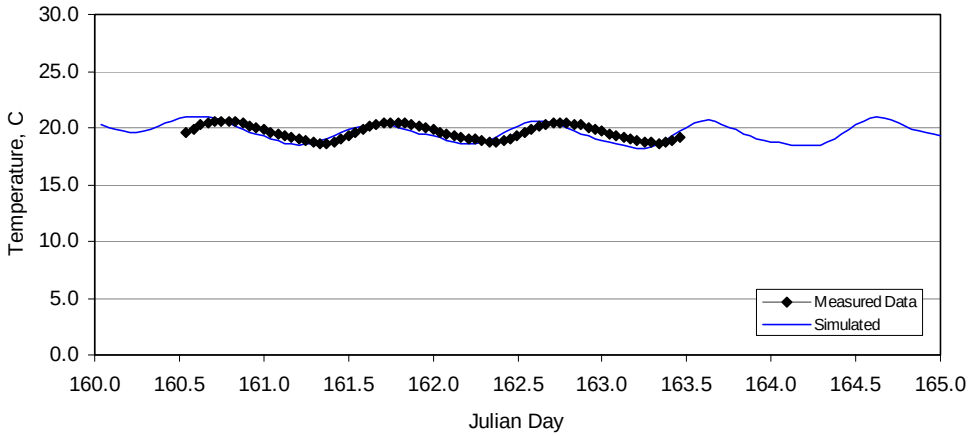


Figure 127. Klamath River above Scott River versus measured water temperature, June 9-12, 2003

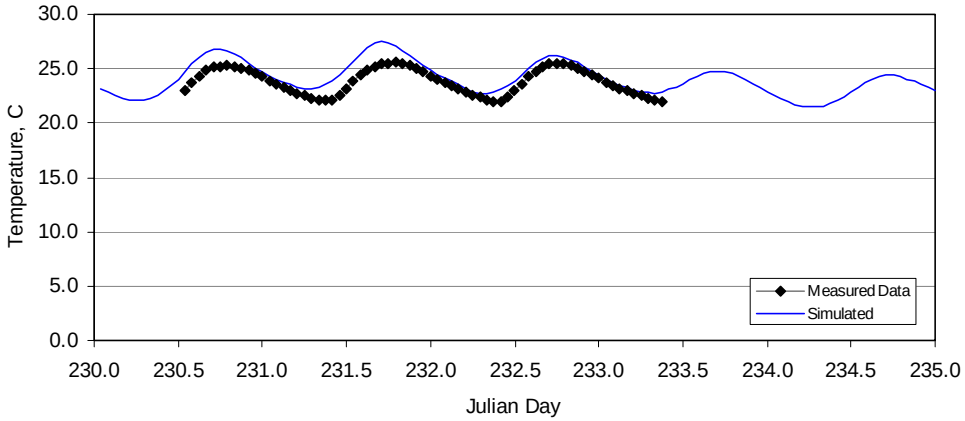


Figure 128. Klamath River above Scott River simulated versus measured water temperature, August 18-21, 2003

At Klamath River near Seiad Valley, the diurnal phase was well represented in both June and August periods. The diurnal range was adequately represented in both periods, with the maximum simulated temperatures slightly higher than observed temperatures. Hourly bias for the June period was 0.05°C with a mean absolute error of 0.13°C, and the shape of the diurnal signal is well represented. Hourly bias for the August period was 0.92°C with a mean absolute error of 0.92°C.

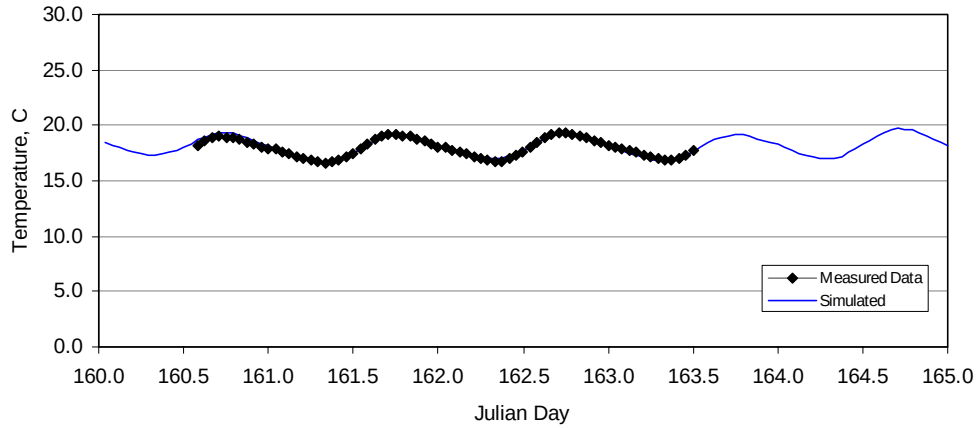


Figure 129. Klamath River near Seiad Valley simulated versus measured water temperature, June 9-12, 2003

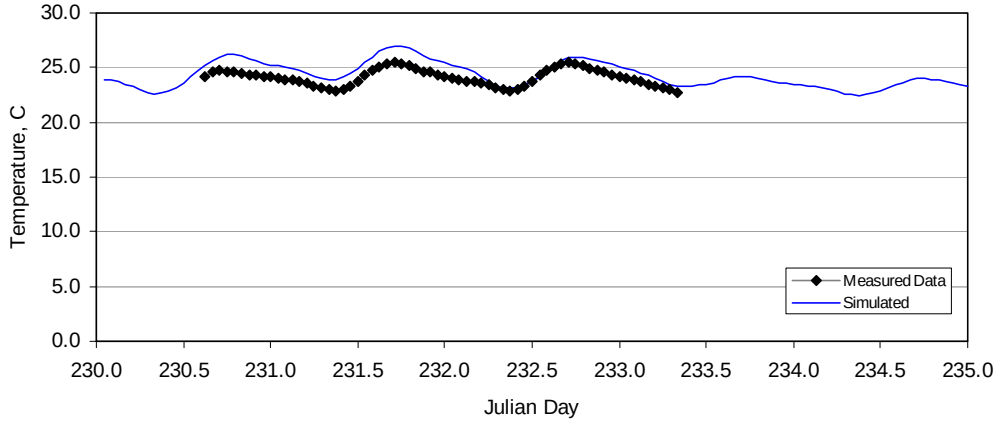


Figure 130. Klamath River near Seiad Valley simulated versus measured water temperature, August 18-21, 2003

At Klamath River above Clear Creek, observations for June were unavailable. The diurnal range for August was well represented. The hourly bias for August was 0.13°C with a mean absolute error of 0.47°C.

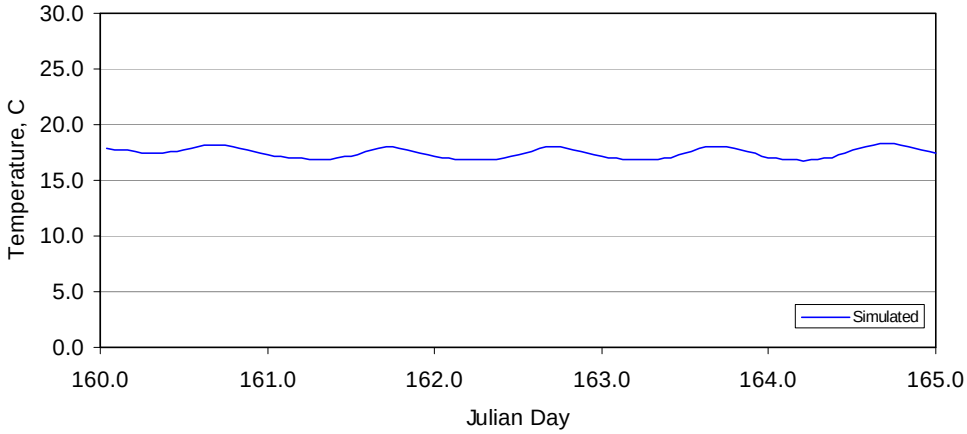


Figure 131. Klamath River ab Clear Creek simulated water temperature, June 9-12, 2003

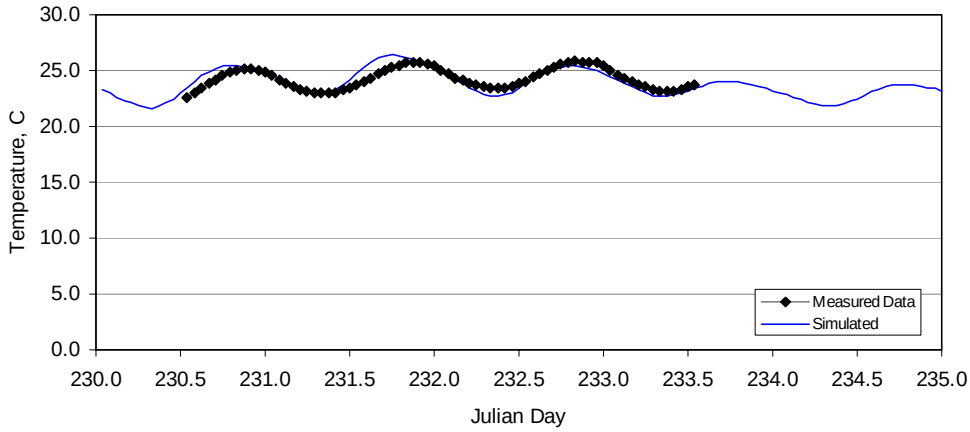


Figure 132. Klamath River ab Clear Creek simulated versus measured water temperature, August 18-21, 2003

At Klamath River above the Salmon River, the diurnal phase was well represented in both June and August periods; however June period simulated temperatures were under predicted. The diurnal range was well represented in both periods. Hourly bias for the June period was -1.44°C with a mean absolute error of 1.44°C. Hourly bias for the August period was 0.15°C with a mean absolute error of 0.43°C.

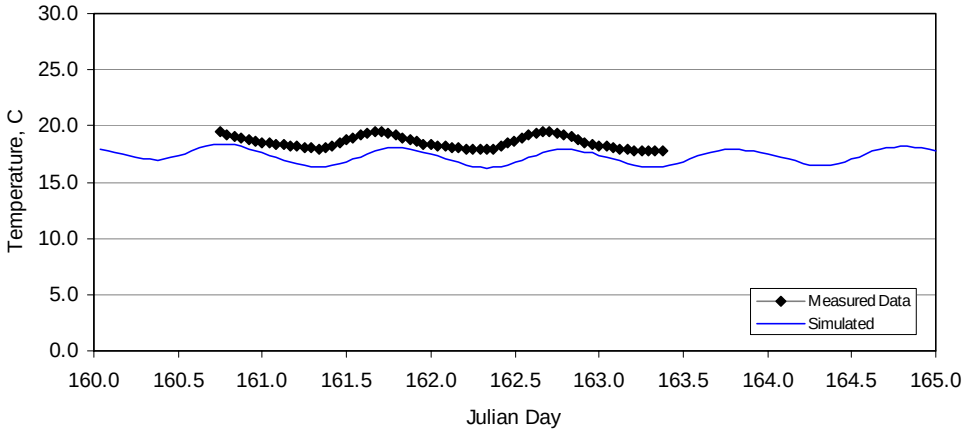


Figure 133. Klamath River ab Salmon River simulated versus measured water temperature, June 9-12, 2003

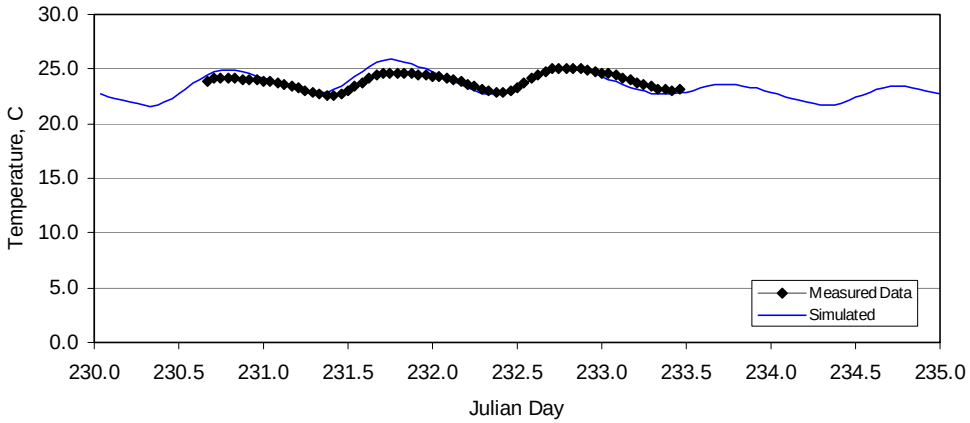


Figure 134. Klamath River ab Salmon River simulated versus measured water temperature, August 18-21, 2003

At Klamath River above the Trinity River the diurnal range was under represented in June, but matched well in August. The diurnal phase for August was generally well represented. Hourly bias for the June period was -0.98°C with a mean absolute error of 0.98°C. Hourly bias for the August period was 0.55°C with a mean absolute error of 0.67°C.

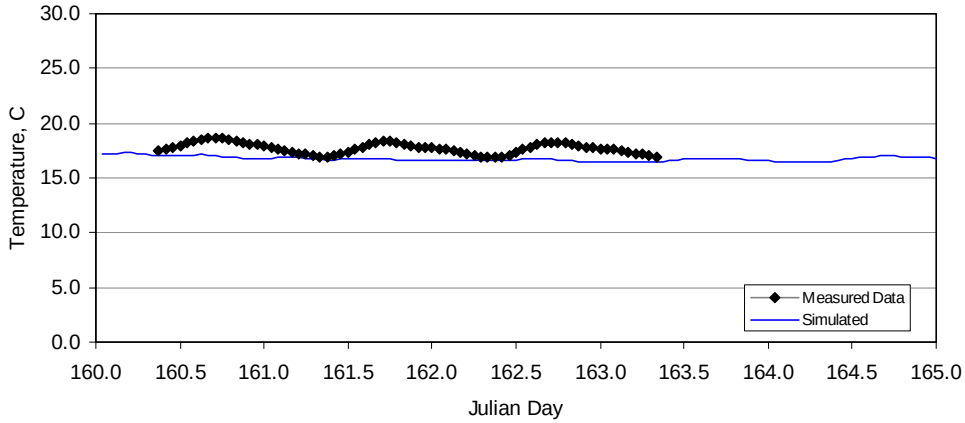


Figure 135. Klamath River ab Trinity River simulated versus measured water temperature, June 9-12, 2003

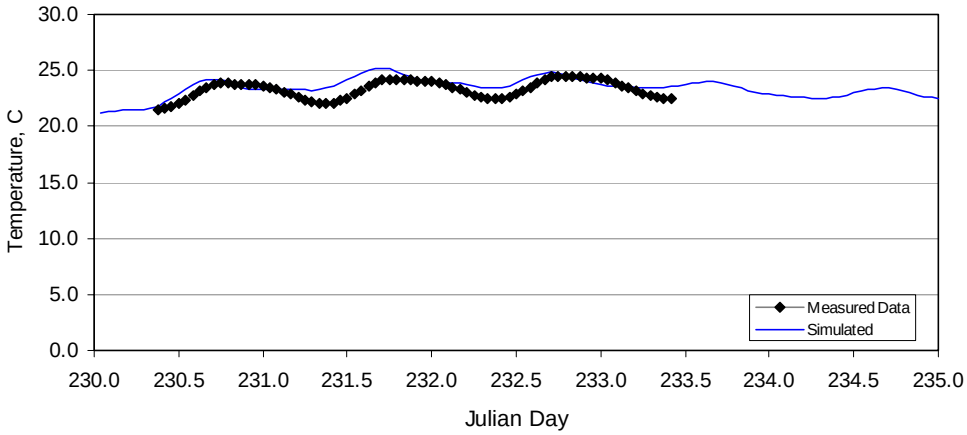


Figure 136. Klamath River ab Trinity River simulated versus measured water temperature, August 18-21, 2003

At Klamath River below the Trinity River in the vicinity of Martins Ferry was assessed at two locations due to movement of the sampling location: Martins Ferry in June and Tully Creek in August. Similar to the site above the Trinity, the simulated diurnal range was largely absent in the June results; however, the mean daily temperature was well represented (MAE = 0.63°C). The moderated diurnal range and phase was replicated in August. Hourly bias for the June period was -0.63°C with a mean absolute error of 0.63°C. Hourly bias for the August period was 0.43°C with a mean absolute error of 0.47°C.

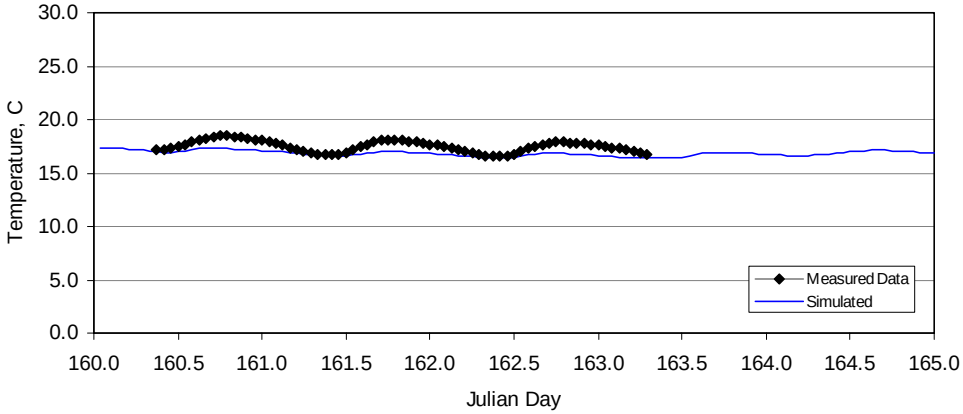


Figure 137. Klamath River ab Martins Ferry simulated versus measured water temperature, June 9-12, 2003

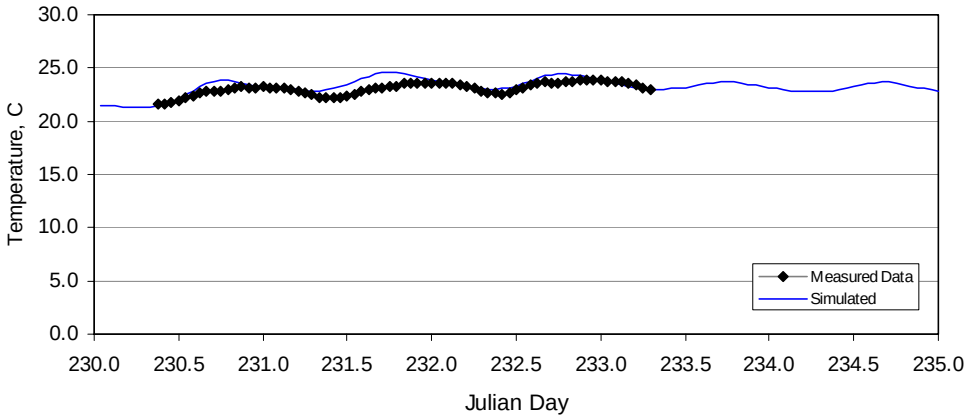


Figure 138. Klamath River ab Tully Creek simulated versus measured water temperature, August 18-21, 2003

At Klamath River below in the lowest reaches was assessed at two locations due to lack of data at Turwar in August: Turwar in June and Blue Creek in August. The June diurnal range was under represented in June, while the diurnal range and phase was generally replicated in August at Blue Creek. Hourly bias for the June period was -0.57°C with a mean absolute error of 0.68°C. Hourly bias for the August period was 0.86°C with a mean absolute error of 0.86°C.

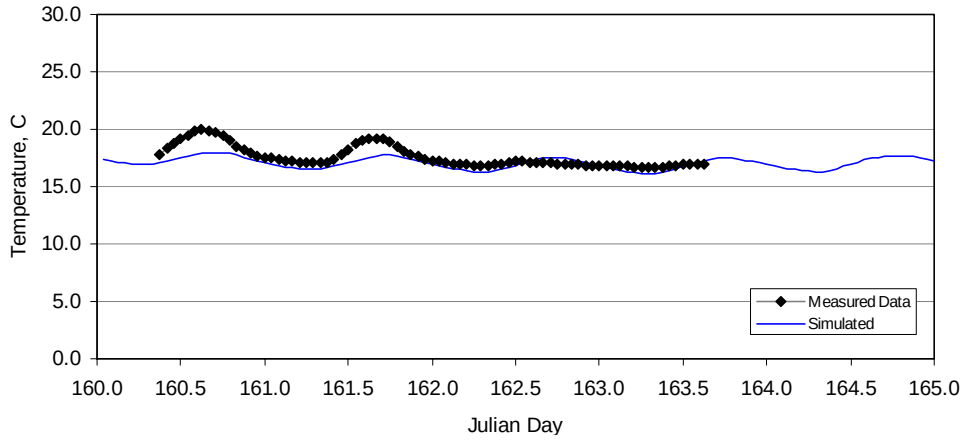


Figure 139. Klamath River at Turwar simulated versus measured water temperature, June 9-12, 2003

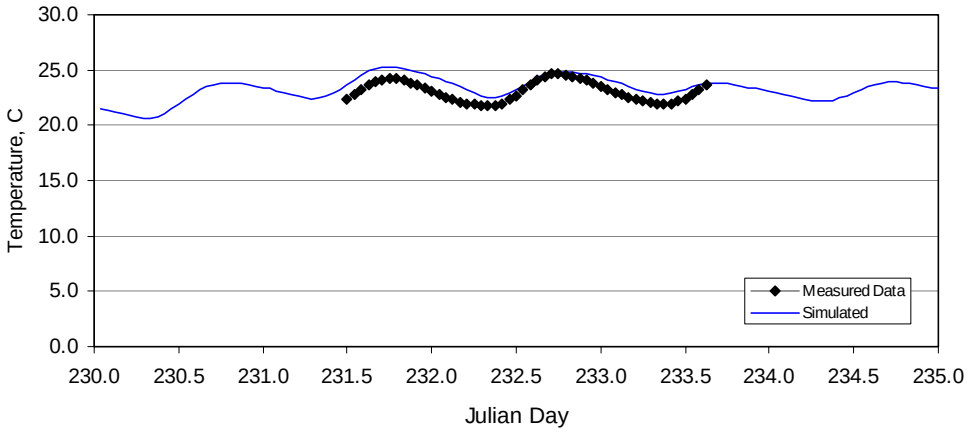


Figure 140. Klamath River ab Blue Creek simulated versus measured water temperature, August 18-21, 2003

Table 65. Klamath River hourly and daily calibration statistics for water temperature 2003

Calibration / Validation Statistics		Hourly		Daily	
	Unit	June	August	June	August
Klamath River ab Shasta River					
Mean Bias[a]	°C	-0.40	0.81	-0.39	0.80
Mean absolute error (MAE)	°C	0.47	0.81	0.39	0.80
Root mean squared error (RMSE)	°C	0.59	0.93	0.39	0.84
n	-	71	75	2	2
Klamath River ab Scott River					
Mean Bias[a]	°C	-0.11	0.91	-0.12	0.92
Mean absolute error (MAE)	°C	0.51	0.91	0.12	0.92
Root mean squared error (RMSE)	°C	0.57	1.08	0.12	0.98
n	-	71	69	2	2
Klamath River near Seiad Valley					
Mean Bias[a]	°C	0.05	0.92	0.04	0.88
Mean absolute error (MAE)	°C	0.13	0.92	0.04	0.88
Root mean squared error (RMSE)	°C	0.17	1.02	0.04	0.94
n	-	71	66	2	2
Klamath River above Clear Creek					
Mean Bias[a]	°C	na	0.03	na	0.03
Mean absolute error (MAE)	°C	na	0.47	na	0.41
Root mean squared error (RMSE)	°C	na	0.59	na	0.41
n	-	na	73	na	2
Klamath River above Salmon River					
Mean Bias[a]	°C	-1.44	0.15	-1.44	0.23
Mean absolute error (MAE)	°C	1.44	0.43	1.44	0.33
Root mean squared error (RMSE)	°C	1.49	0.56	1.44	0.40
n	-	48	68	2	2
Klamath River above Trinity River					
Mean Bias[a]	°C	-0.98	0.55	-0.93	0.66
Mean absolute error (MAE)	°C	0.98	0.67	0.93	0.66
Root mean squared error (RMSE)	°C	1.08	0.80	0.93	0.69
n	-	72	74	2	2
Klamath River at Martins Ferry/Tully Ck[b]					
Mean Bias[a]	°C	-0.67	0.43	-0.63	0.53
Mean absolute error (MAE)	°C	0.67	0.47	0.63	0.53
Root mean squared error (RMSE)	°C	0.75	0.61	0.63	0.55
N	-	71	71	2	2
Klamath River at Blue Creek/Turwar[c]					
Mean Bias[a]	°C	-0.57	0.86	-0.46	0.71
Mean absolute error (MAE)	°C	0.68	0.86	0.46	0.71
Root mean squared error (RMSE)	°C	0.84	0.94	0.57	0.71
n	-	79	52	2	1

[a] Mean bias = simulated – measured
[b] June, Martins Ferry; August, Tully Creek
[c] June, Turwar; August, Blue Creek
na – not available

3.9.3.2 Dissolved Oxygen

Mean absolute error was within 1.0 mg/l for all sites for both June and August conditions with the exception of Klamath River above Salmon River in August, which was just over 1.0 mg/l. Tabulated statistics illustrate that simulated results on a daily basis were also within approximately 1.0 mg/l of observations, with the exception of the above noted site. Further, observation of the diurnal phase and amplitude were generally well represented at the individual locations. The hourly results are presented graphically in Figure 141 through Figure 156. Summary statistics are included in Table 69.

At Klamath River above Shasta River, the diurnal phase is well represented; however, in June the amplitude is moderated in model simulations. The maximum and minimum daily temperatures closely matched observed temperatures. Hourly bias for the June period was 0.64 mg/l with a mean absolute error of 0.84 mg/l. Hourly bias for the August period was 0.69 mg/l with a mean absolute error of 0.69 mg/l.

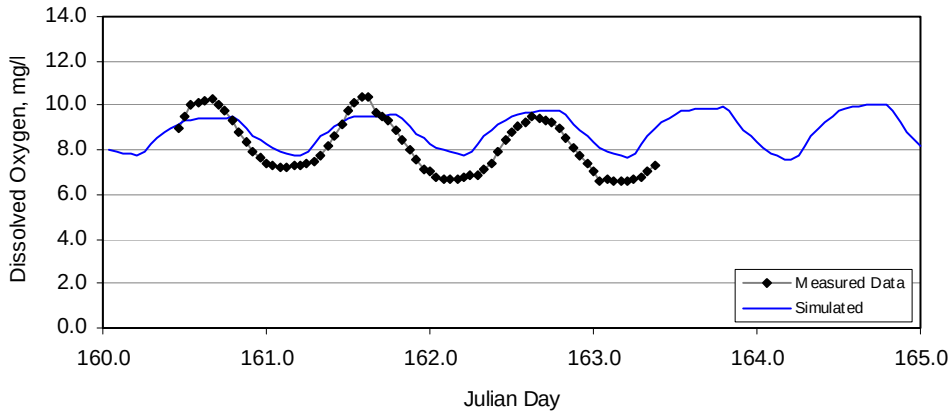


Figure 141. Klamath River above Shasta River simulated versus measured dissolved oxygen, June 9-12, 2003

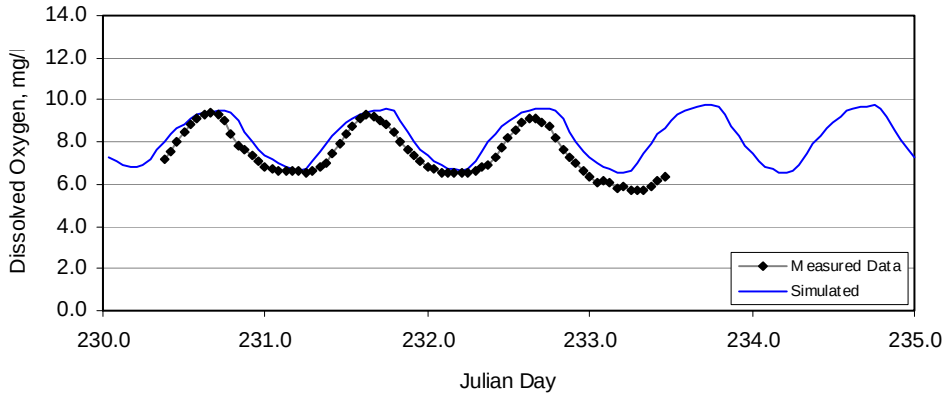


Figure 142. Klamath River above Shasta River simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River above Scott River, the diurnal phase is well represented. The diurnal range is replicated in June, with the model over predicting daily minimum values. In August the maximum values are under represented. Hourly bias for the June period was 0.63 mg/l with a mean absolute error of 0.64 mg/l. Hourly bias for the August period was -0.26 mg/l with a mean absolute error of 0.36 mg/l.

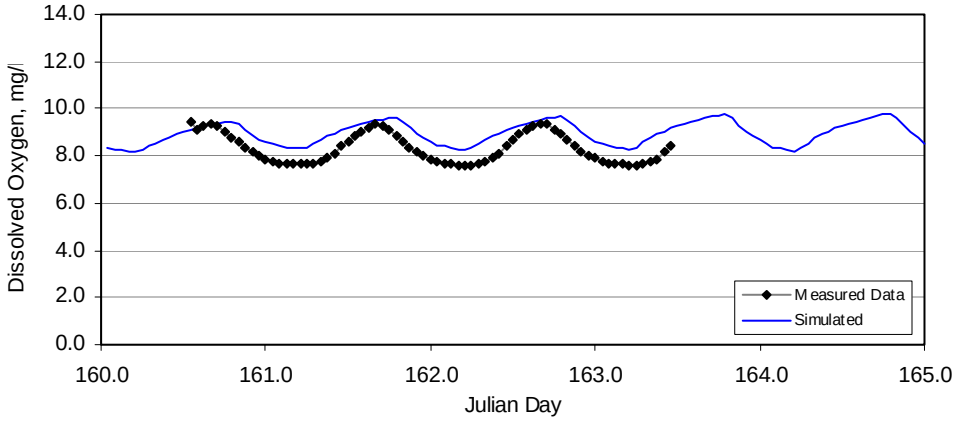


Figure 143. Klamath River above Scott River simulated versus measured dissolved oxygen, June 9-12, 2003

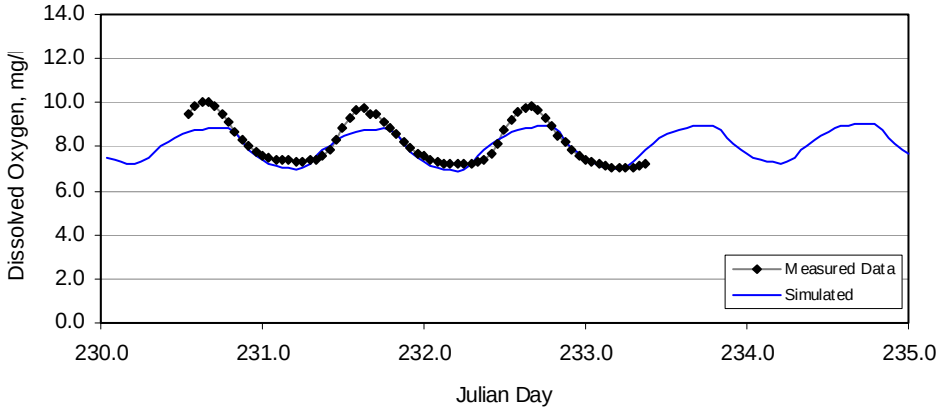


Figure 144. Klamath River above Scott River simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River near Seiad Valley, the diurnal phase is shifted by approximately an our, but the amplitude is well represented in June. In August the maximum values are under represented. Hourly bias for the June period was 0.13 mg/l with a mean absolute error of 0.18 mg/l. Hourly bias for the August period was -0.42 mg/l with a mean absolute error of 0.52 mg/l.

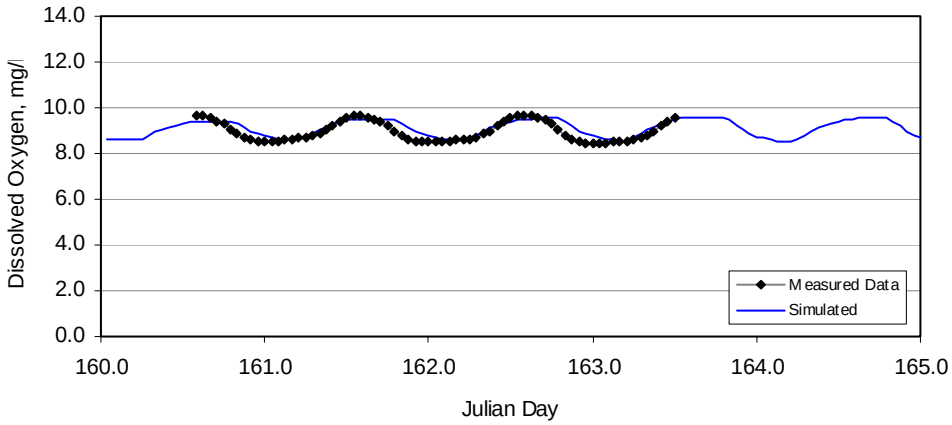


Figure 145. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, June 9-12, 2003

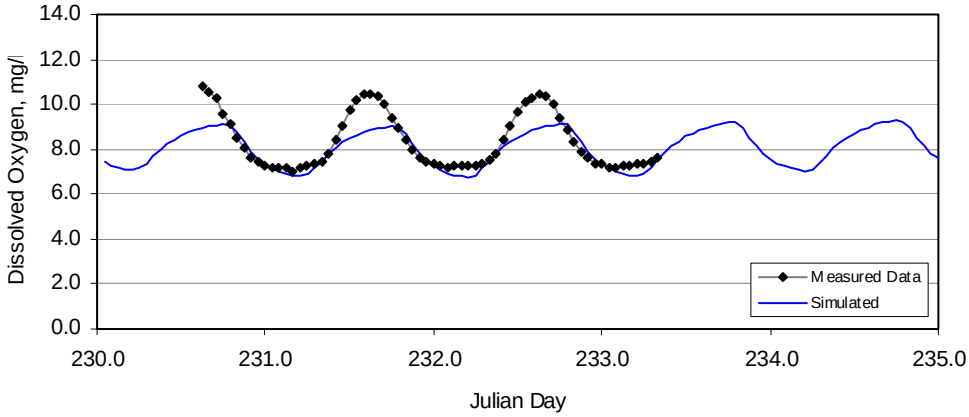


Figure 146. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River above Clear Creek, no data were available for June and August phase and diurnal range are generally well represented; however, the model results are overall lower than the observed values. Hourly bias for the August period was -0.73 mg/l with a mean absolute error of 0.73 mg/l.

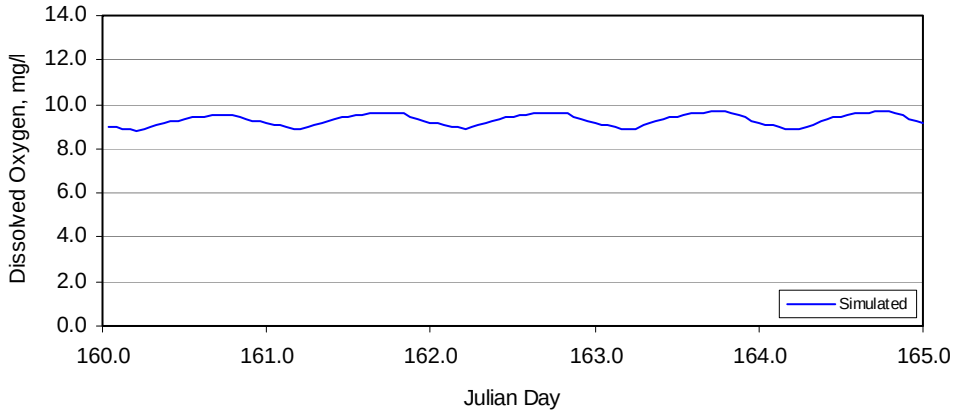


Figure 147. Klamath River above Clear Creek simulated versus measured dissolved oxygen, June 9-12, 2003

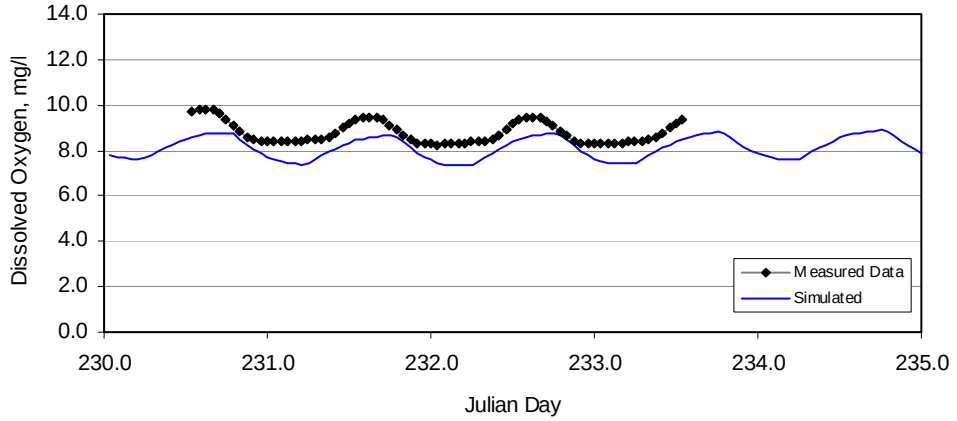


Figure 148. Klamath River above Clear Creek simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River above Salmon River, both the moderated June diurnal signal and larger August diurnal range is replicated by the model; however the model results are lower than the observed values by about 1.0 mg/l. Hourly bias for the June period was 0.13 mg/l with a mean absolute error of 0.18 mg/l. Hourly bias for the August period was -0.42 mg/l with a mean absolute error of 0.52 mg/l.

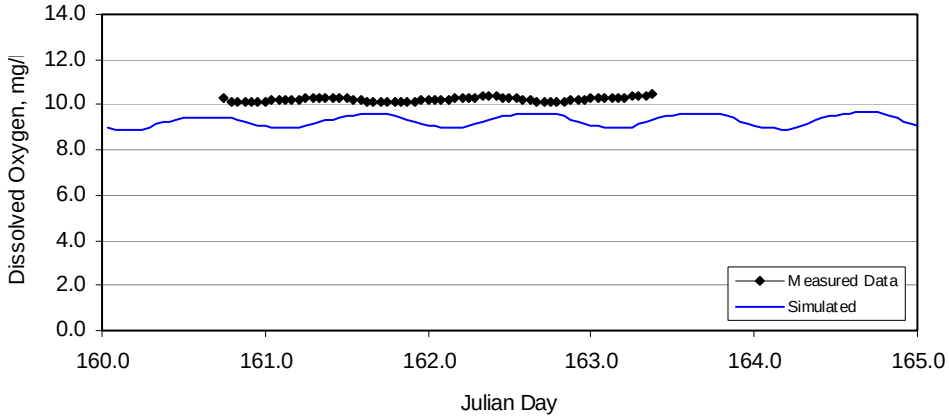


Figure 149. Klamath River above Salmon River simulated versus measured dissolved oxygen, June 9-12, 2003

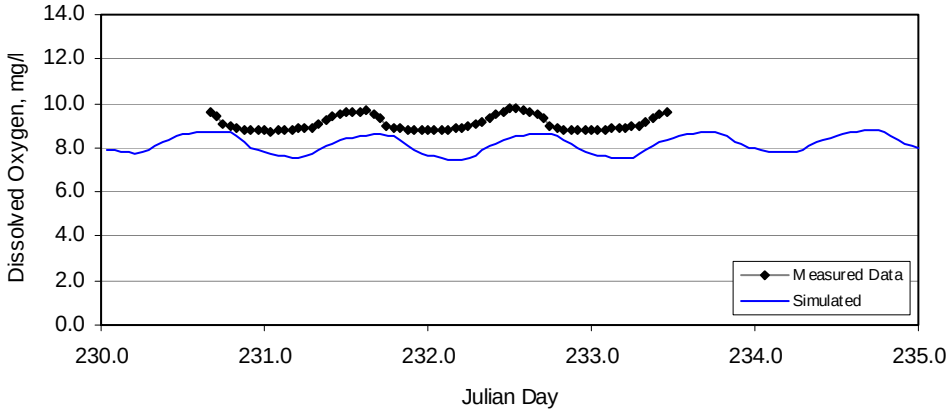


Figure 150. Klamath River above Salmon River simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River above Trinity River, both the moderated June diurnal signal and larger August diurnal range is replicated by the model; however the model results are higher than observations in June and the August diurnal signal is smaller than observed values. Hourly bias for the June period was 0.67 mg/l with a mean absolute error of 0.67 mg/l. Hourly bias for the August period was 0.29 mg/l with a mean absolute error of 0.50 mg/l.

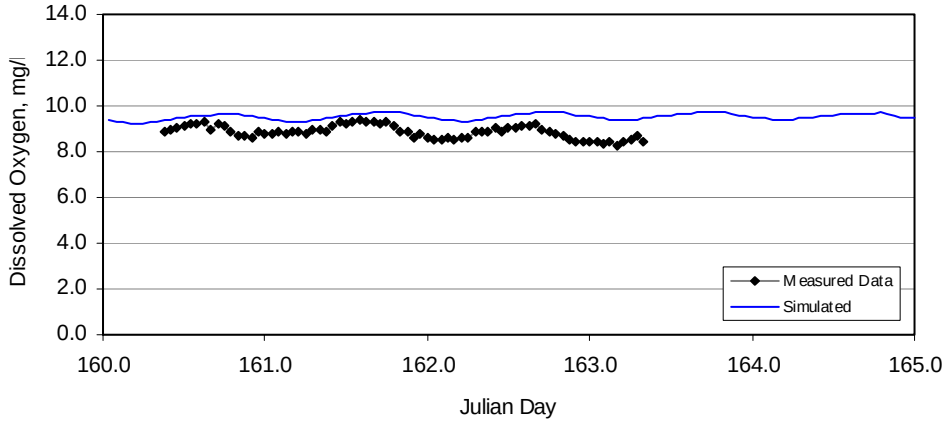


Figure 151. Klamath River above Trinity River simulated versus measured dissolved oxygen, June 9-12, 2003

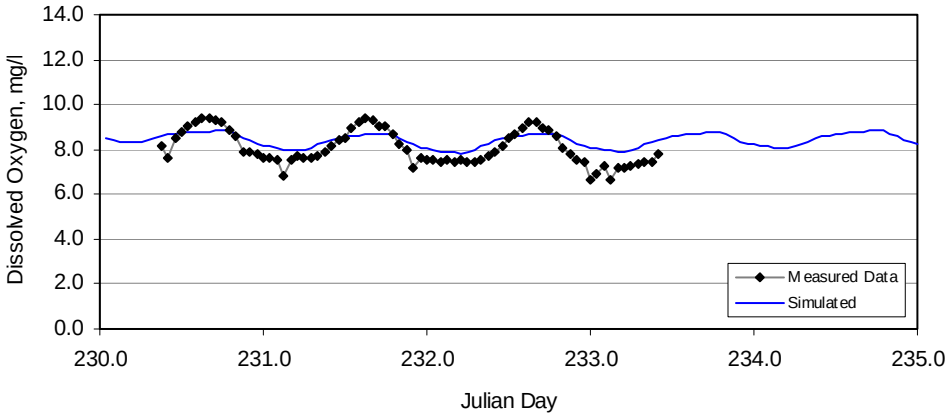


Figure 152. Klamath River above Trinity River simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River nears Martins Ferry as represented by Martins Ferry and Tully Creek, both the moderated June diurnal signal and larger August diurnal range is replicated by the model; however the model results are slightly higher than observations in June and the August diurnal signal is smaller than observed values. Hourly bias for the June period was 0.51 mg/l with a mean absolute error of 0.51 mg/l. Hourly bias for the August period was 0.02 mg/l with a mean absolute error of 0.29 mg/l.

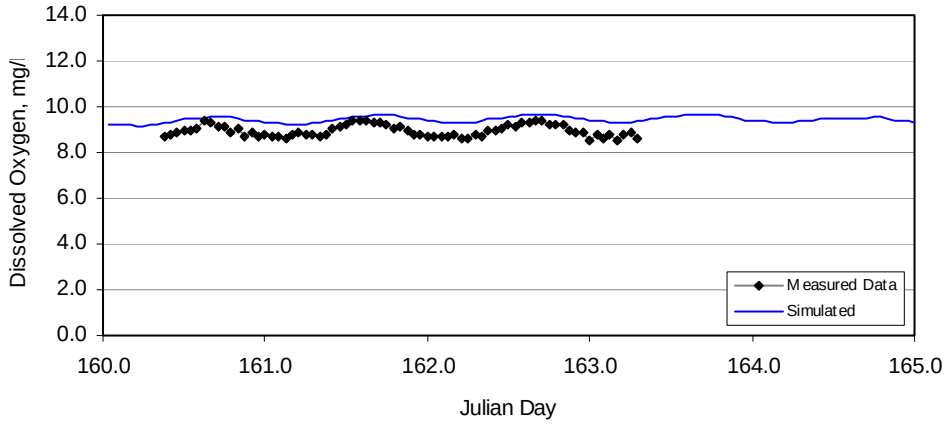


Figure 153. Klamath River at Martins Ferry simulated versus measured dissolved oxygen, June 9-12, 2003

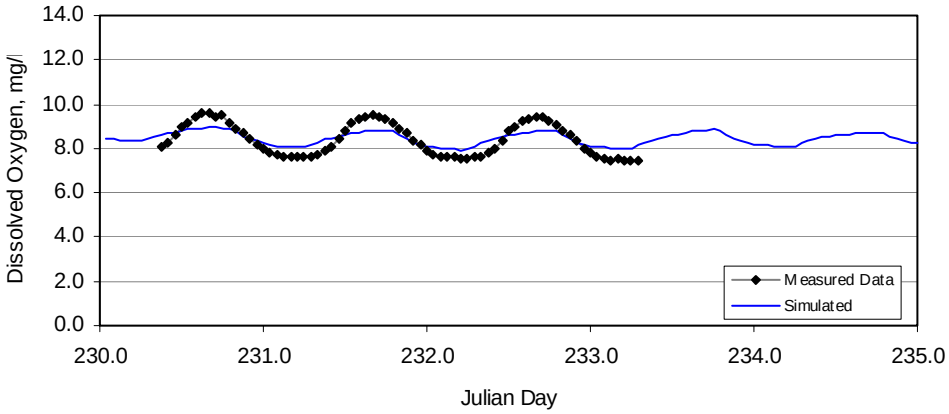


Figure 154. Klamath River at Tully Creek simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River in the extreme lower river as represented by Turwar and Blue Creek the Turwar site has a wider diurnal range than the model (this may be due to deployment location), while the August phase and range are generally well represented at Blue Creek. Hourly bias for the June period was -0.27 mg/l with a mean absolute error of 0.41 mg/l. Hourly bias for the August period was 0.25 mg/l with a mean absolute error of 0.47 mg/l.

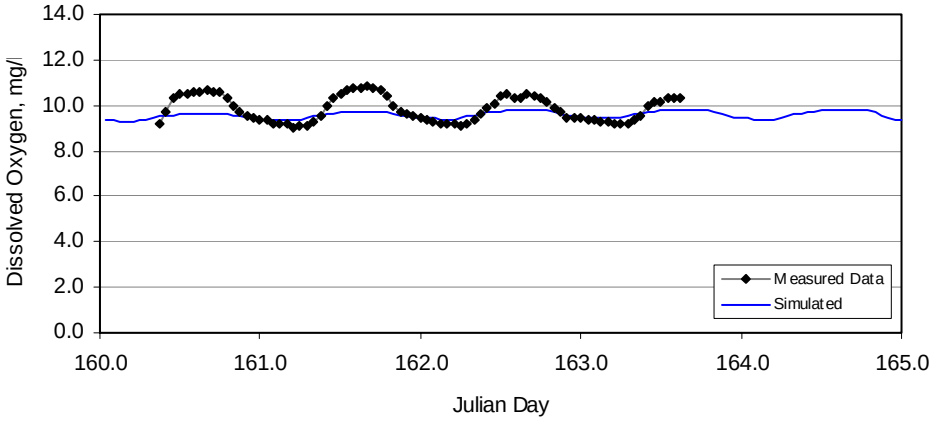


Figure 155. Klamath River at Turwar simulated versus measured dissolved oxygen, June 9-12, 2003

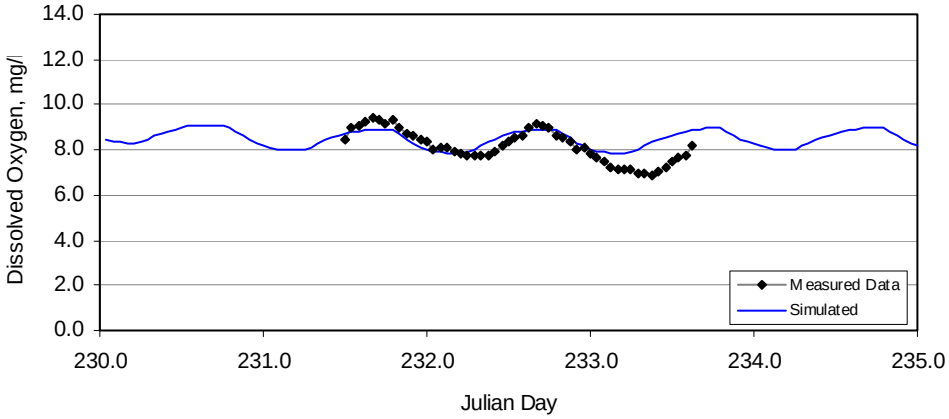


Figure 156. Klamath River at Blue Creek River simulated versus measured dissolved oxygen, August 18-21, 2003

Table 66. Klamath River hourly and daily calibration statistics for dissolved oxygen 2003

Calibration / Validation Statistics		Hourly		Daily	
	Unit	June	August	June	August
Klamath River ab Shasta River					
Mean Bias[a]	°C	0.64	0.69	0.69	0.60
Mean absolute error (MAE)	°C	0.84	0.69	0.69	0.60
Root mean squared error (RMSE)	°C	0.94	0.84	0.75	0.60
n	-	71	75	2	2
Klamath River ab Scott River					
Mean Bias[a]	°C	0.63	-0.26	0.65	-0.25
Mean absolute error (MAE)	°C	0.64	0.36	0.65	0.25
Root mean squared error (RMSE)	°C	0.68	0.49	0.65	0.25
n	-	71	69	2	2
Klamath River near Seiad Valley					
Mean Bias[a]	°C	0.13	-0.42	0.13	-0.44
Mean absolute error (MAE)	°C	0.18	0.52	0.13	0.44
Root mean squared error (RMSE)	°C	0.24	0.73	0.13	0.44
n	-	71	66	2	2
Klamath River above Clear Creek					
Mean Bias[a]	°C	na	-0.73	na	-0.71
Mean absolute error (MAE)	°C	na	0.73	na	0.71
Root mean squared error (RMSE)	°C	na	0.77	na	0.71
n	-	na	73	na	2
Klamath River above Salmon River					
Mean Bias[a]	°C	-0.96	-1.03	-0.91	-1.05
Mean absolute error (MAE)	°C	0.96	1.03	0.91	1.05
Root mean squared error (RMSE)	°C	1.00	1.08	0.91	1.05
n	-	64	68	2	2
Klamath River above Trinity River					
Mean Bias[a]	°C	0.67	0.29	0.64	0.23
Mean absolute error (MAE)	°C	0.67	0.50	0.64	0.23
Root mean squared error (RMSE)	°C	0.71	0.57	0.65	0.23
n	-	72	74	2	2
Klamath River at Martins Ferry/Tully Ck[b]					
Mean Bias[a]	°C	0.51	0.02	0.50	0.00
Mean absolute error (MAE)	°C	0.51	0.39	0.50	0.01
Root mean squared error (RMSE)	°C	0.54	0.43	0.50	0.01
N	-	71	71	2	2
Klamath River at Blue Creek/Turwar[c]					
Mean Bias[a]	°C	-0.27	0.25	-0.24	0.50
Mean absolute error (MAE)	°C	0.41	0.47	0.24	0.50
Root mean squared error (RMSE)	°C	0.53	0.60	0.26	0.67
n	-	79	52	2	2

[a] Mean bias = simulated – measured
[b] June, Martins Ferry; August, Tully Creek
[c] June, Turwar; August, Blue Creek
na – not available

3.9.3.3 Nutrients

Inorganic forms of nitrogen (ammonia, NH_4^+; nitrate, NO_3^-) and phosphorous (orthophosphate, PO_4^{3-}) were sampled once per day during the June and August 2003 monitoring program at the identified sampling sites for calibration. The sites at Blue Creek and at Turwar were not sampled for nutrients and are not included herein. The model results indicate that for all nutrients the bias is within ±0.10 mg/l and the MAE is les than 0.10 mg/l. These values are close to the reporting limits for these nutrients. Results are presented graphically in Figure 157 to Figure 198 and tabulated in Table 67.

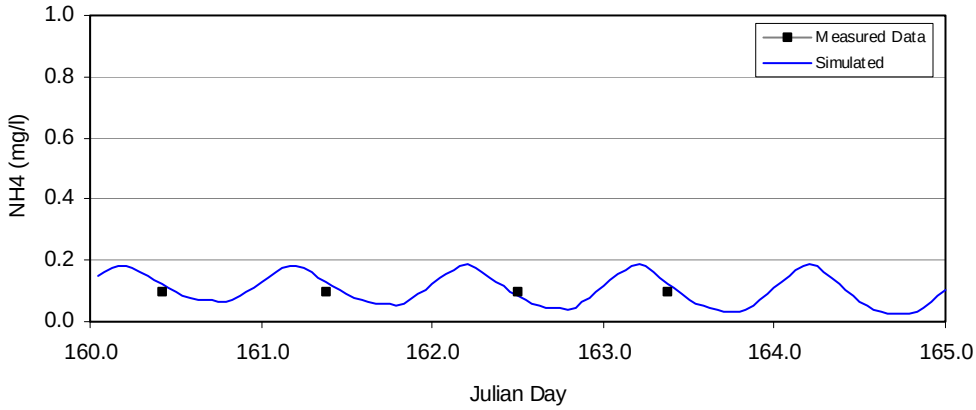


Figure 157. Klamath River above Shasta River simulated versus measured ammonia, June 9-12, 2003

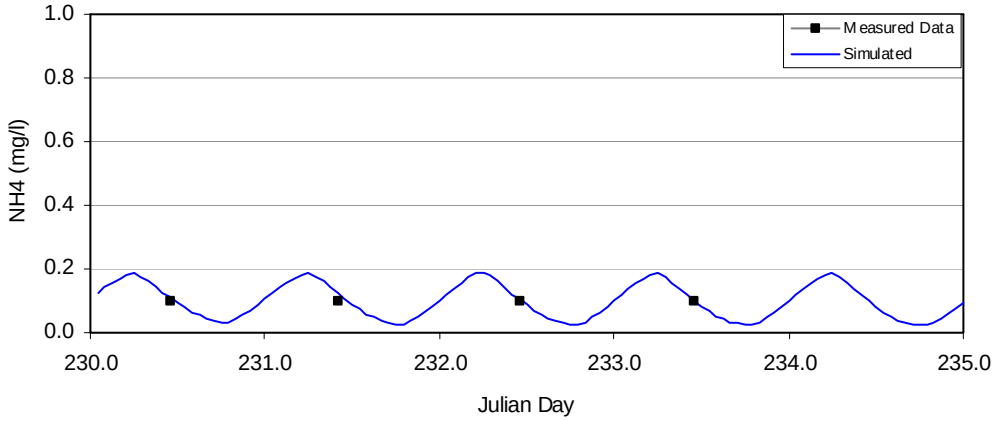


Figure 158. Klamath River above Shasta River simulated versus measured ammonia, August 18-21, 2003

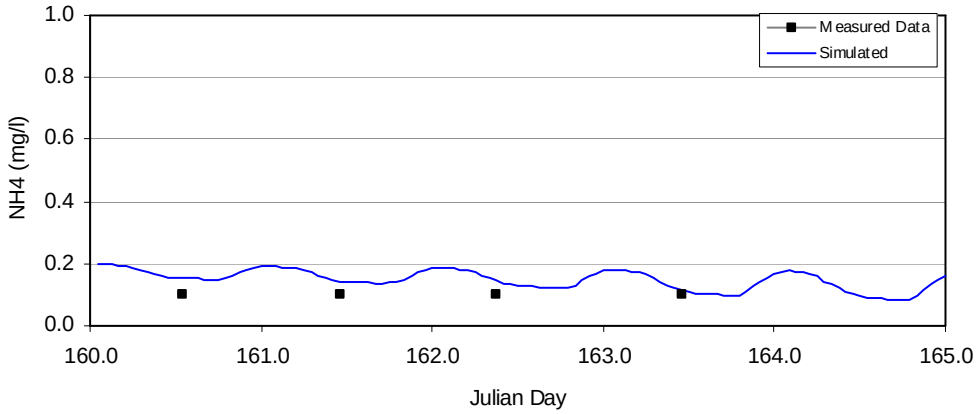


Figure 159. Klamath River above Scott River simulated versus measured ammonia, June 9-12, 2003

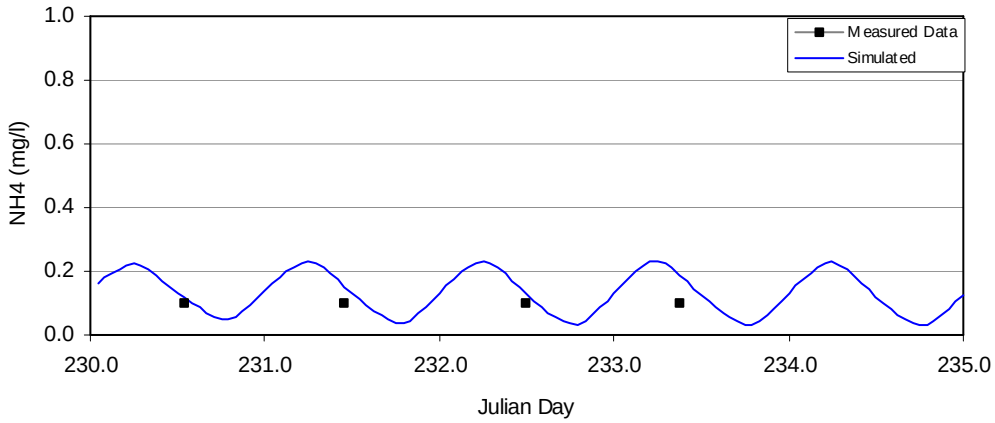


Figure 160. Klamath River above Scott River simulated versus measured ammonia, August 18-21, 2003

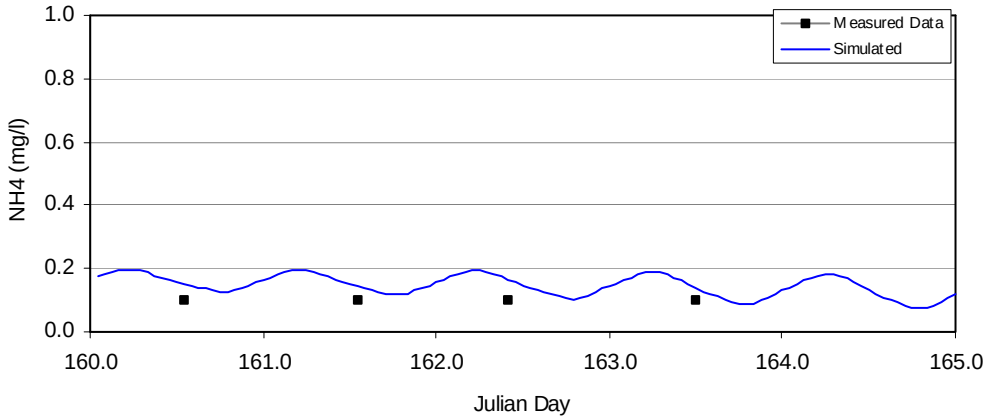


Figure 161. Klamath River near Seiad Valley simulated versus measured ammonia, June 9-12, 2003

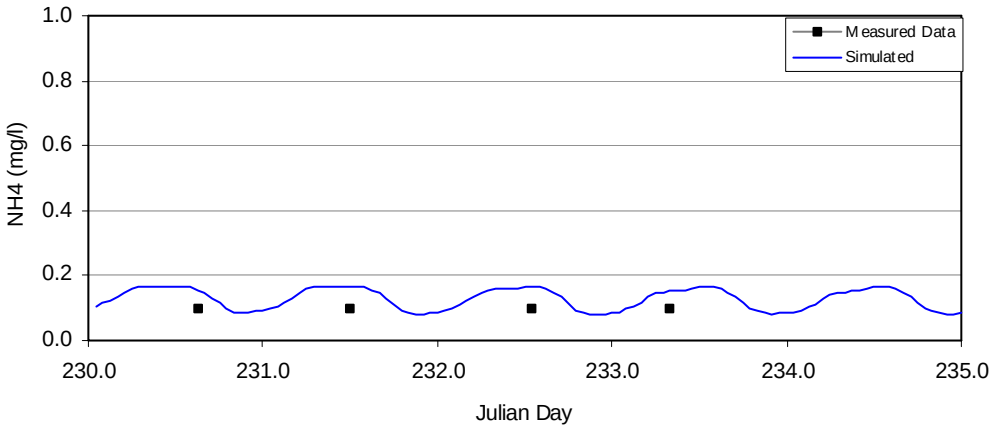


Figure 162. Klamath River near Seiad Valley simulated versus measured ammonia, August 18-21, 2003

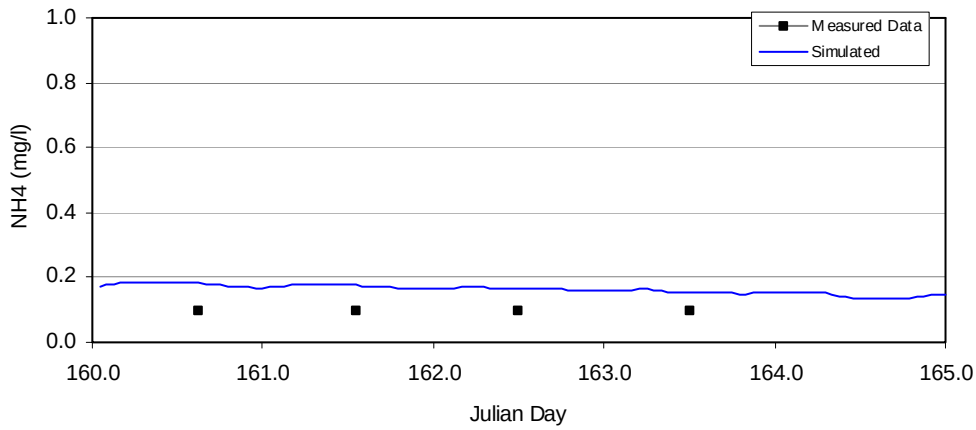


Figure 163. Klamath River above Clear Creek simulated versus measured ammonia, June 9-12, 2003

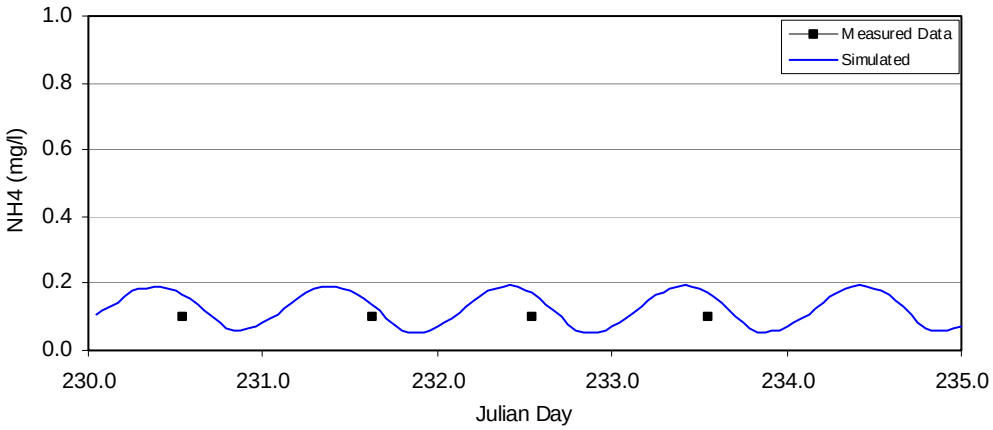


Figure 164. Klamath River above Clear Creek simulated versus measured ammonia, August 18-21, 2003

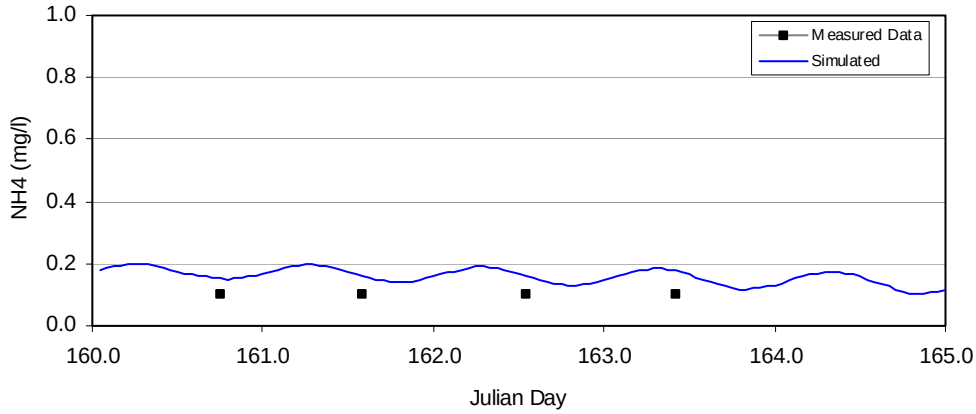


Figure 165. Klamath River above Salmon River simulated versus measured ammonia, June 9-12, 2003

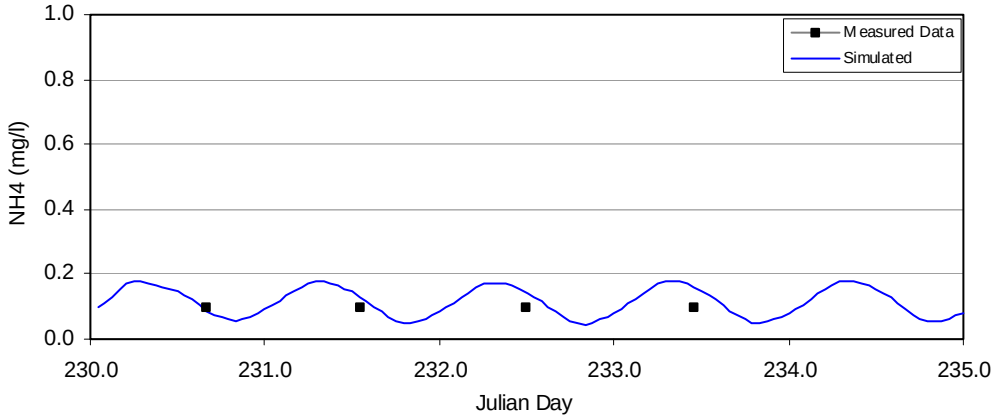


Figure 166. Klamath River above Salmon River simulated versus measured ammonia, August 18-21, 2003

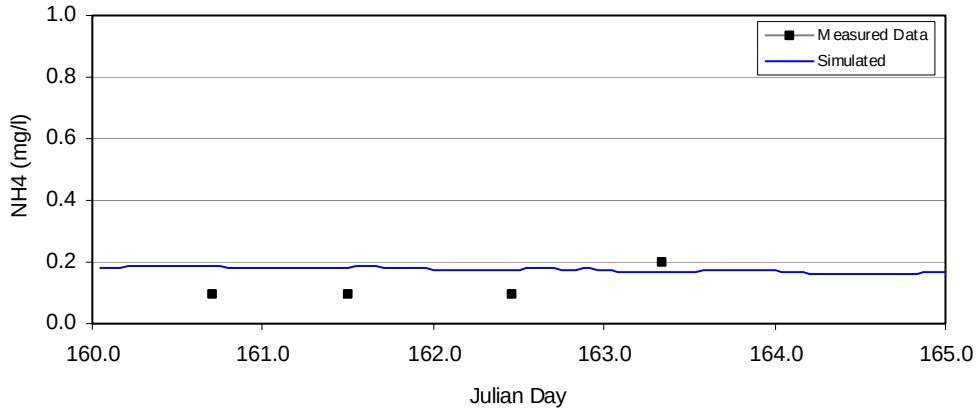


Figure 167. Klamath River above Trinity River simulated versus measured ammonia, June 9-12, 2003

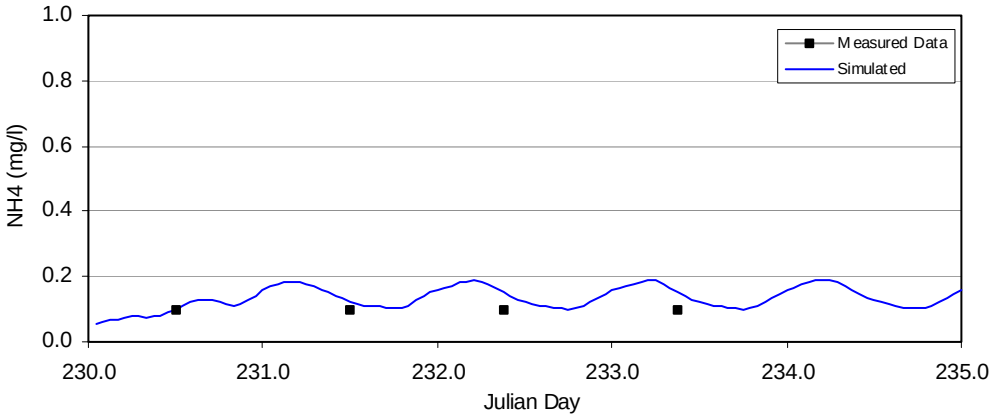


Figure 168. Klamath River above Trinity River simulated versus measured ammonia, August 18-21, 2003

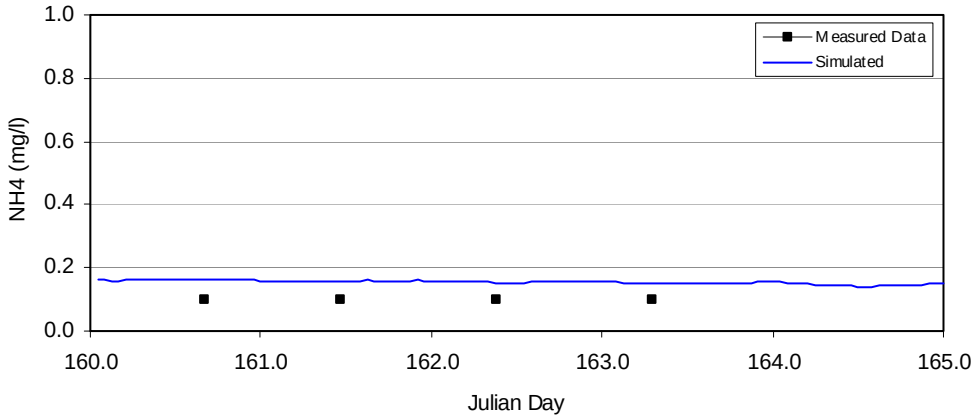


Figure 169. Klamath River at Martins Ferry simulated versus measured ammonia, June 9-12, 2003

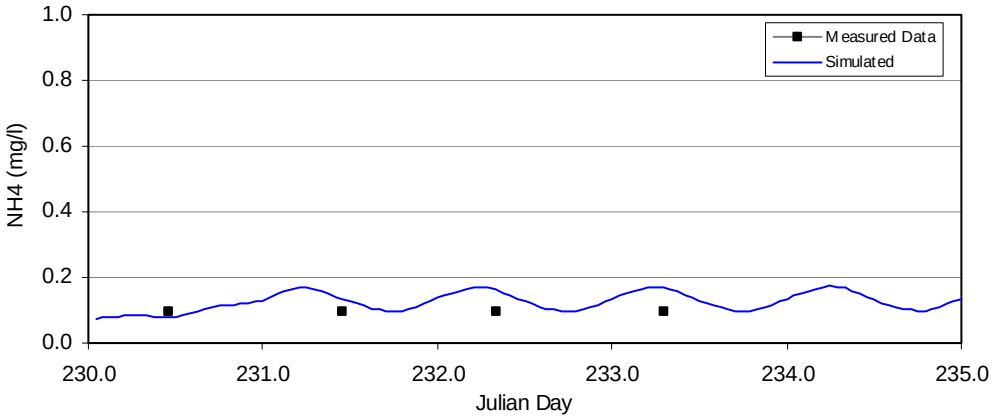


Figure 170. Klamath River at Tully Creek simulated versus measured ammonia, August 18-21, 2003

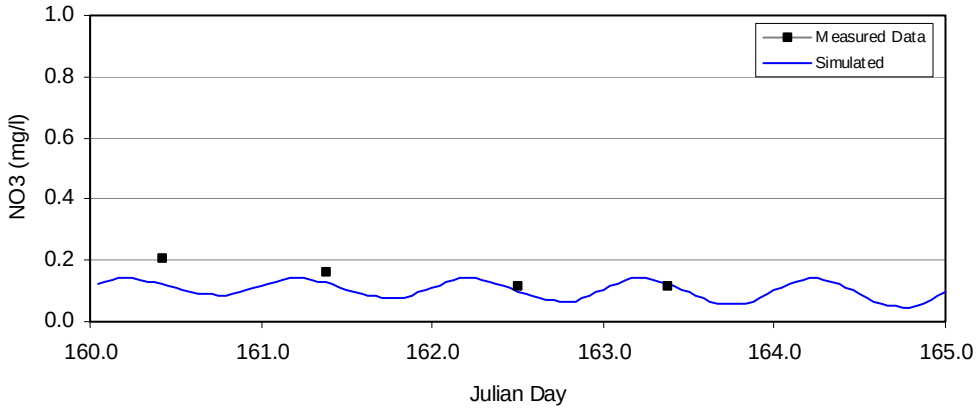


Figure 171. Klamath River above Shasta River simulated versus measured nitrate, June 9-12, 2003

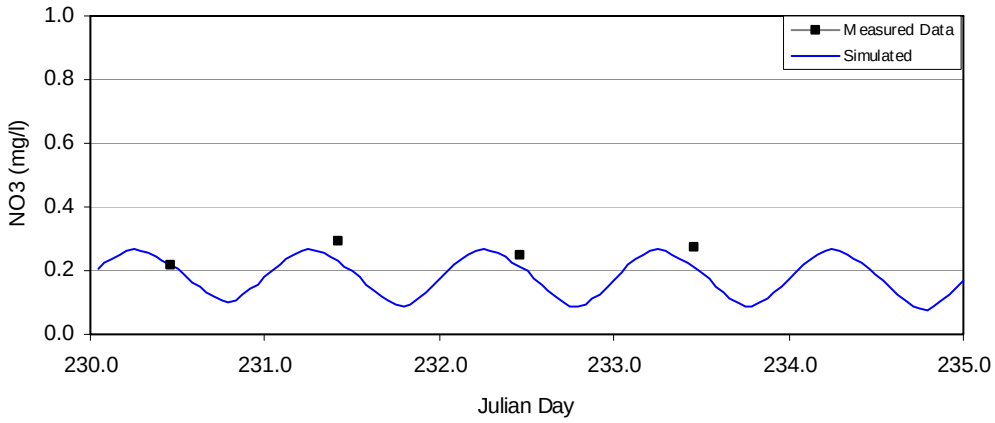


Figure 172. Klamath River above Shasta River simulated versus measured nitrate, August 18-21, 2003

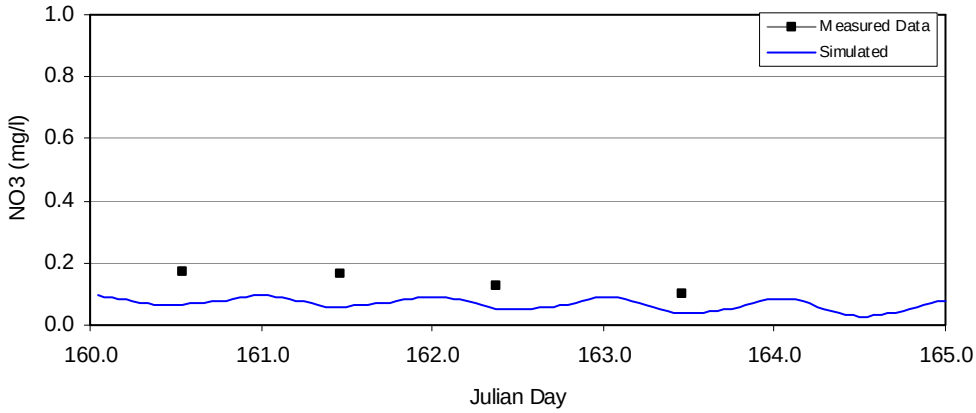


Figure 173. Klamath River above Scott River simulated versus measured nitrate, June 9-12, 2003

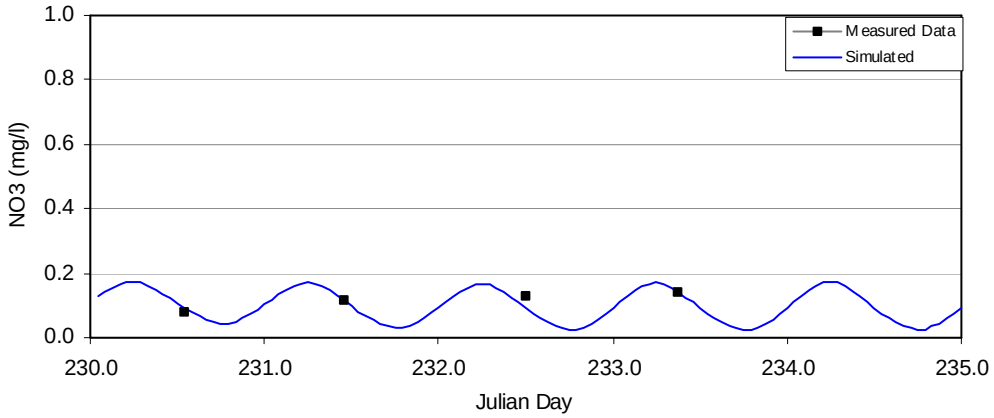


Figure 174. Klamath River above Scott River simulated versus measured nitrate, August 18-21, 2003

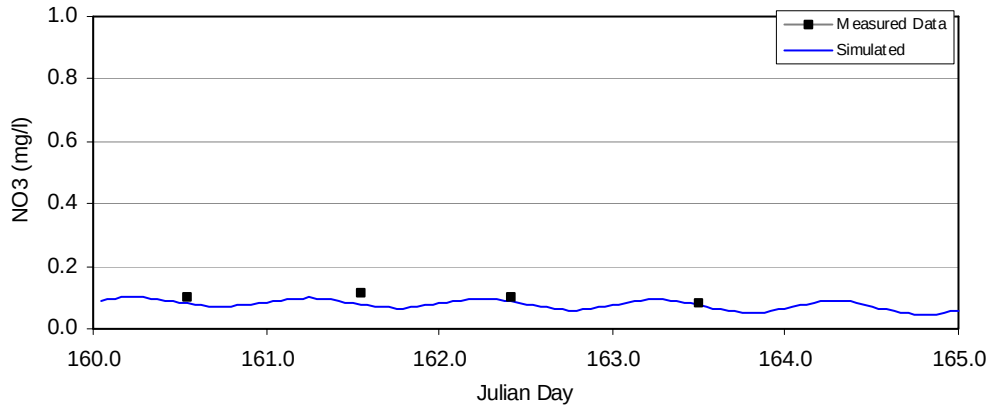


Figure 175. Klamath River near Seiad Valley simulated versus measured nitrate, June 9-12, 2003

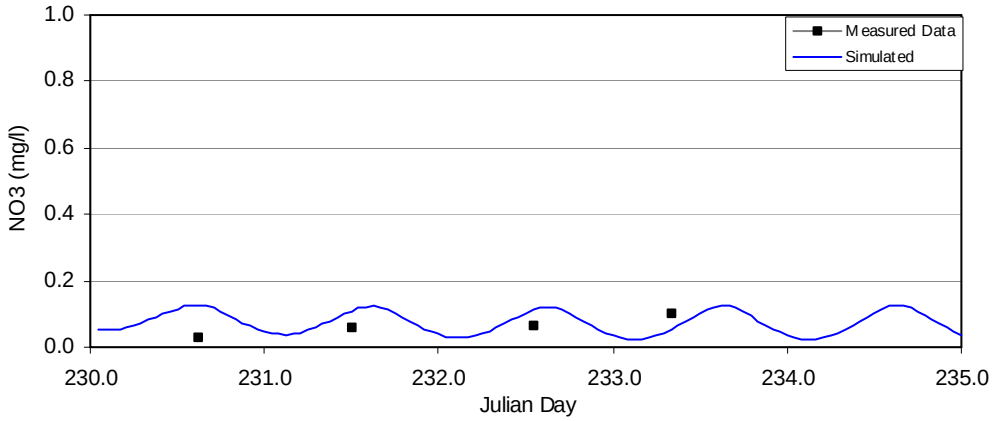


Figure 176. Klamath River near Seiad Valley simulated versus measured nitrate, August 18-21, 2003

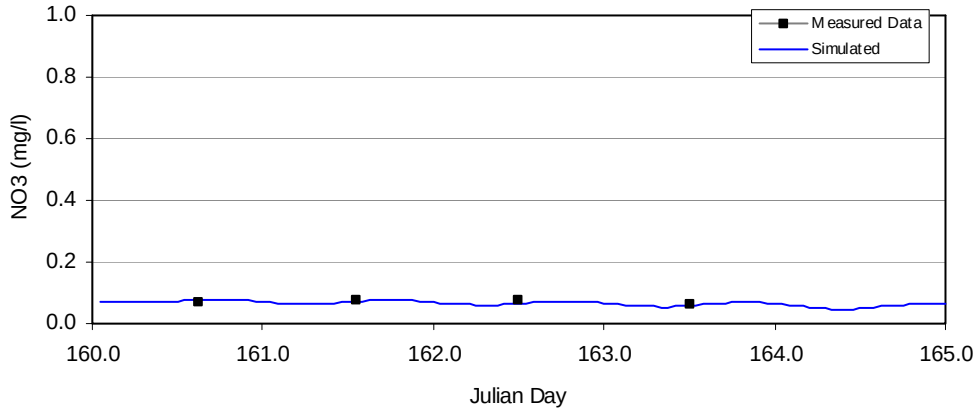


Figure 177. Klamath River above Clear Creek simulated versus measured nitrate, June 9-12, 2003

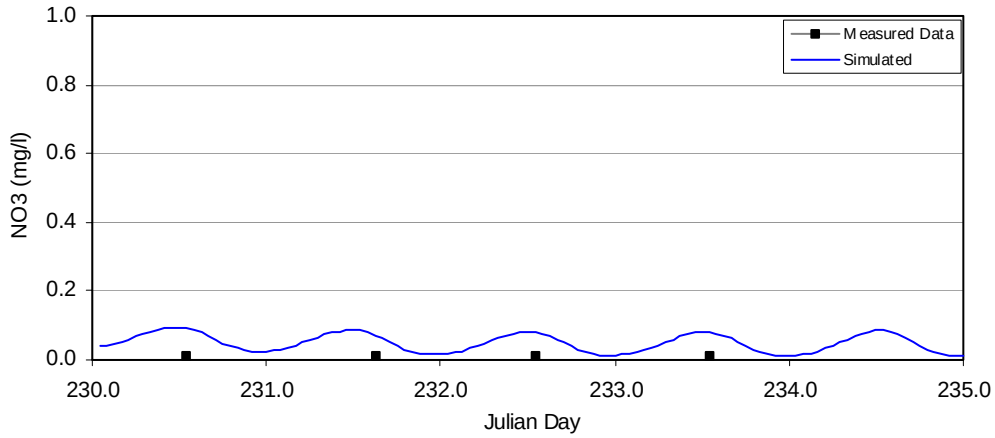


Figure 178. Klamath River above Clear Creek simulated versus measured nitrate, August 18-21, 2003

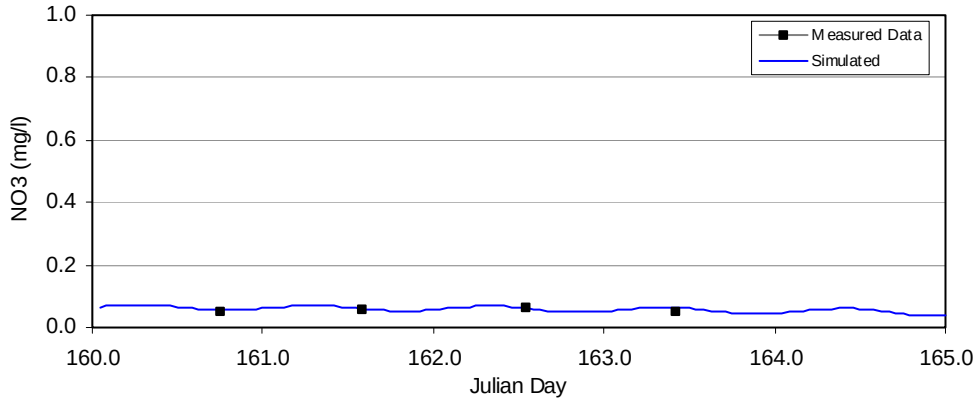


Figure 179. Klamath River above Salmon River simulated versus measured nitrate, June 9-12, 2003

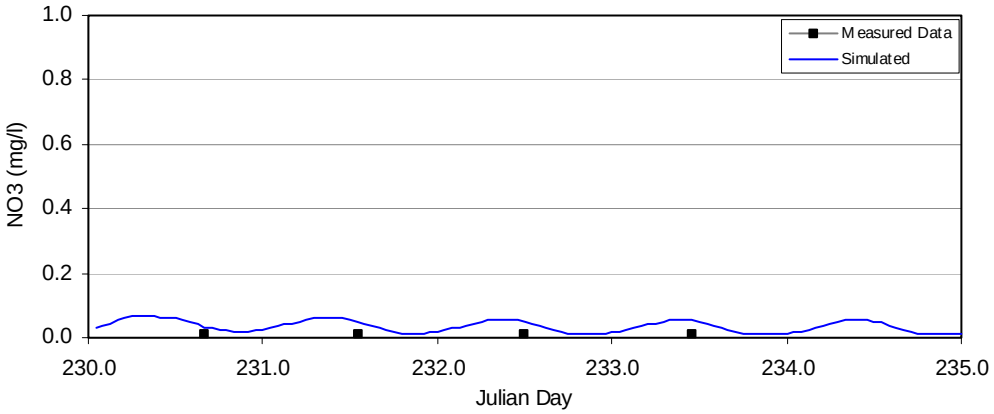


Figure 180. Klamath River above Salmon River simulated versus measured nitrate, August 18-21, 2003

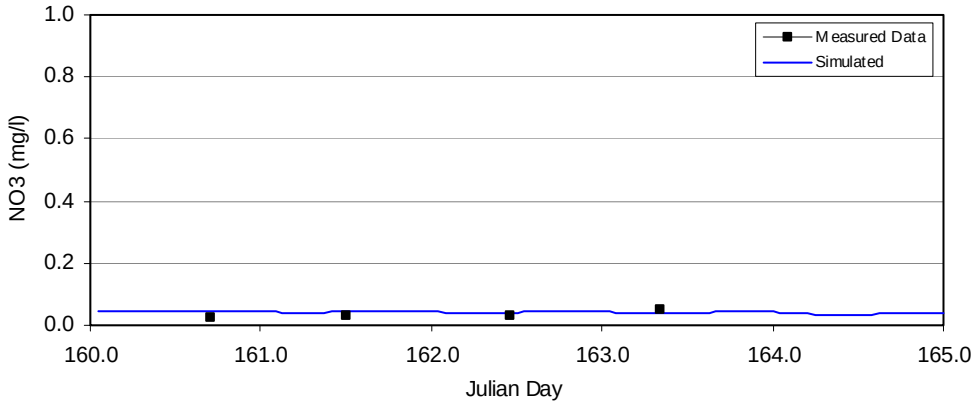


Figure 181. Klamath River above Trinity River simulated versus measured nitrate, June 9-12, 2003

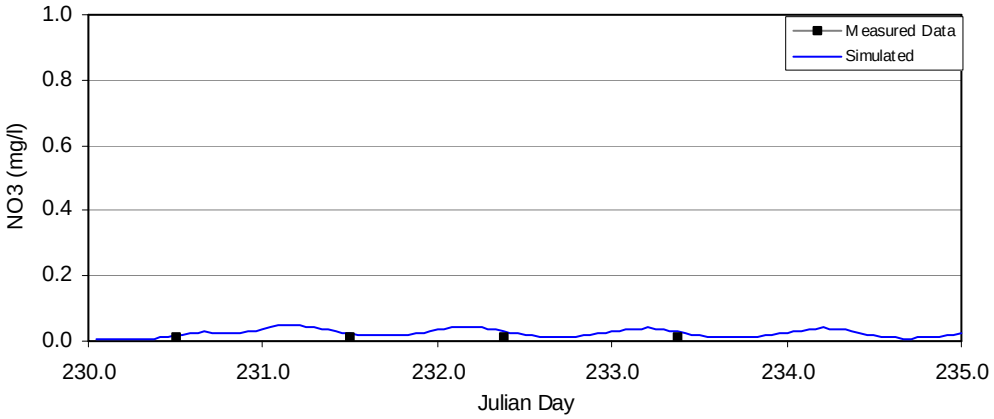


Figure 182. Klamath River above Trinity River simulated versus measured nitrate, August 18-21, 2003

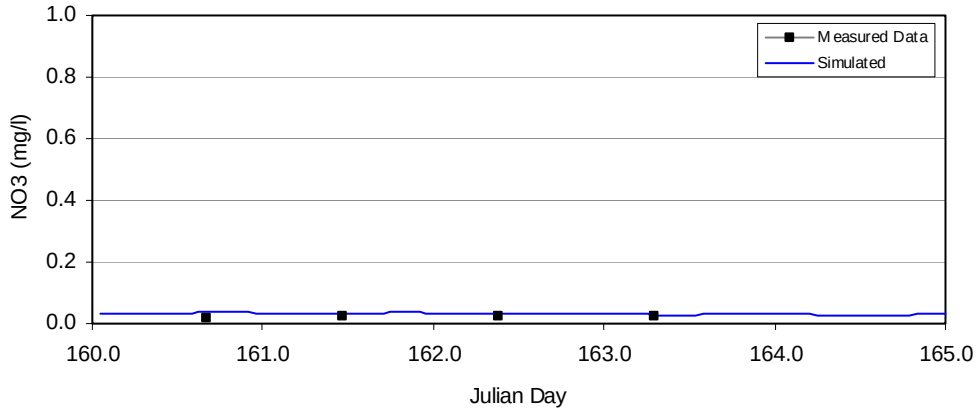


Figure 183. Klamath River at Martins Ferry simulated versus measured nitrate, June 9-12, 2003

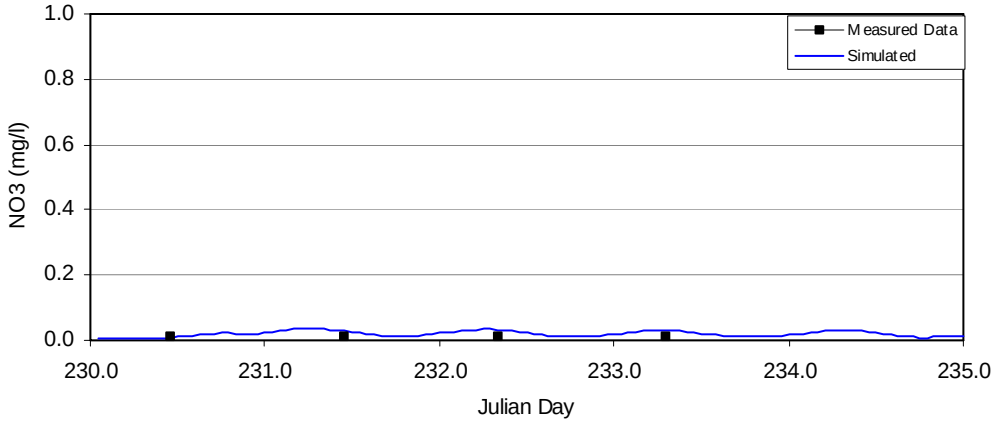


Figure 184. Klamath River at Tully Creek simulated versus measured nitrate, August 18-21, 2003

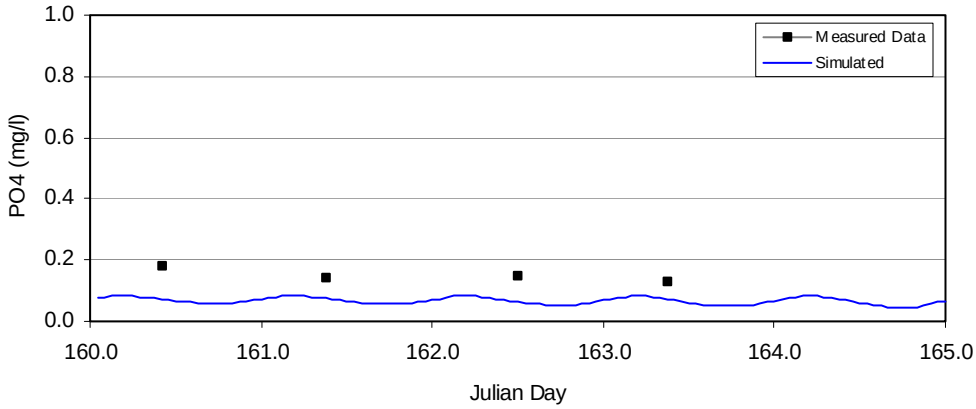


Figure 185. Klamath River above Shasta River simulated versus measured orthophosphate, June 9-12, 2003

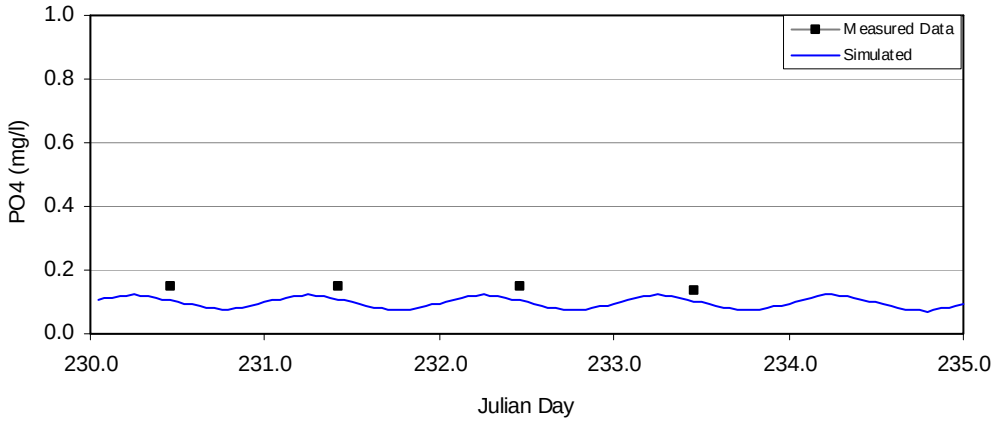


Figure 186. Klamath River above Shasta River simulated versus measured orthophosphate, August 18-21, 2003

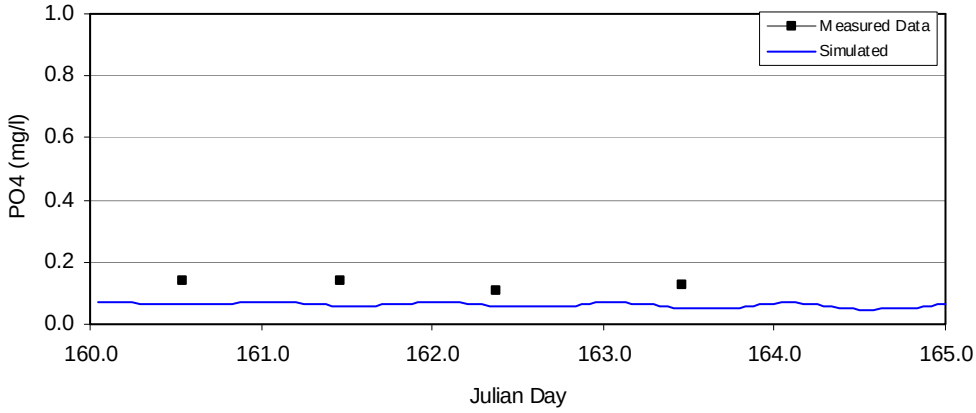


Figure 187. Klamath River above Scott River simulated versus measured orthophosphate, June 9-12, 2003

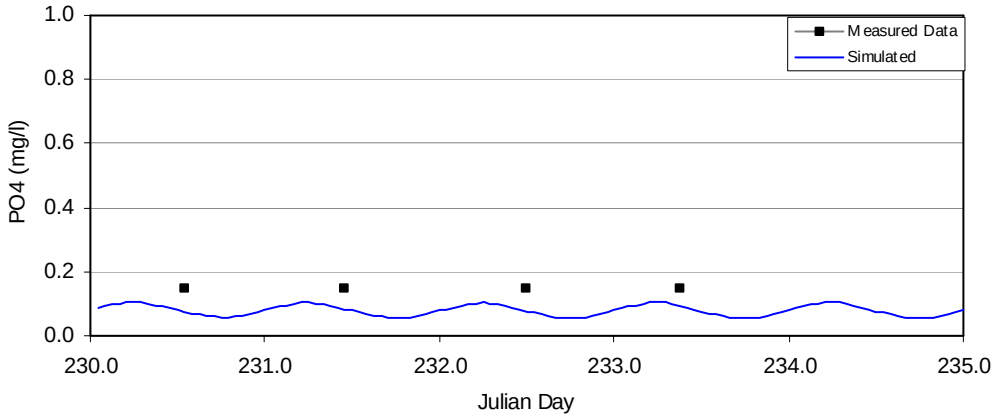


Figure 188. Klamath River above Scott River simulated versus measured orthophosphate, August 18-21, 2003

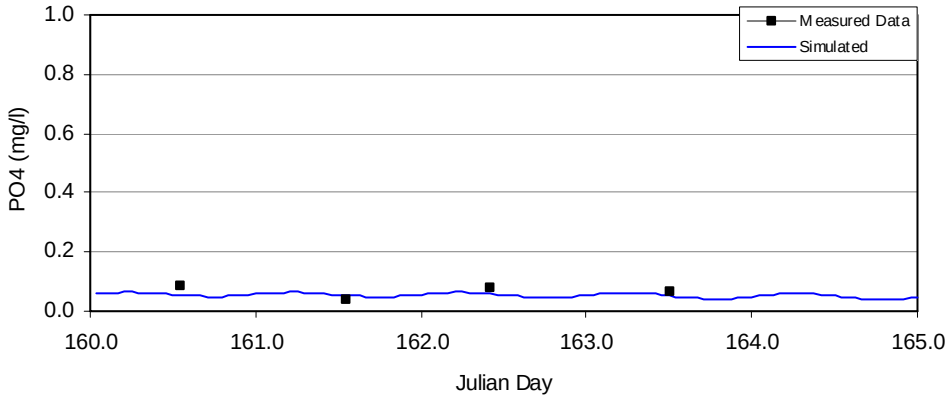


Figure 189. Klamath River near Seiad Valley simulated versus measured orthophosphate, June 9-12, 2003

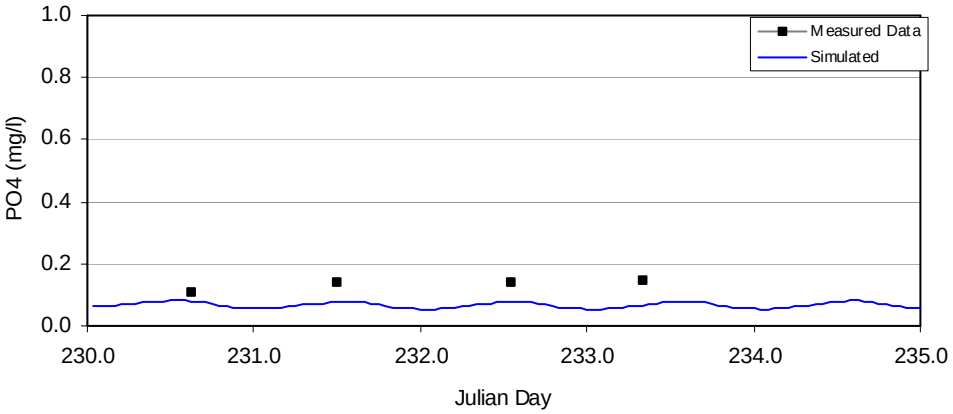


Figure 190. Klamath River near Seiad Valley simulated versus measured orthophosphate, August 18-21, 2003

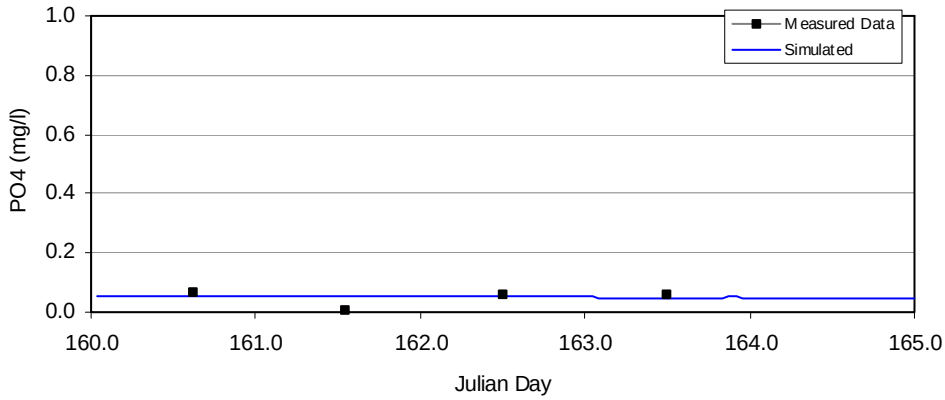


Figure 191. Klamath River above Clear Creek simulated versus measured orthophosphate, June 9-12, 2003

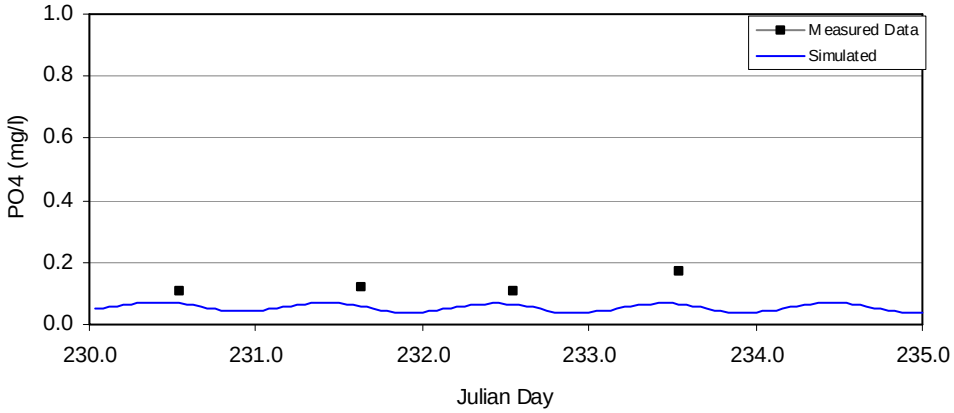


Figure 192. Klamath River above Clear Creek simulated versus measured orthophosphate, August 18-21, 2003

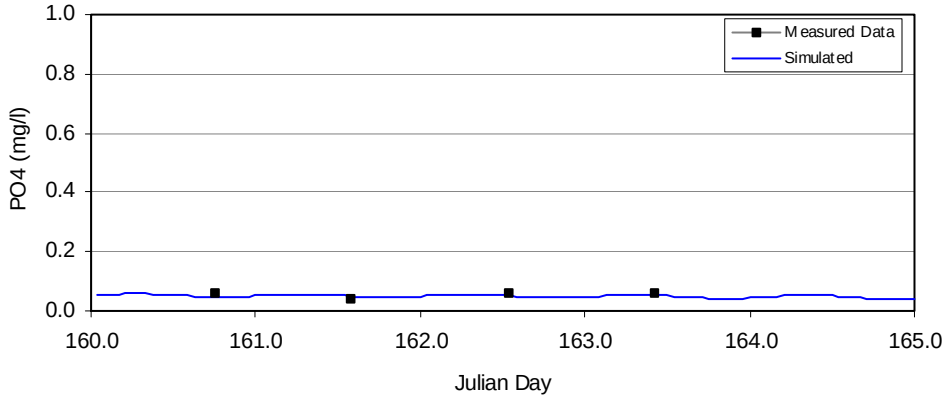


Figure 193. Klamath River above Salmon River simulated versus measured orthophosphate, June 9-12, 2003

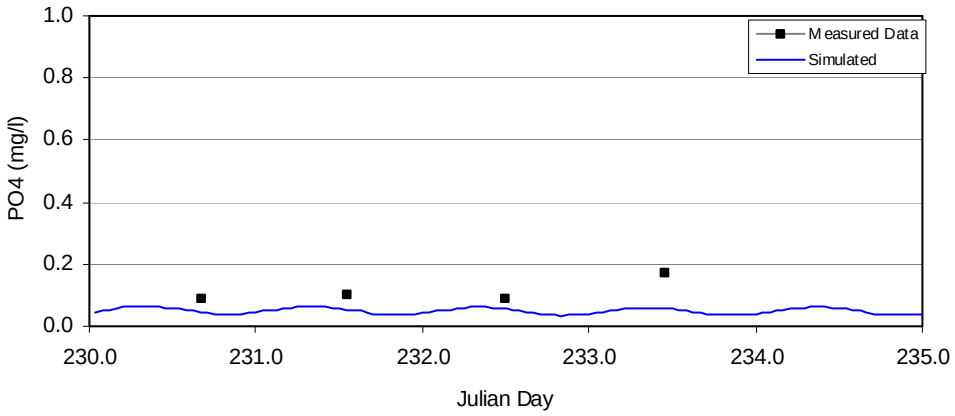


Figure 194. Klamath River above Salmon River simulated versus measured orthophosphate, August 18-21, 2003

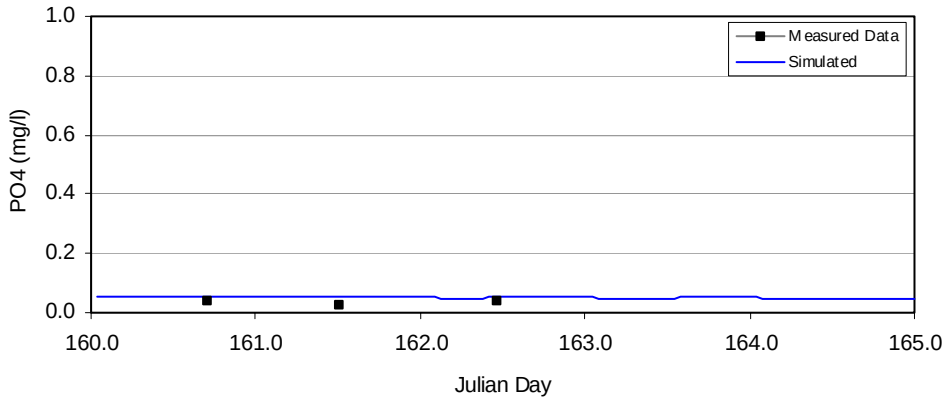


Figure 195. Klamath River above Trinity River simulated versus measured orthophosphate, June 9-12, 2003

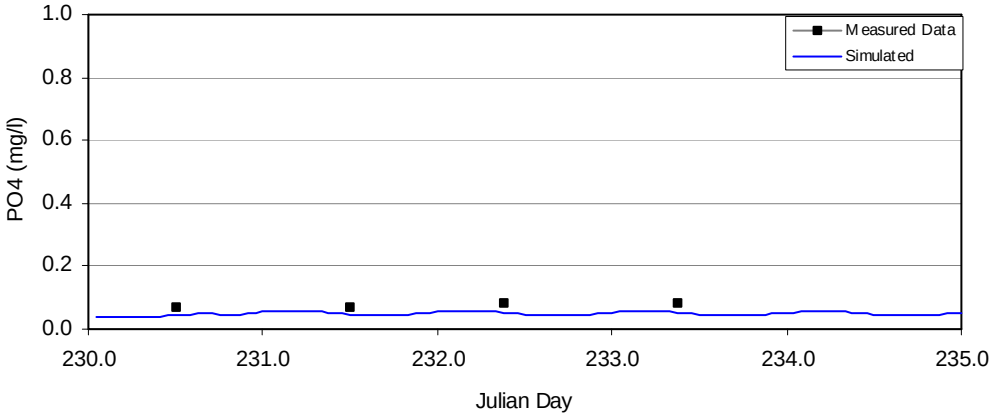


Figure 196. Klamath River above Trinity River simulated versus measured orthophosphate, August 18-21, 2003

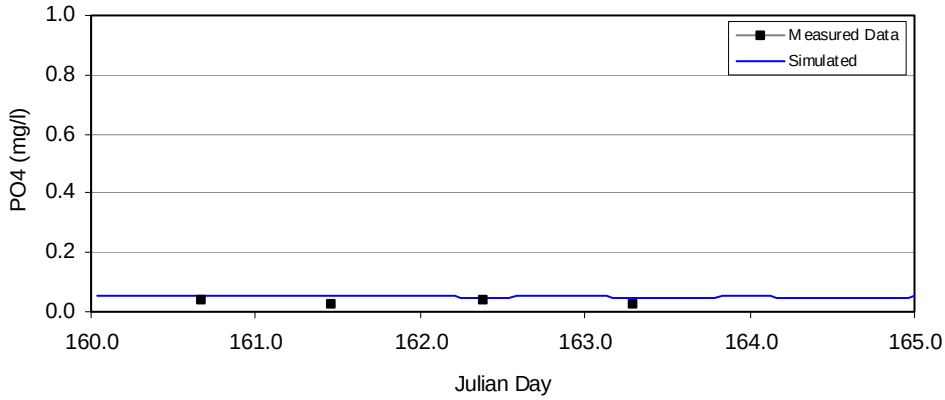


Figure 197. Klamath River at Martins Ferry simulated versus measured orthophosphate, June 9-12, 2003

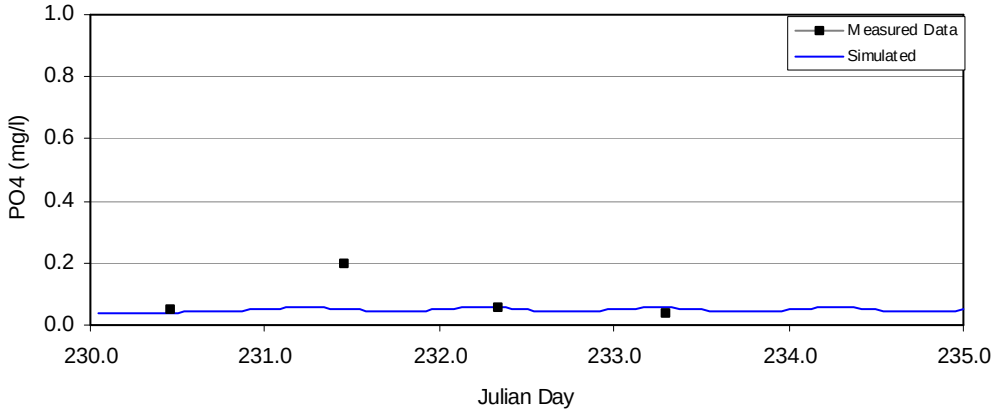


Figure 198. Klamath River at Tully Creek simulated versus measured orthophosphate, August 18-21, 2003

Table 67. Klamath River hourly and daily calibration statistics for nutrients 2003

Ammonia, NH_4^+

JUNE	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	Near Martins Ferry
Bias	0.02	0.04	0.05	0.07	0.06	0.05	0.06
MAE	0.02	0.04	0.05	0.07	0.06	0.07	0.06
RMSE	0.03	0.05	0.05	0.07	0.06	0.07	0.06
n	4	4	4	4	4	4	4

AUGUST	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	At Tully Ck
Bias	0.01	0.05	0.06	0.06	0.03	0.03	0.04
MAE	0.01	0.05	0.06	0.06	0.04	0.03	0.05
RMSE	0.01	0.06	0.06	0.06	0.03	0.04	0.05
n	4	4	4	4	4	4	4

Nitrate, NO_3^-

JUNE	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	Near Martins Ferry
Bias	-0.03	-0.09	-0.02	-0.01	0.01	0.01	0.01
MAE	0.04	0.09	0.02	0.01	0.01	0.01	0.01
RMSE	0.05	0.10	0.03	0.01	0.00	0.02	0.01
n	4	4	4	4	4	4	4

AUGUST	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	At Tully Ck
Bias	-0.04	0.00	0.04	0.07	0.04	0.01	0.02
MAE	0.04	0.01	0.06	0.07	0.04	0.01	0.02
RMSE	0.04	0.01	0.06	0.07	0.03	0.02	0.02
n	4	4	4	4	4	4	4

Orthophosphate, PO_4^{3-}

JUNE	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	Near Martins Ferry
Bias	-0.08	-0.07	-0.02	0.00	0.00	0.02	0.02
MAE	0.08	0.07	0.02	0.02	0.01	0.02	0.02
RMSE	0.08	0.07	0.03	0.03	0.01	0.02	0.02
n	4	4	4	4	4	3	4

AUGUST	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	At Tully Ck
Bias	-0.04	-0.07	-0.06	-0.06	-0.06	-0.03	-0.04
MAE	0.04	0.07	0.06	0.06	0.06	0.03	0.04
RMSE	0.04	0.07	0.06	0.05	0.04	0.03	0.07
n	4	4	4	4	4	4	4

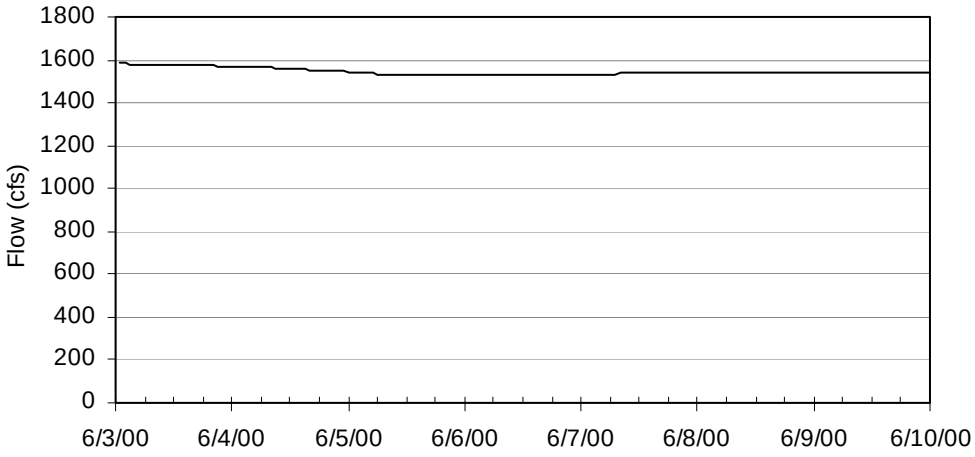
3.9.4 Model Application for 2000

The model was applied to the 2000 period and compared with available data: June 5-7, 2000 (Julian Day 157-159) and August 7-9, 2000 (JD 220-222). The process of identifying initial conditions, boundary conditions, and calibration data were the same as in 2003. These data are briefly discussed below, but the graphical and tabular presentation is not presented for sake of brevity.

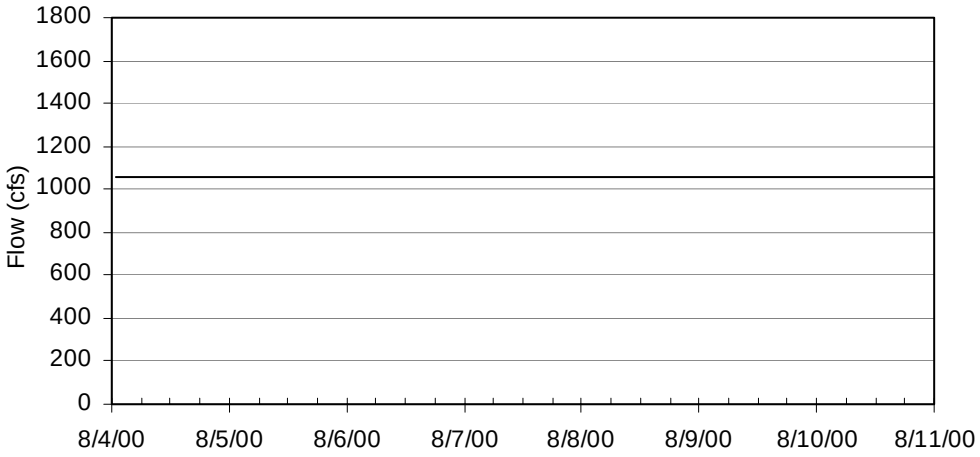
3.9.4.1 Data: 2000

Boundary Conditions at Iron Gate Dam

Flow data were derived in a similar fashion to 2003. The temperature and dissolved oxygen boundary conditions data for Iron Gate Dam were derived from hourly data recorded by sondes deployed in 2000 by USBR at Klamath River below Iron Gate Dam. The constituent concentration boundary condition data for the Iron Gate Dam was derived from 2000 grab samples (USBR, 2003), which were collected three times per day during the June and August periods. The concentrations were averaged for each period and the average was applied to the calibration or validation period as a constant boundary condition (Table 68). All boundary conditions for the tributaries were those used in model implementation, as described in section 2.3.8, and are not revisited herein.



(a)



(b)

Figure 199. Gauged flow at Klamath River below Iron Gate Dam for Iron Gate to Turwar reach model 2000: (a) June, (b) August

Table 68. Water quality constituent boundary conditions for the Klamath River below Iron Gate Dam: June and August 2000

Constituent	Unit	June	August
Temp	C	hourly	hourly
DO	mg/l	hourly	hourly
BOD	mg/l	2.00	2.00
OrgN	mg/l	0.70	0.55
NH4	mg/l	0.10	0.10
NO2	mg/l	0.00	0.00
NO3	mg/l	0.06	0.30
OrgP	mg/l	0.05	0.00
PO4	mg/l	0.25	0.15
Chlor_a	mg/m^3	10.00	10.00

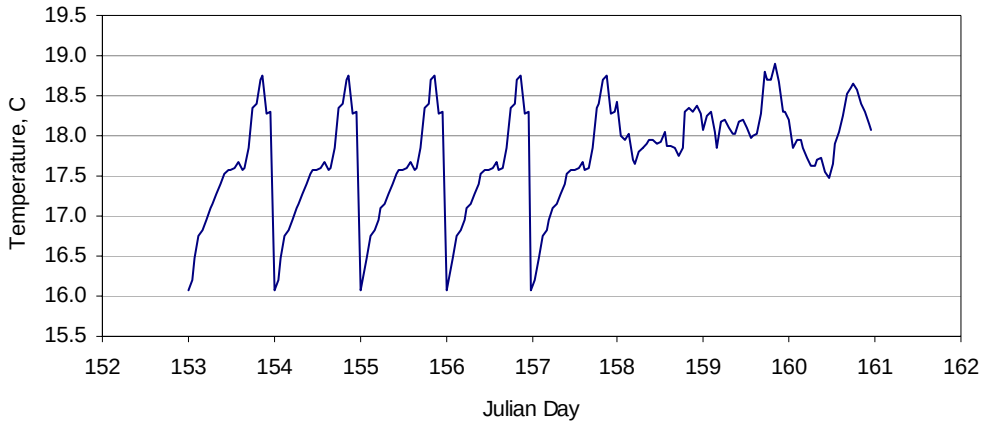


Figure 200. Klamath River below Iron Gate water temperature: June 1-9, 2000 (JD 153-161)

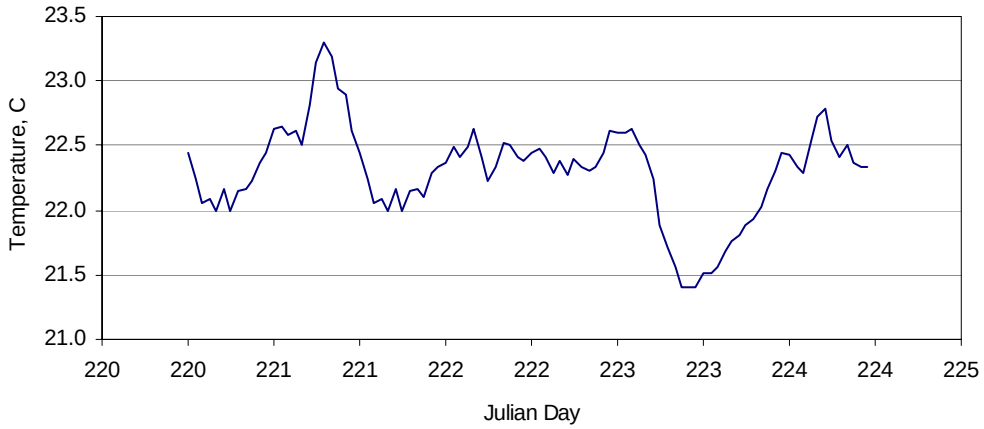


Figure 201. Klamath River below Iron Gate water temperature : August 7-15, 2000 (JD 220-224)

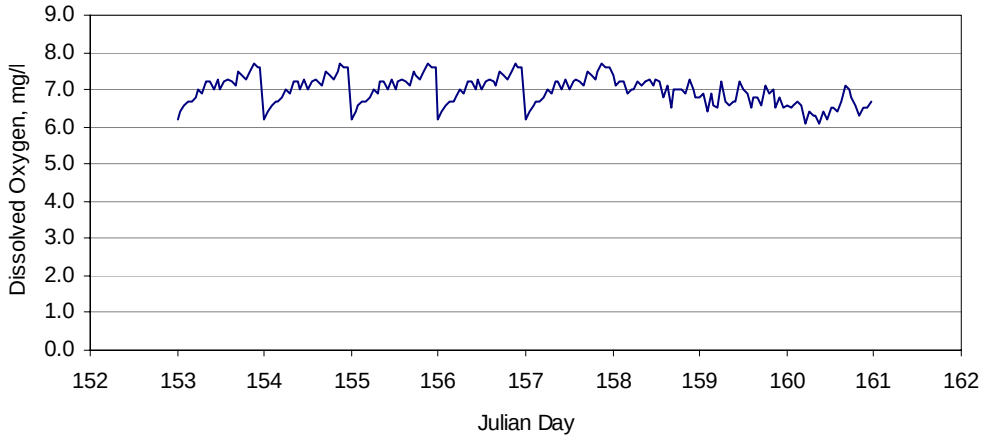


Figure 202. Klamath River below Iron Gate dissolved oxygen: June 1-9, 2000 (JD 153-161)

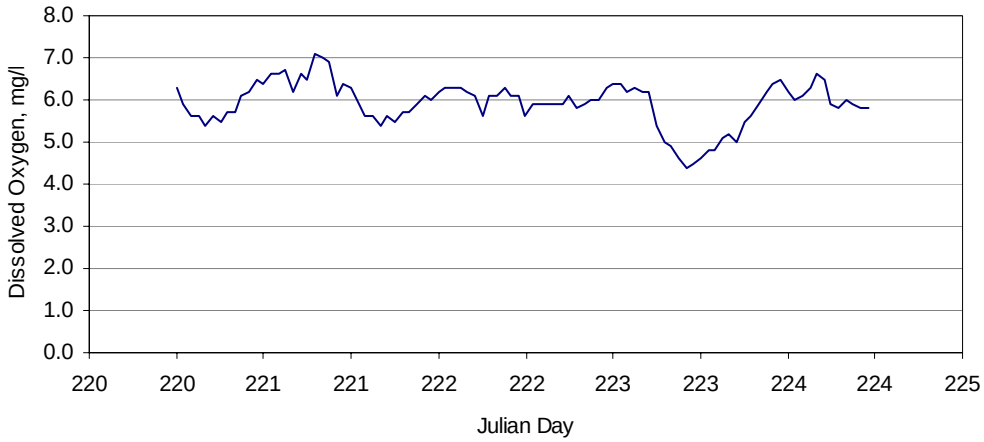


Figure 203. Klamath River below Iron Gate dissolved oxygen: August 7-15, 2000 (JD 220-224)

Initial Conditions

The model was run for two days prior to the 2000 calibration period (approximate travel time from Iron Gate to Seiad Valley) to provide an initial condition for simulations. The initial bed algae mass was estimated at 5 g/m^2. Where field data were unavailable, the conditions of the first day of available field data were applied.

Model Output Locations

For the 2000 simulation, model output was compared with observations at: Klamath River above Shasta River, above Walker Road Bridge, above Scott River, and near Seiad Valley. For dissolved oxygen there was only sufficient data for the Klamath River above the Shasta River and near Seiad Valley. Water quality probes and/or temperature loggers were employed to record conditions at the identified locations, and grab samples were available from USBR (2003). These data are displayed in the following section with model results.

All water quality probes and grab samples were collected from near-shore areas and although all efforts were made to identify locations that were deemed consistent with overall main stem conditions (e.g., areas that readily exchanged water with main flow in the river), several factors could result in potential deviation main stem conditions. The primary factor is probably the rapidly descending hydrographs in the June sampling periods which changed local conditions at some sampling locations and required successive re-deployment of water quality probes as water levels fell.

3.9.5 Results 2000

Results of year 2000 simulations were complete for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents (i.e., summary statistics were not computed). Field observations for temperature and dissolved oxygen were available from water quality probes on an hourly interval for June and August 2000 at multiple sites from Iron Gate Dam to Seiad Valley allowing for summary statistics to be calculated both on hourly and daily basis.

3.9.5.1 Water Temperature

Overall simulated results indicate that phase and amplitude were well represented during the 2000 periods and the mean absolute error between hourly simulated and observed value was less than 1.2°C at all locations. The mean absolute error in daily averaged values was 1.0°C or less at all locations. Simulated and observed temperatures results for each location are presented below.

At Klamath River above Shasta River, the diurnal range and phase were well represented in both periods of examination. Hourly bias for the June period was –0.17°C with a mean absolute error of 1.19°C. Hourly bias for the August period was 0.54°C with a mean absolute error of 0.70°C.

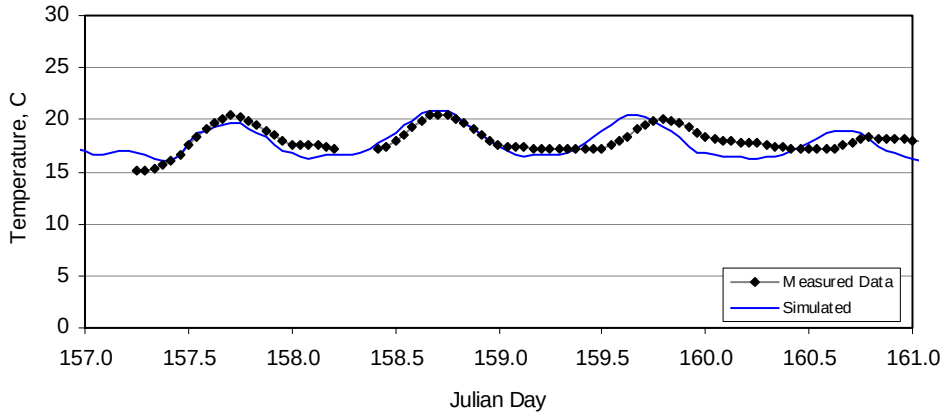


Figure 204. Klamath River above Shasta River simulated versus measured water temperature, June 5-7, 2000

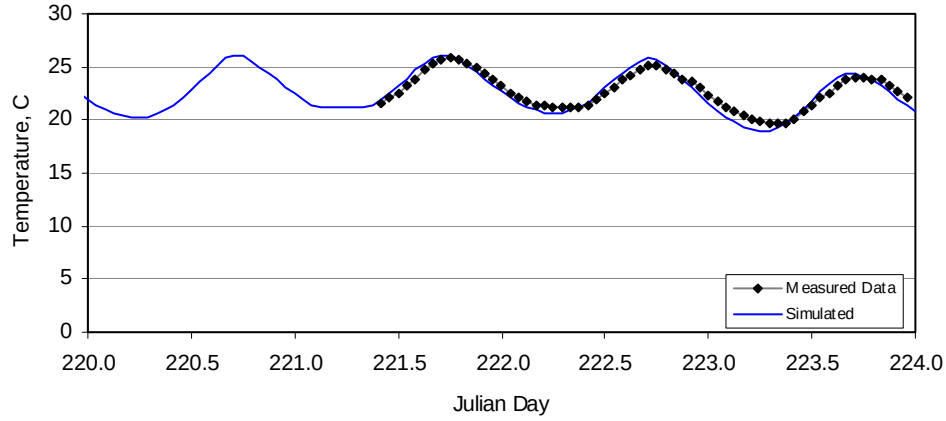


Figure 205. Klamath River above Shasta River simulated versus measured water temperature, August 7-9, 2000

At Klamath River at Walker Road Bridge, the moderated diurnal phase associated with the node of minimum diurnal variation due to Iron Gate Dam operations was well represented for both June and August periods. Hourly bias for the June period was 0.26°C with a mean absolute error of 0.47°C. Hourly bias for the August period was -0.25°C with a mean absolute error of 0.75°C.

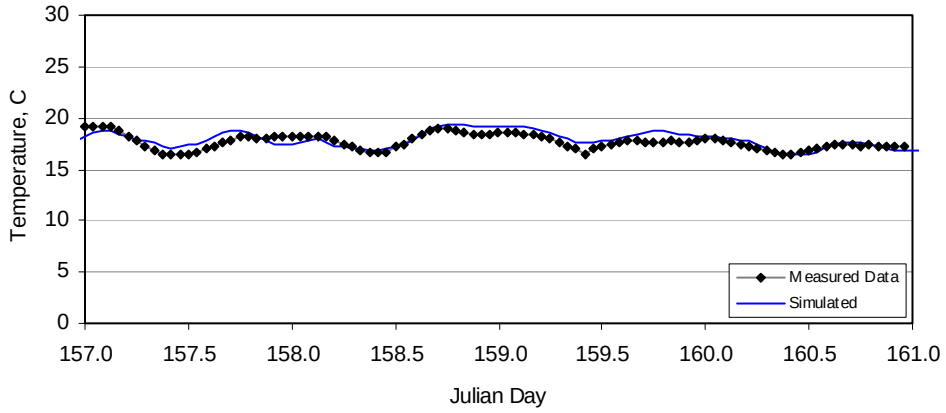


Figure 206. Klamath River above Walker Road Bridge (RM 156) simulated versus measured water temperature, June 5-7, 2000

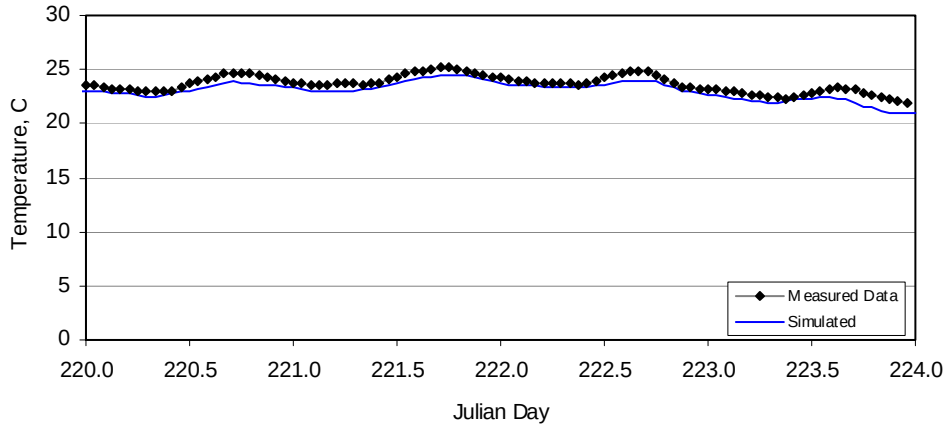


Figure 207. Klamath River above Walker Road Bridge (RM 156) simulated versus measured water temperature, August 7-9, 2000

At Klamath River above Scott River, the diurnal range and phase were generally well represented in both periods of examination. Hourly bias for the June period was 0.02°C with a mean absolute error of 0.51°C. Hourly bias for the August period was -0.53°C with a mean absolute error of 0.98°C.

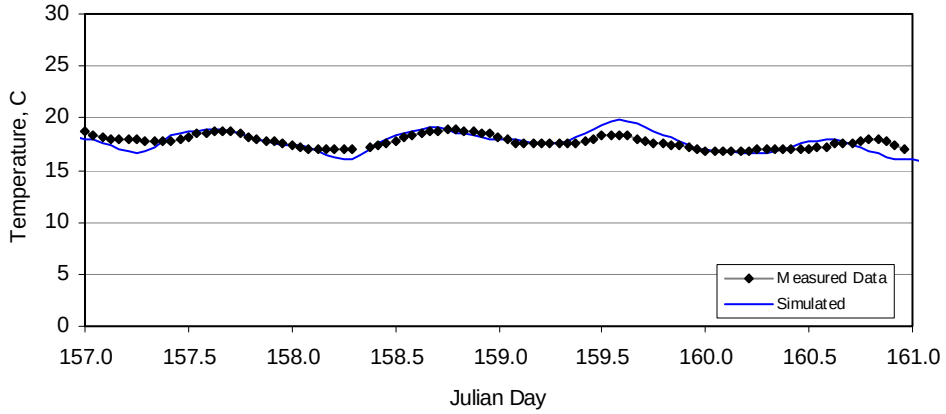


Figure 208. Klamath River above Scott River versus measured water temperature, June 5-7, 2000

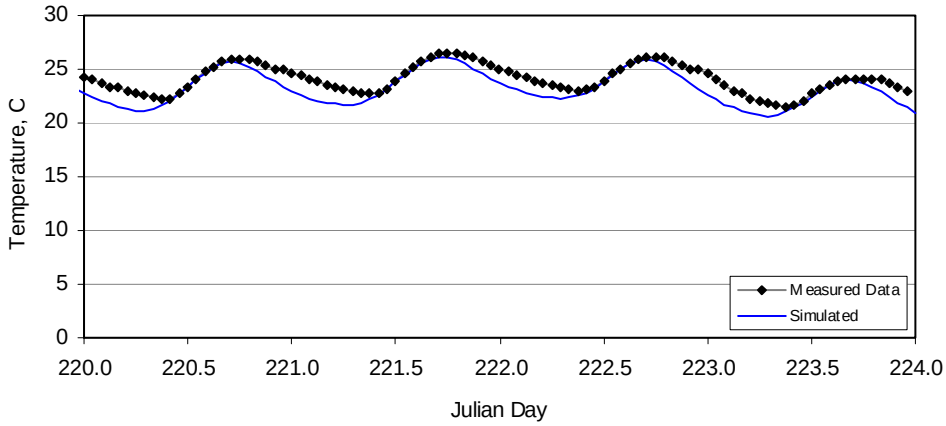


Figure 209. Klamath River above Scott River simulated versus measured water temperature, August 7-9, 2000

At Klamath River near Seiad Valley, the diurnal range and phase were well represented in both periods of examination; however, the model systematically under predicts in August. Hourly bias for the June period was -0.04°C with a mean absolute error of 0.38°C. Hourly bias for the August period was -0.78°C with a mean absolute error of 1.06°C.

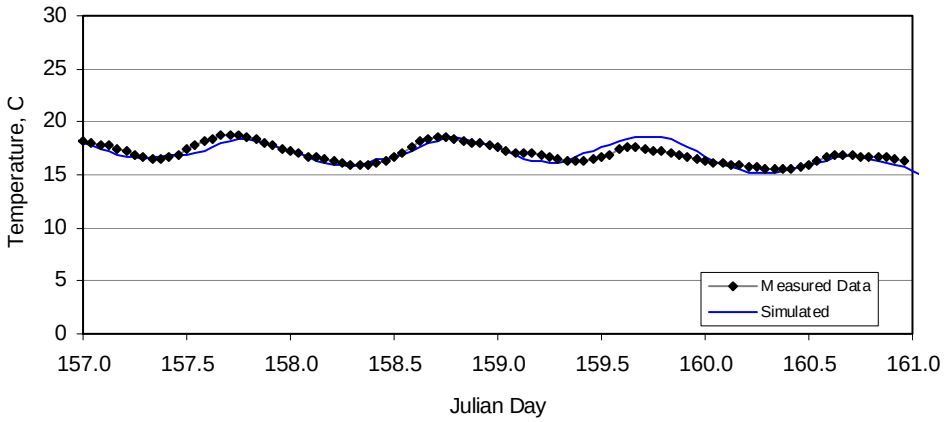


Figure 210. Klamath River near Seiad Valley versus measured water temperature, June 5-7, 2000

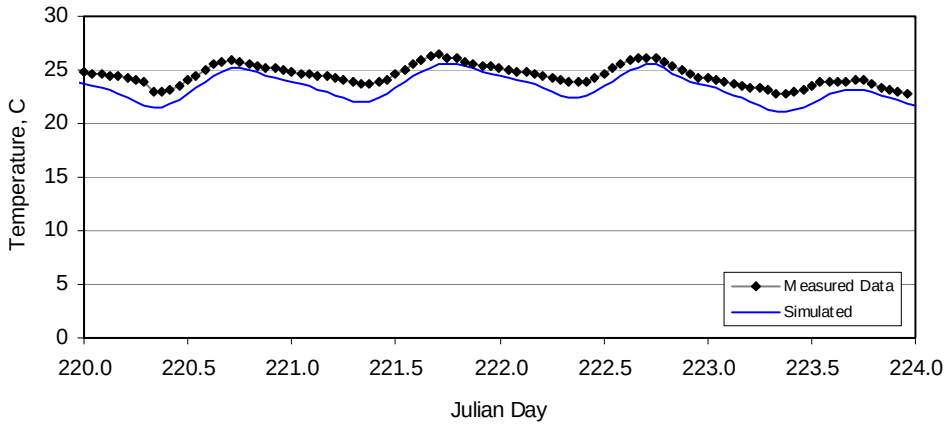


Figure 211. Klamath River near Seiad Valley versus measured water temperature, August 7-9, 2000

Table 69. Klamath River hourly and daily calibration and validation period statistics for water temperature 2000

Calibration / Validation Statistics		Hourly		Daily	
	Unit	June	August	June	August
Klamath River ab Shasta River					
Mean Bias[a]	°C	-0.17	0.54	-0.25	0.68
Mean absolute error (MAE)	°C	1.19	0.70	0.25	0.68
Root mean squared error (RMSE)	°C	1.48	0.87	0.26	0.77
n	-	92	62	3	2
Klamath River at Walker Road Bridge					
Mean Bias[a]	°C	0.26	-0.25	0.26	-0.25
Mean absolute error (MAE)	°C	0.47	0.75	0.26	0.67
Root mean squared error (RMSE)	°C	0.56	0.84	0.36	0.74
n	-	96	96	4	4
Klamath River ab Scott River					
Mean Bias[a]	°C	0.02	-0.53	0.01	-0.53
Mean absolute error (MAE)	°C	0.51	0.98	0.31	0.87
Root mean squared error (RMSE)	°C	0.67	1.19	0.36	0.92
n	-	95	96	4	4
Klamath River near Seiad Valley					
Mean Bias[a]	°C	-0.04	-0.78	-0.04	-0.78
Mean absolute error (MAE)	°C	0.38	1.06	0.26	1.00
Root mean squared error (RMSE)	°C	0.50	1.21	0.30	1.08
n	-	96	96	4	4

[a] Mean bias = simulated – measured

3.9.5.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates, and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeled in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from upstream Iron Gate Reservoir, growth rates were set to very low numbers in river reaches.

The hourly results are presented graphically in Figure 212 through Figure 216. Tabulated statistics are presented in Table 70.

At Klamath River above Shasta River, the diurnal phase is well represented during both June and August periods. However, the diurnal range in June is under represented and the shape of the daily cycle deviates from observed data. Hourly bias for the June period was 0.29 mg/l with a mean absolute error of 0.46 mg/l. Hourly bias for the August period was 0.48 mg/l with a mean absolute error of 0.56 mg/l.

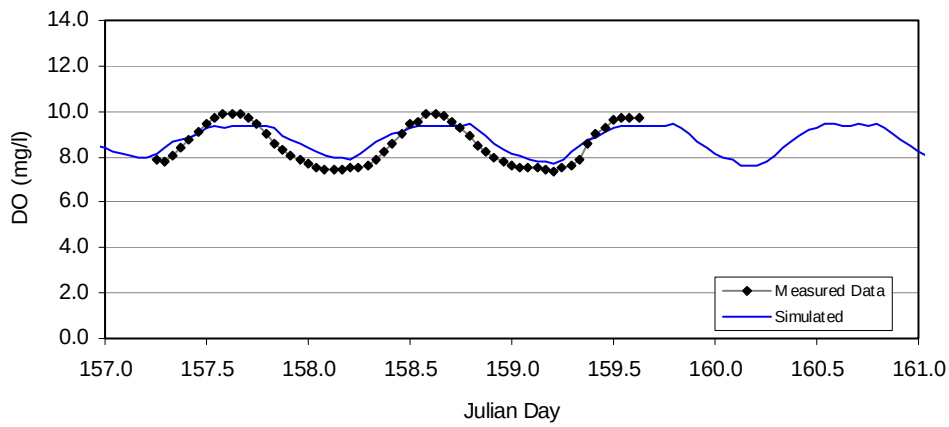


Figure 212. Klamath River above Shasta River simulated versus measured dissolved oxygen, June 5-7, 2000

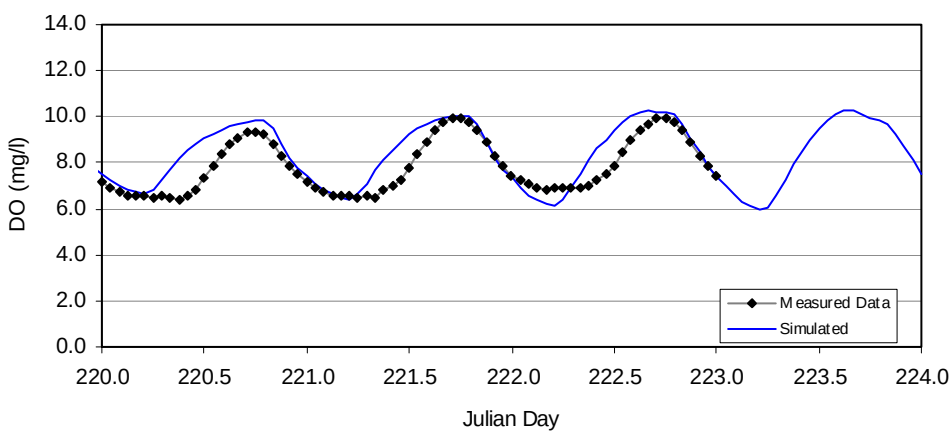


Figure 213. Klamath River above Shasta River simulated versus measured dissolved oxygen, August 7-9, 2000

There were no dissolved oxygen observations at Klamath River at Walker Road Bridge.

At Klamath River above Scott River, dissolved oxygen observations were only available during the August period (June data were unavailable). While the diurnal phase and range were well represented, the simulated values were offset approximately 1.5 mg/l higher than observations. Saturated dissolved oxygen concentration, included in the figure, suggest that the observed data were well below saturation, while model results are much more consistent with saturation dissolved oxygen values on a daily basis. Hourly bias for the August period was 1.50 mg/l with a mean absolute error of 1.50 mg/l.

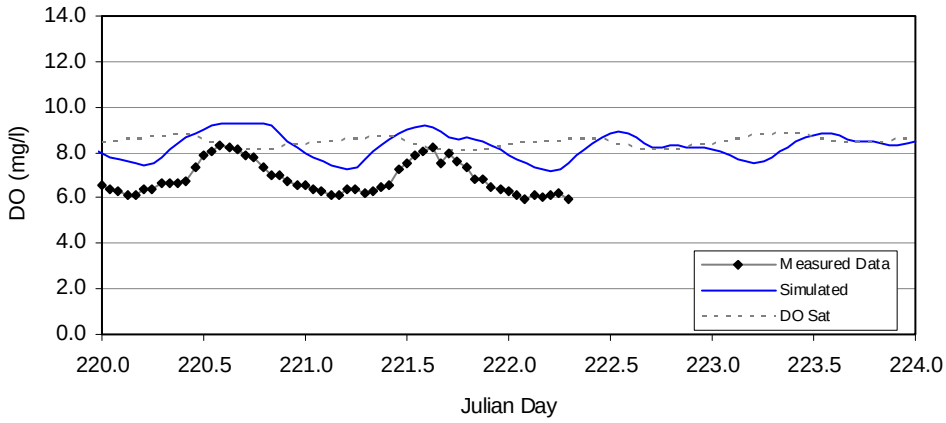


Figure 214. Klamath River above Scott River simulated versus measured dissolved oxygen, August 7-9, 2000

At Klamath River near Seiad Valley, during both June and August the diurnal phase and range were well represented; however, the simulated August values were offset by over 1.0 mg/l higher than observations. Saturated dissolved oxygen concentration, included in the figure, suggest that the observed data were well below saturation, while model results are much more consistent with saturation dissolved oxygen values on a daily basis. Hourly bias for the June period (calibration) was 0.19 mg/l with a mean absolute error of 0.27 mg/l. Hourly bias for the August period (validation) was 1.19 mg/l with a mean absolute error of 1.19 mg/l.

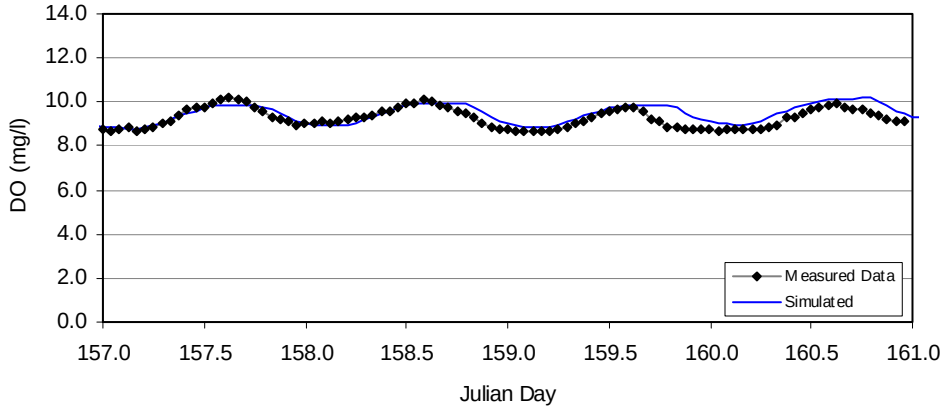


Figure 215. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, June 5-7, 2000

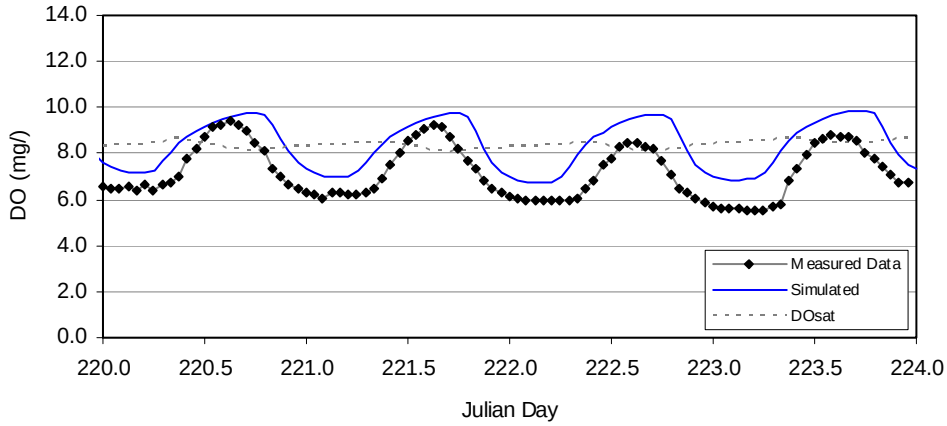


Figure 216. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, August 7-9, 2000

Table 70. Klamath River hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Klamath River ab Shasta River					
Mean Bias[a]	mg/l	0.29	0.48	0.35	0.49
Mean absolute error (MAE)	mg/l	0.46	0.56	0.35	0.49
Root mean squared error (RMSE)	mg/l	0.51	0.76	0.35	0.52
n	-	52	73	1	3
Klamath River ab Scott River					
Mean Bias[a]	mg/l	n/a	1.50	n/a	1.51
Mean absolute error (MAE)	mg/l	n/a	1.50	n/a	1.51
Root mean squared error (RMSE)	mg/l	n/a	1.54	n/a	1.51
n	-	n/a	56	n/a	2
Klamath River near Seiad Valley					
Mean Bias[a]	mg/l	0.19	1.19	0.19	1.19
Mean absolute error (MAE)	mg/l	0.27	1.19	0.19	1.19
Root mean squared error (RMSE)	mg/l	0.34	1.29	0.26	1.21
n	-	96	96	4	4

[a] Mean bias = simulated – measured

3.9.5.3 Nutrients

Nutrient concentrations were not formally calibration in the Iron Gate to Turwar reach. That is, values for nutrient interactions (e.g. stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the

dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 217 through Figure 234. Simulated concentrations for ammonia, nitrate, and orthophosphate were consistent with field observations. There is some scatter in the observed data that is not replicated within the model.

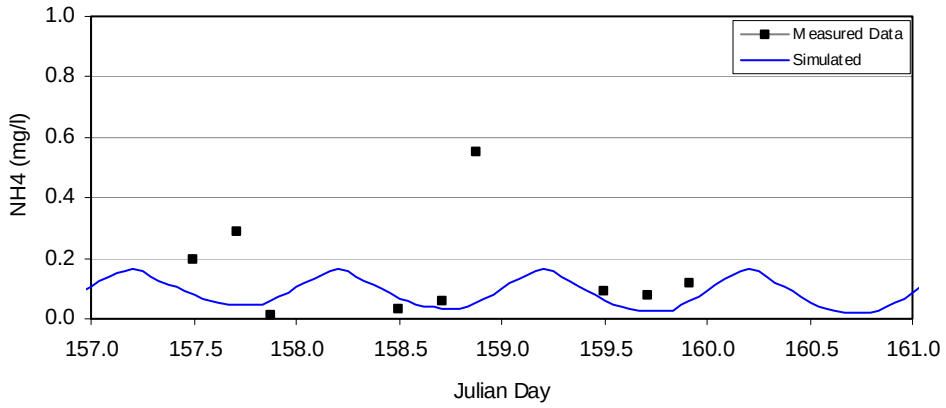


Figure 217. Klamath River above Shasta River simulated versus measured ammonia, June 5-7, 2000

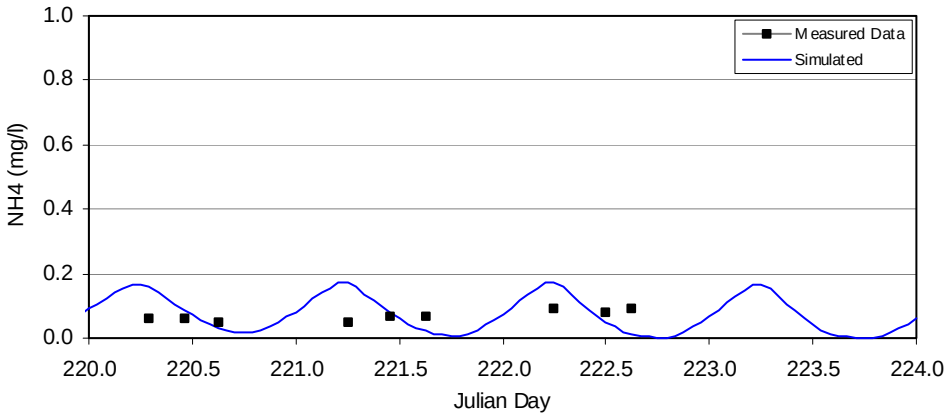


Figure 218. Klamath River above Shasta River simulated versus measured ammonia, August 7-9, 2000

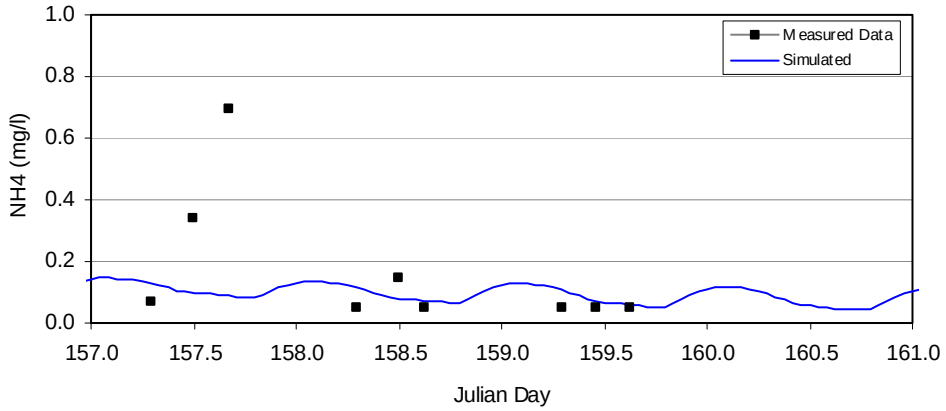


Figure 219. Klamath River above Scott River simulated versus measured ammonia, June 5-7, 2000

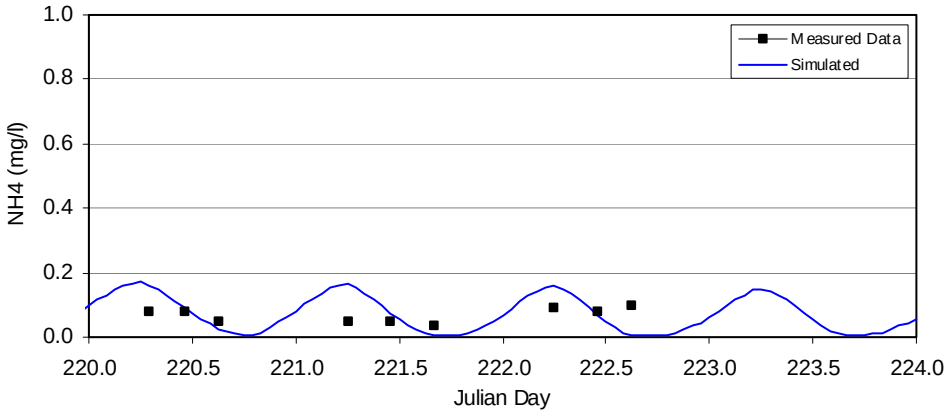


Figure 220. Klamath River above Scott River simulated versus measured ammonia, August 7-9, 2000

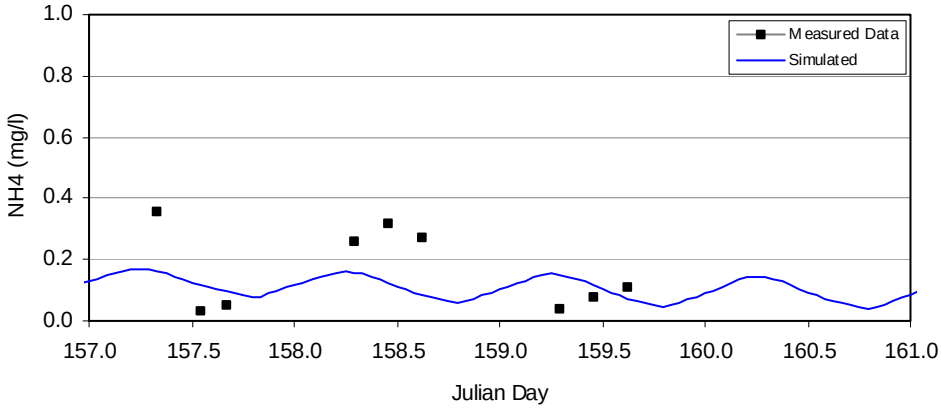


Figure 221. Klamath River near Seiad Valley simulated versus measured ammonia, June 5-7, 2000

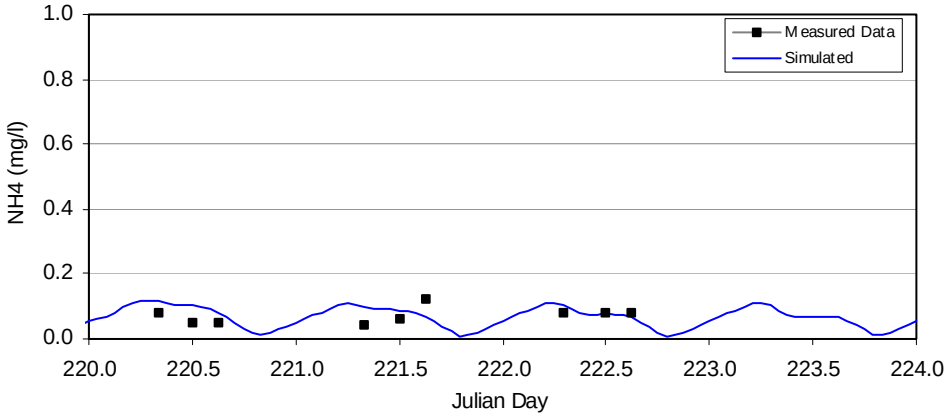


Figure 222. Klamath River near Seiad Valley River simulated versus measured ammonia, August 7-9, 2000

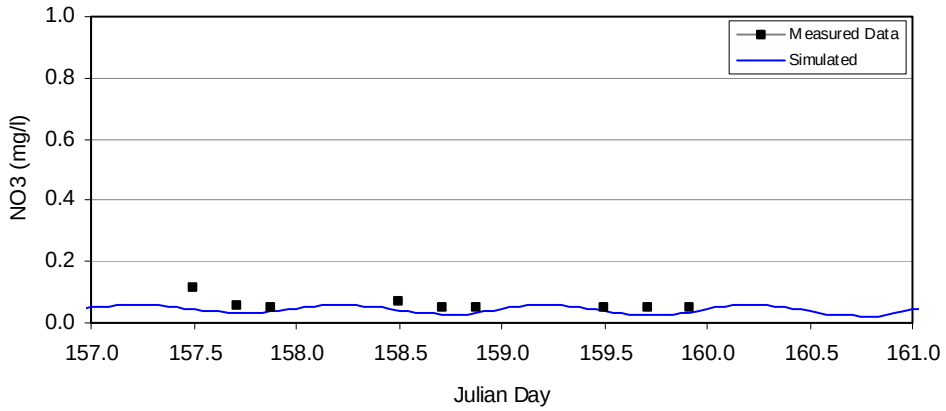


Figure 223. Klamath River above Shasta River simulated versus measured nitrate, June 5-7, 2000

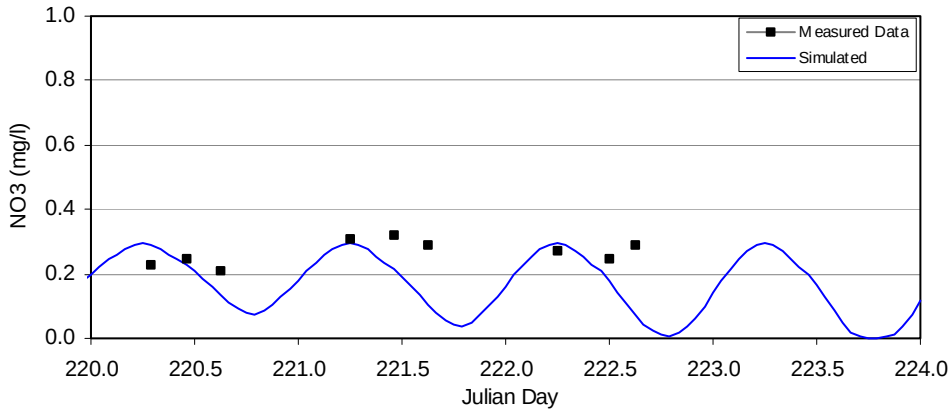


Figure 224. Klamath River above Shasta River simulated versus measured nitrate, August 7-9, 2000

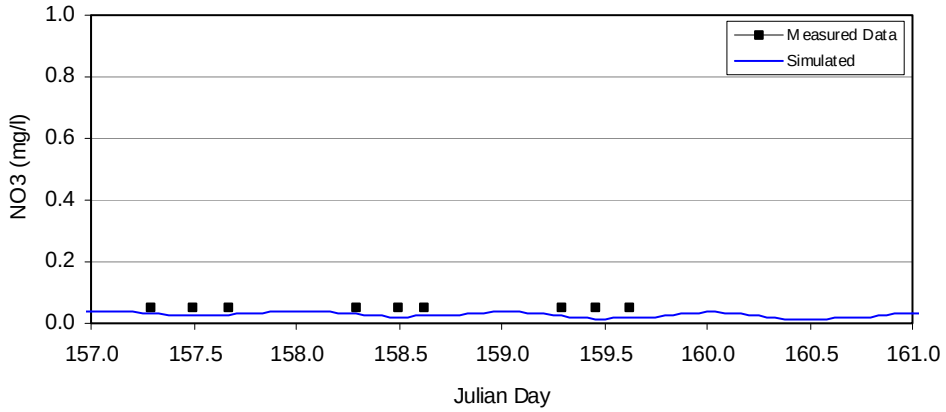


Figure 225. Klamath River above Scott River simulated versus measured nitrate, June 5-7, 2000

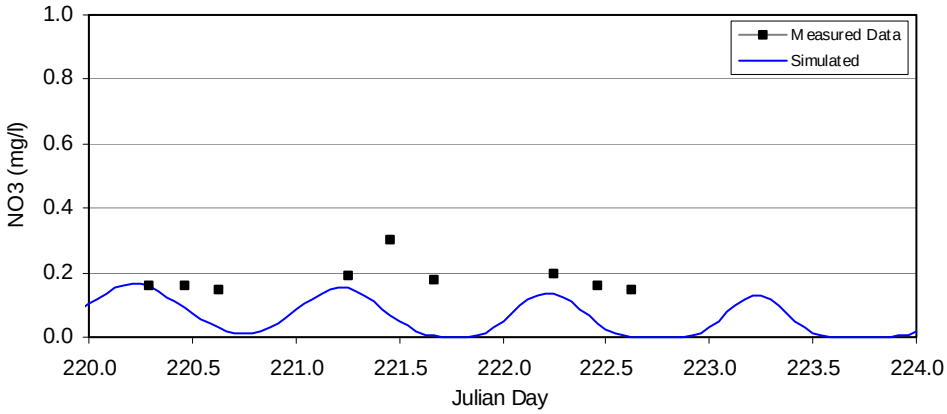


Figure 226. Klamath River above Scott River simulated versus measured nitrate, August 7-9, 2000

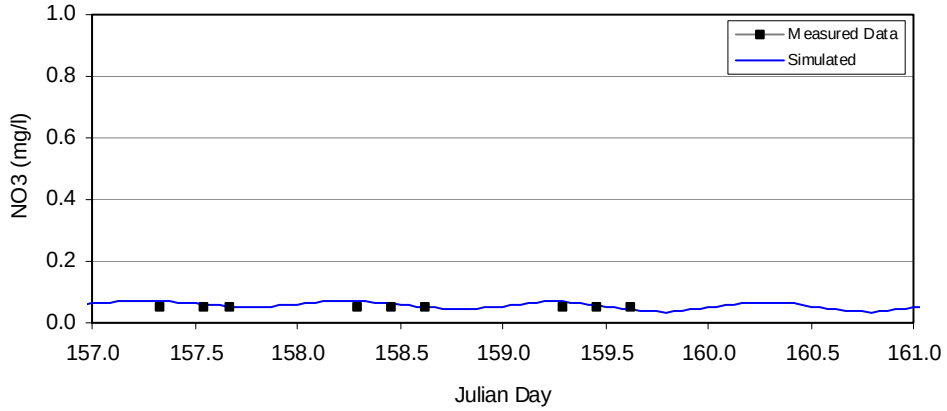


Figure 227. Klamath River near Seiad Valley simulated versus measured nitrate, June 5-7, 2000

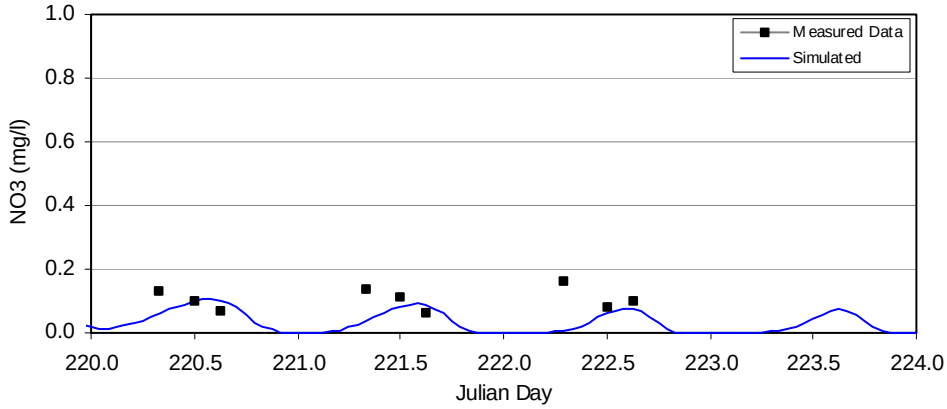


Figure 228. Klamath River near Seiad Valley simulated versus measured nitrate, August 7-9, 2000

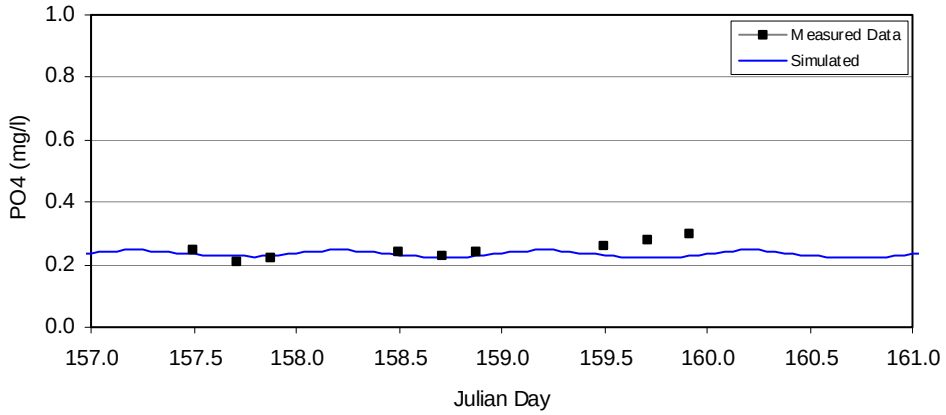


Figure 229. Klamath River above Shasta River simulated versus measured orthophosphate, June 5-7, 2000

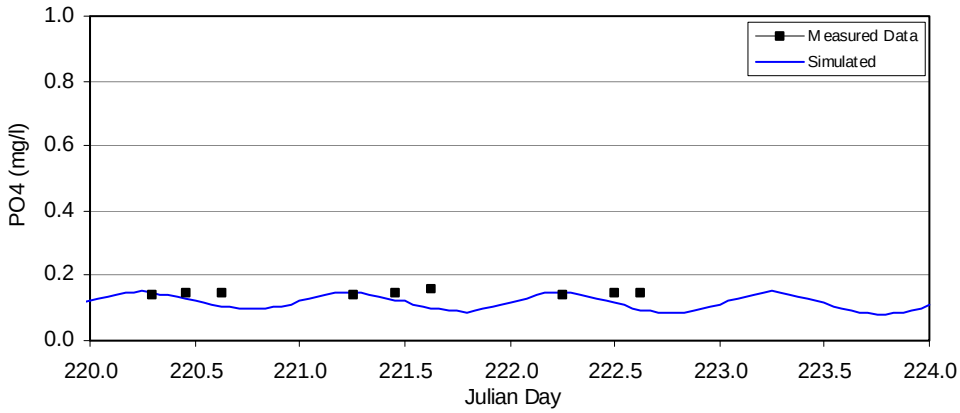


Figure 230. Klamath River above Shasta River simulated versus measured orthophosphate, August 7-9, 2000

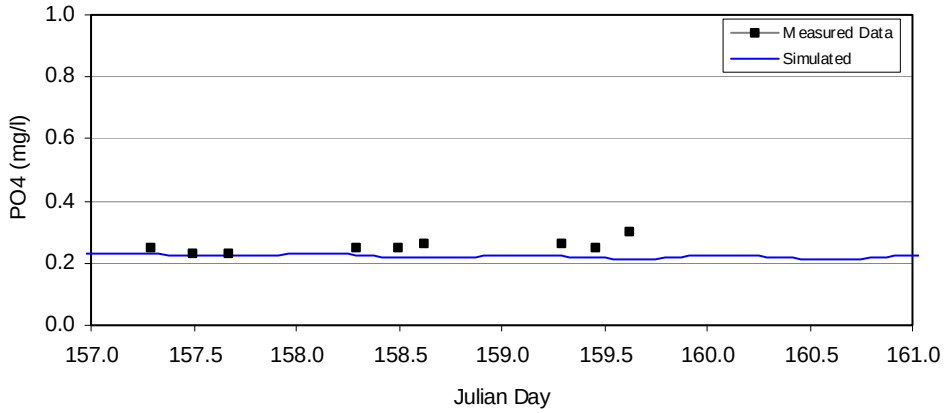


Figure 231. Klamath River above Scott River simulated versus measured orthophosphate, June 5-7, 2000

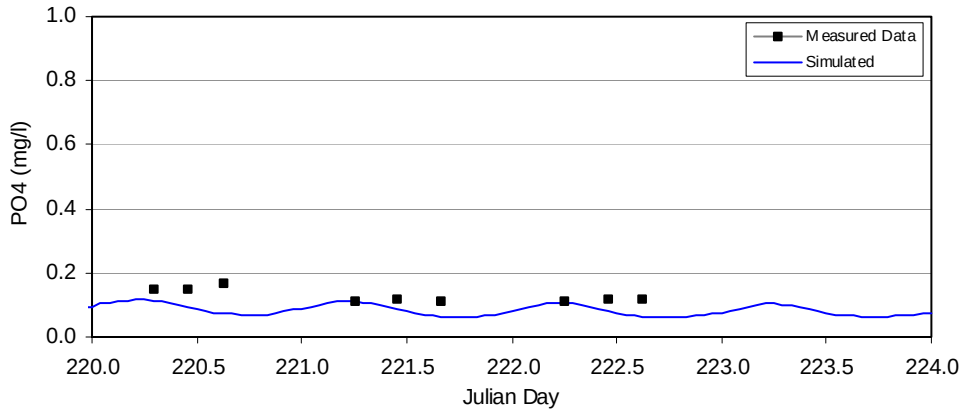


Figure 232. Klamath River above Scott River simulated versus measured orthophosphate, August 7-9, 2000

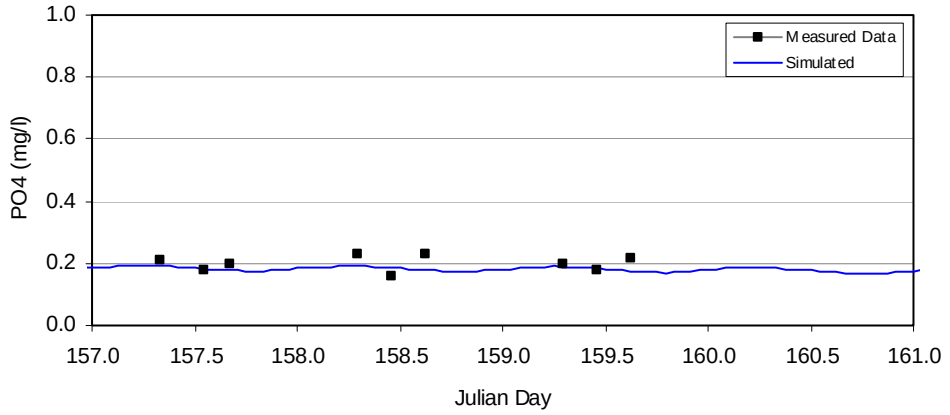


Figure 233. Klamath River near Seiad Valley simulated versus measured orthophosphate, June 5-7, 2000

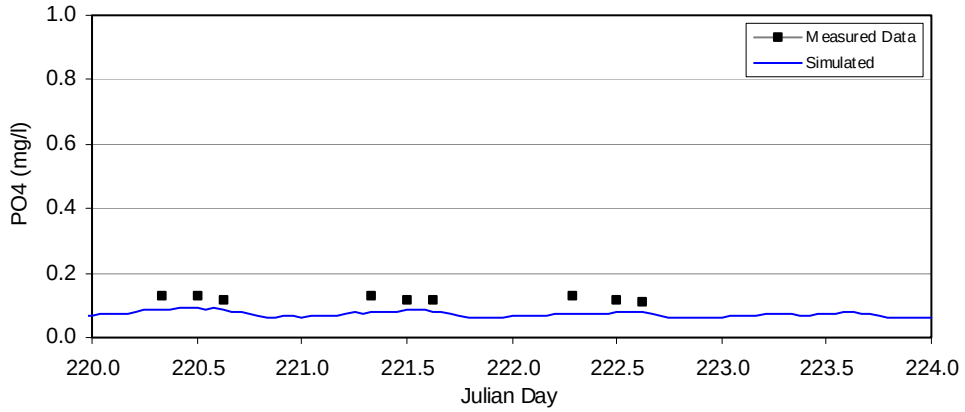


Figure 234. Klamath River near Seiad Valley simulated versus measured orthophosphate, August 7-9, 2000

3.9.6 Summary of Parameters

Table 71. RMA-2 and RMA-11 Model rates, coefficients and constants for the Iron Gate Dam to Turwar

Variable Name	Description, units	Value
	Time step, hr	1.0
	Space step, m	75 (cal) 150 (application)
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
	Slope Factor	0.80
ELEV	Elevation of site, m	520.00
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coefficient a, m hr^{-1} mb^{-1}	0.000015
EVAPB	Evaporative heat flux coefficient b, m hr^{-1} mb^{-1} $(m/h)^{-1}$	0.000010
EXTINC	Light Extinction coefficient, used when algae is not simulated, 1/m	0.25
ALP0	Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.072
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.010
LAMB1	Linear algal self-shading coefficient, phytoplankton, 1/m	n/a
LAMB2	Non-linear algal self shading coefficient, phytoplankton, 1/m	n/a
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.01
RESP	Local respiration rate of algae, phytoplankton, 1/d	0.05
SIG1	Settling rate of algae, phytoplankton, 1/d	0.0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m^{-2} s^{-1}	0.01
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.01
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.001
PREFN	Preference factor for NH3-N, phytoplankton	0.6
ABLP0	Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A	50
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
LAMB1	Linear algal self shading coefficient, bed algae, 1/m	n/a
LAMB2	Non-linear self shading coefficient, bed algae, 1/m	n/a
MUMAX	Maximum specific growth rate, bed algae, 1/d	1.5
RESP	Local respiration rate of algae, bed algae, 1/d	0.60
MORT	Mortality, bed algae, 1/d	0.10
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.01
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.002
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m^{-2} s^{-1}	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.3
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.5
BET3	Rate constant: hydrolysis Org N to NH3-N, 1/d	0.3
BET4	Rate constant: transformation Org P to P-D, 1/d	0.3
KNINH	First order nitrification inhibition coefficient, mg^{-1}	n/a
ALP3	Rate O_2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.6
ALP4	Rate O_2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.6
ABLP3	Rate O_2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.6
ABLP4	Rate O_2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.6
ALP5	Rate O_2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O_2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
K1	Deoxygenation rate constant: BOD, 1/d	0.3
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	3.0
SIG6	BOD settling rate constant, 1/d	0.0

n/a – not applicable

3.10 Model Sensitivity

A sensitivity analysis is the test of a model in which the value of a single variable or parameter is changed (while the others remain constant) and the impact of this change on the independent variable is observed. Such analyses can be used to identify the characteristics of importance in a system. Uses of sensitivity analysis include:

- serving as an aid to confirming that the model is consistent with theory
- indicating the effects of errors in each of the variables and parameters, on the dependent variables
- identifying sensitive parameters or variables that must be reliably estimated
- indicating the relationship between control variables and decision variables to help ensure that a change in control variable can have a desirable effect on the decision variables, and
- identifying regions of "design invariance" where desirable levels of the decision variables are insensitive to possible errors of estimation in the model variables and parameters.

Other methods of quantifying uncertainty include first order analysis, Monte Carlo simulations and Kaman filtering, and are based on aggregate error terms and determine the total estimation (or prediction) error in a particular variable (Reckhow and Chapra, 1983). These multivariate methods are beyond the scope of this project.

Selected model parameters in both the RMA and CE-QUAL-W2 models were examined to determine relative sensitivity. There were too many variables to explore, and because many were not altered from default values, only those that were explored during calibration were examined. The input data sets, field observations or estimated values for flow and water quality boundary conditions and meteorological parameters, were not altered.

This qualitative assessment determined the general sensitivity of a particular parameter, (e.g., low, moderate, or high sensitivity, or insensitive), provided insight on model performance (e.g., was model consistent with theory), and to indicate the effects of modifying said parameters on the dependent variables. Many of the changes were carried out over modest ranges in parameter value, i.e., testing the model over extreme ranges for each parameter was not considered. Findings for the RMA models (RMA-2 and RMA-11) and CE-QUAL-W2 are outlined below. Sensitivity identified herein for the Klamath River system may not represent other responses encountered in other systems, i.e., not all of these analysis may be transferable to other river basins.

3.10.1 RMA parameters studied for sensitivity

Sensitivity was completed for the RMA-2 and RMA-11 models for selected parameters. In most cases literature values or default values for model constants and coefficients were applied. Through calibration and application of the models it was determined that certain parameters were sensitive. These parameters were explored further to determine the general sensitivity to perturbation.

Conditions are highly variable throughout the system and sensitivity varied by season (cooler periods or periods when there was more or less water in the system) and location. Also, longer river reaches (e.g., Klamath River from Iron Gate Dam to Turwar), where impacts could occur over long distance and long travel times may show more sensitivity than short reaches where water quality changes little from upstream to downstream (e.g. Link River). The parameters discussed herein include:

- n - Manning roughness coefficient
- SF - Slope Factor fraction to reduce bed slope of river to approximate water surface slope in solution of flow equations
- EVAPA, EVAPB – Evaporative heat flux coefficients
- IREAER* – (Minimum reaeration rate)
- MUMAX – nominal bed algae growth
- RESP – bed algae respiration rate
- EXTINC – non-algal light extinction
- EA – atmospheric pressure
- PBREFN –algal preference for ammonia

For a full description of model parameters the reader is referred to the user's manual for RMA-2 and RMA-11.

Table 72 outlines the general findings of the sensitivity testing. Generally temperature was sensitive to bed roughness and slope factor – both parameters that directly impact travel time (akin to residence time) through the river reaches. Likewise, temperature was highly sensitive to the evaporative heat flux parameters.

Dissolved oxygen was sensitive to the minimum reaeration value specified for the river reaches (thus the ultimate value was set relatively low), and highly sensitive to algal growth and respiration parameters.

Nutrients were generally moderately sensitive or experienced low sensitivity to algal growth parameters; however, the ammonia preference factor suggested sensitivity for ammonia and nitrate. The nutrients were moderately sensitive to extinction in certain river reaches – under high extinction rates benthic algal growth was light limited and nutrient uptake suppressed. Algae was very sensitive to growth and respiration rates as well as light extinction.

In addition temperature was examined under different geometric representations of the system. Specifically, temperature output from several reaches was examined while varying river width as well as side slope. The impacts were generally modest, with the exception that marked changes in river width can dramatically impact travel time and thus water temperature. Finally, the river models were run with node-to-node distances of 150 meters and 75 meters, with minimal differences in results. The exception being the hydrodynamic model required the 75 meter grid and fifteen minute time steps to retain stability under the highly variable flow regime of the peaking reach.

Table 72. RMA-11 water quality constituent sensitivity to different modeling parameters

Parameter	Sensitivity to Parameter					
	Temperature	DO	PO4	NH4	NO3	Algae
Manning n	H	-	-	-	-	-
SF	H	-	-	-	-	-
EVAPA	H	L	-	-	-	-
EVAPB	H	L	-	-	-	-
IREAER*	N	H	N	L	S	-
MUMAX	N	H	N	L	S	H
RESP	N	H	N	-	-	H
PBREFN	N	-	N	M	M	L
EXTINC	N	M	-	L	L	H
EA	N	L	-	-	-	-
Bathymetry	M	L	-	-	-	-

N – not sensitive

L – low sensitivity
M – moderate sensitive

H – high sensitivity

If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

3.10.2 CE-QUAL-W2 Parameters studied for sensitivity

Sensitivity was completed for the CE-QUAL-W2 models for selected parameters using the several reservoir applications. In most cases literature values or default values for model constants and coefficients were applied. Through calibration and application of the model to the various reservoirs it was determined that certain parameters were sensitive. These parameters were explored further to determine the general sensitivity to perturbation.

Conditions are highly variable throughout the system reservoirs and sensitivity varied by season (cooler periods or periods when there was more or less water in the system) and location. Response to varying model parameters varied among the shallow Lake Ewauna-Keno Reservoir, the short residence time J.C. Boyle reservoir, and the deep, longer residence time reservoirs of Copco and Iron Gate. The parameters discussed herein include:

- AFW, BFW, and CFW - Evaporative heat flux coefficients
- AG - Algal Growth Rate:
- AR - Algal Respiration Rate: AR
- AM - Algal Mortality Rate:
- ASAT - Algal light saturation intensity at the maximum photosynthetic rate.
- SOD- Sediment Oxygen Demand
- CBHE - Bed heat conduction coefficient

- TSED - Specified bed temperature: TSED
- EXSS Light Extinction due to inorganic suspended solids:
- EXOM - Light extinction due to organic matter
- EXH20 - Light extinction due to water
- EXA - Light extinction due to algae
- BETA - Solar radiation absorption fraction: the BETA parameter is the fraction of incident solar radiation absorbed at the water surface
- LDOMDK - Labile organic matter decay rate
- POMS - Particulate organic matter settling rate
- NH4DK - Ammonia decay rate
- NO3DK - Nitrate decay rate
- O2LIM - Aerobic/anaerobic oxygen Limit: user defined oxygen limit refers to the concentration below which anaerobic processes begin to be simulated.

Table 73 outlines the general findings of the sensitivity testing. Generally temperature was sensitive to the evaporative heat flux parameters. In the deeper reservoirs the impacts were observed over longer periods than in the shallow reservoirs. IN the deeper reservoirs with longer residence time, the bed heat exchange coefficient was modestly sensitive in bottom water temperature.

Dissolved oxygen was sensitive to algal growth, respiration, and mortality parameters, and parameters associated with algal growth such as the various light extinction parameters. The organic matter decay rates also impacted dissolved oxygen concentrations to some degree: the impact was larger in the long residence time reservoirs. Dissolved oxygen sensitivity to ammonia decay rate was low.

Nutrients were generally moderately sensitive or experienced low sensitivity to algal growth parameters (and associated parameters such as extinction); however, nitrate was notably more sensitive to these parameters than ammonia. Algae was very sensitive to growth and respiration rates as well as light extinction.

Two aspects of the reservoir geometric representation were explored: layer thickness and bathymetric representation. The layer thickness in Lake Ewauna-Keno Reservoir was set at 0.61 meters are per Wells (1996). The layer thickness in J.C. Boyle Reservoir was initially set at 0.61 meters; however simulation time exceeded 20 hours (1.2 GHz processor) due to the model frequently dropping and adding segments and layers in this small hydropower peaking reservoir.

The layer resolution was increased to 1.0 meters and the simulation time dropped to approximately 15 minutes, with no significant changes in model output. The 1.0 meter layer thickness was retained. Tests were completed in Iron Gate Reservoir at layer thicknesses of 5 meters, 2.5 meters, and 1 meter. Results between the 5 meter and 2.5 meter layer thickness cases varied considerably; however, the differences between the 2.5 meter and one meter layer thicknesses was insignificant. Iron Gate representation utilized 2.5 meter layer thickness to accommodate run time considerations (approximately 2 hours for a 1.2 GHz processor).

Finally, Lake Ewauna-Keno Reservoir was modeled under multiple bathymetric representations: the original work from Wells (1996), a fictitious bathymetry to determine

if model results were sensitive to a different geometry, and utilizing a new bathymetric survey from 2003. The findings suggest that results are sensitive to bathymetry and that using the best available data is important in effective representation – the 2003 data is currently used in the model.

Table 73. CE-QUAL-W2 water quality constituent sensitivity to different modeling parameters

Parameter	Sensitivity to Parameter					
	Temperature	DO	PO4	NH4	NO3	Algae
AFW	M	-	-	-	-	-
BFW	M	-	-	-	-	-
CFW	L	-	-	-	-	-
AG	N	L	L	L	H	H
AR	N	M	L	L	M	H
AM	N	M	L	L	M	H
ASAT	-	-	-	-	-	-
SOD	N	M	M	N	N	L
CBHE	M	-	-	-	-	-
EXSS / EXOM	N	H	L	L	M	H
EXH2O	N	H	M	L	M	H
BETA	N	H	M	L	M	H
EXA	N	H	L	L	H	H
LDOMDK	N	M	L	L	L	N
POMS	N	L	L	L	L	N
NH4DK	N	L	N	L	L	N
NO3DK	N	N	N	N	M	N
O2LIM	N	N	M	N	L	N
Bathymetry	H	H	H	H	H	H

N – not sensitive
L – low sensitivity
M – moderate sensitive
H – high sensitivity

If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

The water quality model parameters most sensitive in the prediction of temperature and dissolved oxygen are similar for both RMA-11 and CE-QUAL-W2:

- Evaporative heat flux parameters for temperature
- Algal growth dynamics and light extinction for dissolved oxygen and algae.

It is useful to note that these are common calibration parameters in water quality modeling.

In addition to these studies, many informal sensitivity tests have been completed to assess model performance including

- Varying the vertical resolution of layers in CE-QUAL-W2
- Varying the spatial resolution in the RMA models
- Modifying the locations of accretion/depletions in river and reservoir reaches
- Testing to see if tributary input temperatures affect mainstem or reservoir conditions
- Modified input quantity and quality of major agricultural returns
- Modifying geometry to identify need for more detailed studies
- Modifying meteorological inputs to determine sensitivity,

As well as many other tests during model implementation, calibration, and application. If the findings identified notable changes, the models were updated or modified to more fully represent conditions to recommendations specified to assist in further characterizing the system.

3.11 Summary – Model Calibration and Validation

All system components have been calibrated. There are a few notable reaches where additional information and model testing is recommended; however, the modeling framework is, by and large, complete. Although additional data needs and model testing has been identified, the framework and its individual components have been extremely effective at illustrating flow and water quality processes throughout the system. The exercise of system characterization, model implementation, sensitivity testing, and calibration have resulted in a dramatically improved understanding of Klamath River flow and water quality issues, as well as identifying need for additional data. Available data precluded formal calibration of the models during the winter months. Brief synopses of each reach, plus identified recommendations are outlined below.

3.11.1 Link River

This short river reach is fairly insensitive to model conditions, with the exception when Link Dam bypass flows are low and most of the water is passed through the East Side and West Side powerhouses. However, any variability imparted on Link Dam releases by conditions within Link River is quickly overwhelmed in the Lake Ewauna to Keno Dam reach. This reach has been calibrated.

Recommendations: Because Link Dam forms a critical boundary condition for all downstream reaches it is recommended that a formal monitoring program be considered to characterize water quality conditions and more completely characterize the short-term variability at the head of Link River.

3.11.2 Lake Ewauna-Keno Dam

The Lake Ewauna-Keno Dam reach is a dynamic and complex reach to model for water quality. This reach is intensively developed for water resources and related activities. There are multiple diversions from the system for industrial and agricultural use, as well as their associated return flows. The Klamath River also is a receiving water for municipal discharge of treated wastewater. Land use practices, predominately

agricultural, but also municipal and industrial activities, occur adjacent to the river throughout much of this reach. Finally, review of available literature and discussions with stakeholders suggest historical log rafting and timber industry practices have left considerable organic matter throughout the upper portion of this reach.

Other water resources development of importance include the impoundment of Upper Klamath Lake for diversion to the Reclamation project, as well as impoundment of the reach in question by Keno Dam. The operations of Link Dam, namely actively managing storage in Upper Klamath Lake for summer application within the Reclamation Project, has reduced the frequency, and to some degree the magnitude, of winter flows through the Lake Ewauna to Keno Dam reach. This coupled with impoundment at Keno Dam has created a slow moving waterway that allows primary production (as phytoplankton versus riverine forms of algae) to occur as well as favors deposition. Upstream inputs from hyper-eutrophic Upper Klamath Lake, as well as historical and continued inputs from municipal, industrial, agricultural, and non-point discharges lead to considerable oxygen demands within this reach.

Additional field work in 2003, as well as review of previous data collection efforts suggests that the advective nature of the reservoir – there is a notable current at mid-channel throughout the reach (on the order of 0.2-0.3 feet per second) – coupled with the daily weak stratification and wind dynamics creates a complex conditions within this reach that directly impact water quality. By and large, the Lake Ewauna-Keno Reach is very sensitive to influent conditions from Upper Klamath Lake for dissolved oxygen, nutrients, and algae. All downstream reaches are likewise impacted by outflow water quality conditions at Link Dam. (The exception is water temperature which is only moderately affected in downstream reaches because waters in Upper Klamath Lake are near equilibrium temperature.)

Given the level of complexity encountered within this reach, model application to this dynamic reach was by-and-large successful for temperature. For dissolved oxygen, nutrients, and algae, it was apparent that the resolution (i.e., monitoring frequency) of upstream boundary condition (actually conditions at Link Dam) governed processes within this reach. Sensitivity testing Link Dam as well as other boundary conditions, including sediment oxygen demand supported finding. As such, the model replicates seasonal dissolved oxygen response, but short term conditions are not always well represented. Model performance for nutrients varies dramatically between 2000 and 2001 applications. With the more complete data set of 2001, the model replicates observed conditions appreciably better than in 2000, when composite upstream boundary conditions were applied. The model has undergone a wide range of testing to assess variable conditions and response to modifying model parameters, and, given the level of available data can be considered preliminarily calibrated for dissolved oxygen and nutrients. Recommendations for additional studies are outlined below.

<u>Recommendations</u>: Several of the field studies completed in 2003 were not completed prior to the calibration of the model. These include sediment studies (SOD), and limited field studies. It is recommended that the results of these studies be reviewed and, as necessary, incorporated into the modeling effort. In addition, should a more refined calibration be required, additional field studies should be designed to further characterize conditions throughout the Lake Ewauna-Keno Reach. Field studies should include

sampling of appropriate parameters to address nutrient conditions, biochemical oxygen demand, organic matter, algae, and pH, as well as temperature, dissolved oxygen, and other physical parameters. Such field studies should recognize the spatial and temporal scales of critical processes identified herein. If completed, results of these studies should be used to further refine the model application. The recommendation for the Link River reach – improving the information (boundary condition) at the Link Dam is imperative to this effort.

3.11.3 Keno Dam to J.C. Boyle

The Keno Dam to J.C. Boyle reach is fairly short with a transit time of a few hours. The models performed well in this steep river reach, replicating temperature and dissolved oxygen well, as well as nutrient concentrations.

Recommendations: Continue monitoring upstream and downstream water quality conditions as necessary.

3.11.4 J.C. Boyle Reservoir

J.C. Boyle Reservoir is a small reservoir and experiences residence times of less than a day to more than 3 days. As such it is heavily influenced by inflow water quantity and quality. The system was modeled with CE-QUAL-W2 under several levels of detail and has been tested for a wide range of conditions using calendar year 2000 data. (The system was also modeled with WQRRS prior to applying CE-QUAL-W2.) The model is performs well and is calibrated, but results are sensitive to influent conditions, which are ultimately driven by the boundary condition at Link Dam.

Recommendations: Continue in reservoir monitoring.

3.11.5 Bypass / Peaking Reach

The bypass reach experiences a highly dynamic flow regime and variable water quality due to peaking operations and the influence of a large springs complex. Modeling this reach required representing the physical features of this steep reach as well as the short duration hydropower operations. The models performed well for all parameters. This reach is calibrated.

Recommendations: Exploratory field work was carried out in 2003 to assess the benthic algae community. If further model refinement is necessary it is recommended that a more comprehensive survey of benthic algae and the role it may play in dissolved oxygen concentration dynamics as well as nutrient conditions within the reach should be explored.

3.11.6 Copco Reservoir

Copco Reservoir receives a peaking flow regime from upstream Klamath River inflows as well as providing peaking flows at Copco Dam for a significant portion of the year. The reservoir was modeled for calendar year 2000 and performance was generally good for both temperature and dissolved oxygen. The model is considered calibrated; however it is sensitive to the upstream boundary condition – inflow from the Klamath River – which is in turn somewhat sensitive to the conditions at Link Dam.

Recommendations: Data from the 2003 field season included more detailed vertical profiles of the reservoir. This data collection and processing was not completed in time to be included herein. If additional model refinement is required, it is recommended that these data be reviewed and, as necessary, used to refine model calibration. Update SOD as information becomes available.

3.11.7 Iron Gate Reservoir

Iron Gate Reservoir receives a peaking flow regime from upstream Copco Reservoir and re-regulated the river to provide a steady flow regime below Iron Gate Dam for a significant portion of the year. The reservoir was modeled for calendar year 2000 and performance was generally good for both temperature and dissolved oxygen. The model is considered calibrated; however it is sensitive to the upstream boundary condition – inflow from Copco Reservoir – which is in turn somewhat sensitive to the conditions at Link Dam.

Recommendations: Data from the 2003 field season included more detailed vertical profiles of the reservoir. This data collection and processing was not completed in time to be included herein. If additional model refinement is required, it is recommended that these data be reviewed and, as necessary, used to refine model calibration. Update SOD as information becomes available.

3.11.8 Iron Gate Dam to Turwar

The Iron Gate Dam to Turwar reach is the longest single reach in the modeling framework. Multiple tributaries and variable meteorological conditions add complexity to this generally steep reach. Sufficient information was available to calibrate the models throughout the reach for, temperature, dissolved oxygen, and inorganic nutrients.

Recommendations: During 2003 benthic algae surveys were completed providing information on the distribution and approximate biomass at multiple locations within this reach. This information was important in improving the understanding of algal dynamics. Expansion of this information, coupled with the appropriate water quality conditions, could further improve the application of the model.

3.11.9 Additional Recommendations

General recommendations, some of which are addressed above, include

- the maintenance of the long term reservoir monitoring programs (profiles),
- maintain the thermistor deployment throughout the project area to characterize water temperatures,
- maintenance of existing meteorological stations at main stem reservoirs,
- ongoing reporting of flow, storage, and operations at project facilities,
- ongoing model updates and maintenance to consider, include
  - improve characterization of organic matter in CE-QUAL-W2 and RMA-11, including sensitivity if model results to organic matter partitioning. If necessary incorporate more detailed organic matter formulation in RMA-11,

  - further sensitivity testing of light extinction conditions in the river reaches on benthic algae,
  - improved distribution of benthic algae in river reaches, including sensitivity to scour (requires field observations),
  - incorporate existing pH model (external processor) into RMA-11,
  - improve sampling frequency and locations of total inorganic carbon (TIC) and alkalinity to support pH modeling,
  - improve representation of A/D as additional flow data and analyses come available,
  - further sensitivity of bed sediment oxygen demand in river reaches. Support with field studies,
  - explore meteorological observations from recently installed meteorological stations in the middle and lower Klamath River regions and re-assess meteorological assumptions,
- improve winter data collections to extend the model application into winter periods, as necessary (identify specific needs first),
- as well as other identified studies.

Long-term studies to improve understanding of the system are encouraged on an as needed basis.

4 Model Application

4.1 Introduction

Upon completion of model calibration, the models were applied to four system-wide scenarios: existing conditions, steady-flow, and without project (II). These scenarios were intended to bracket the range of potential physical and operational conditions within the project area. Further, these analyses were completed for the years 2000 and 2001.

For each scenario the models were applied for a full calendar year, which allowed the larger reservoirs to attain stratified conditions from an initial isothermal state, as well as exhibit fall turnover. System conditions from Link Dam to the Klamath River at Turwar were simulated – a distance of approximately 250 miles. The existing condition scenario represents the baseline status and is used for comparing conditions without peaking hydropower operations (steady flow scenario) and a river system without hydropower facilities (without project scenario). The without project (II) scenario attempted to smooth river flows at Keno Dam to produce a hydrograph that did not exhibit the fluctuations due to US Bureau of Reclamation project operations.

These analyses are intended to examine large scale system response over periods when critical water quality conditions tend to occur (spring – fall) in the Klamath River basin. More detailed analysis focusing on critical reaches, specific operations, and limited time periods are addressed separately. Basic assumptions for each scenario are discussed below and presented in Table 74.

Table 74. Basic scenario assumptions

Scenario	Geometry / Bathymetry	Meteorology	Hydrology for Boundary Conditions	Water Quality for Boundary Conditions	Operations
Existing Conditions (EC)	Base	Base	Base	Base	Base
Steady Flow (SF)	Base	Base	Base	Base	Modified
Without Project (WOP)	Modified	Base	Base	Base	No Operations
Without Project II (WOPII)	Modified	Base	Modified[a]	Base	No Operations

Base – refers to baseline conditions or those applied to the existing condition scenario

Modified – identifies if any basic data information was modified for the identified scenario

Modified[a] – modified from Iron Gate Dam to Keno Dam

The basic output extracted from each scenario was hourly time series data at multiple locations for temperature and dissolved oxygen, although all other parameters are available at the hourly output frequency. The output locations from the models (nodes or segments) and the corresponding physical locations are presented in Table 77. Processed

output for all three scenarios included daily mean data, daily maximum data, daily minimum data, monthly mean data, and 7 day maximum average data.

4.2 Model Coordination

The models are applied in series, starting with upper most reach – Link River – and passing the output from one reach to the next. The flow conditions are generally not passed from reach to reach. Exceptions include reaches where there is no upstream flow record (i.e., measured flow) above Copco Reservoir, wherein the hydrodynamic model is used to route peaking flows on an hourly basis down to Copco Reservoir – these flows are then used in the CE-QUAL-W2 simulation of Copco Reservoir. For certain scenarios (e.g., without project), flows are passed from one modeled reach to the next because flow conditions cannot be explicitly specified.

Water quality is passed downstream between all simulated river reaches. The river models (RMA) and the reservoir model (CE-QUAL-W2) do not represent all water quality parameters in the same fashion. The river models represent organic matter as organic nitrogen and organic phosphorous, while the reservoir model represents organic matter as refractory and labile dissolved and particulate organic matter. A stoichiometric equivalent is used to convert the fraction of organic matter or nutrients when passing information from one model to the next. Specifically, organic nitrogen from RMA-11 is converted to dissolved labile organic matter for input to CE-QUAL-W2 (the nitrogen fraction of organic matter is assumed to be 0.08 (USACOE-HEC, 1986)). No attempt is made to partition the organic matter among the refractory and labile or the dissolved and particulate compartments due to a lack of sufficient field data. When passing information from CE-QUAL-W2 to RMA-11, the derived constituent for total organic nitrogen and total organic phosphorous are employed; however, the algal component of organic nitrogen and phosphorous are removed from this value so as not to double count the algal fraction (the nitrogen and phosphorous fractions of algae is assumed to be 0.08 and 0.005, respectively (Cole and Wells, 2002)).

4.3 Existing Conditions Scenario (EC)

The existing conditions scenario models the actual conditions in the Klamath River during 2000 and 2001. All projects were assumed to be in place and operating under historical 2000 and 2001 conditions. All input information are those recorded in, calculated from records, or estimated for 2000 and 2001 conditions.

The models used in this scenario were RMA2 / RMA11 for the river reaches and CEQUALW2 for the reservoirs.

4.3.1 Geometry

The geometry (or bathymetry) for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.3.2 Meteorology

The meteorology for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.3.3 Hydrology

The hydrology for boundary conditions for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.3.4 Water Quality

The water quality data for boundary conditions for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.3.5 Operations

The project operations for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.4 Steady Flow Scenario (SF)

The steady flow scenario models alternative flows to those recorded in 2000 and 2001. All projects were assumed to be in place and but were not assumed to be operating under historical 2000 and 2001 conditions.

The models used in this scenario were RMA2 / RMA11 for the river reaches and CEQUALW2 for the reservoirs.

4.4.1 Geometry

The geometry (or bathymetry) for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

4.4.2 Meteorology

The meteorology for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

4.4.3 Hydrology

The hydrology for boundary conditions for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

4.4.4 Water Quality

The water quality data for boundary conditions for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

4.4.5 Operations

The project operations for each reach of the steady flow scenario were not the same as those described in the basic modeling framework. In the steady flow scenario, the

reservoirs were operated with approximately no change in water surface elevation for the entire year. Calculations started by assuming the dam releases from Irongate Reservoir were the same as those used in the existing conditions scenario, calculating overall smoothed existing conditions accretions/depletions for each reach and then moving upstream using a water balance method between each reservoir up to Link Dam. The smoothing method used for the accretion/depletion calculation was to take the average flow of the flow for the day of interest and the following six days. In Table 75 the calculations for the un-smoothed accretion/depletion are presented. In Table 76 the steady flow scenario dam release calculations are presented. Spring flows in the fullflow reach were assumed to be a constant 225 cubic feet per second for these calculations. Fish releases from Irongate and J.C. Boyle reservoirs were assumed to be 50 and 100 cfs respectively. The East side and West Side turbine flows were calculated as a percentage of daily flow from Upper Klamath Lake. The percentage of daily flow was determined per day from existing conditions flows.

As these calculations assumed no daily change in storage in each of the reservoirs, the starting and ending elevations of the reservoirs were those recorded in each reservoir on January 1st, 2000 and 2001.

Below Irongate Reservoir, all flows were assumed to be the same as those used in the existing conditions scenario.

Table 75. Calculation of un-smoothed accretion/depletions by reach

Accretion Depletion	Calculation
Copco to Irongate	Irongate Out $_{PacifiCorp}$ – Copco Out $_{PacifiCorp}$ + Storage Change in Irongate
J.C. Boyle to Copco	Copco Out $_{PacifiCorp}$ - USGS 11510700 + Storage Change in Copco
Copco	½ J.C. Boyle to Copco A/D
Fullflow	½ J.C. Boyle to Copco A/D
J.C. Boyle	Assumed to be zero
Keno to J.C. Boyle	J.C. Boyle Out $_{PacifiCorp}$ - USGS 11509500 + Storage Change in J.C. Boyle
Lake Ewauna to Keno	USGS 11509500 – (USGS 11507500 + West Turbine $_{PacifiCorp}$ + Net Lost River $_{USBR}$ + Klamath Straits Drain $_{USBR}$ – North Canal $_{USBR}$ – ADY Canal $_{USBR}$) + Storage Change in Keno

Table 76. Calculation of steady flow dam releases by reach

Release	Calculation
Irongate Dam	Actual 2000 or 2001 release
Copco Dam	Irongate Dam release – "A/D Copco to Irongate"
J.C. Boyle Dam	Copco Dam release – "A/D J.C. Boyle to Copco" – Fullflow Spring flow
Keno Dam	J.C. Boyle Dam release – "A/D J.C. Boyle" – "A/D Keno to J.C. Boyle"
Link Dam	Keno Dam releases – "A/D Lake Ewauna to Keno" – East Side – West Side Turbines.

4.5 Without Project Scenario (WOP)

The without project scenario models the Klamath River as if there are projects in the Klamath River downstream of Link Dam.

The models used in this scenario were RMA2 / RMA11.

4.5.1 Geometry

The geometry for the river reaches of the without project scenario followed the basic modeling framework outlined in the implementation documentation. The reservoirs were replaced with river reaches, with the geometry of the reaches estimated from the deepest points in the reservoir bathymetries. River widths within the reservoirs were a linear interpolation between the river width in the element immediately preceding the reservoir and the river width in the element immediately following the reservoir. This process is illustrated in Figure 235, Figure 236, Figure 237 and . All other river widths were the same as those used in the existing conditions scenario. Figure 239 illustrates the method used to create element orientations for the reservoir sections of the without project grid. Other element information, such as element length, was not determined in this way as a uniform grid was used, creating elements of the same length for the entire river. Through this process the existing condition river miles were preserved, except for in Copco Reservoir, where the river was lengthened to capture the sinuosity of the old river bed under the reservoir.

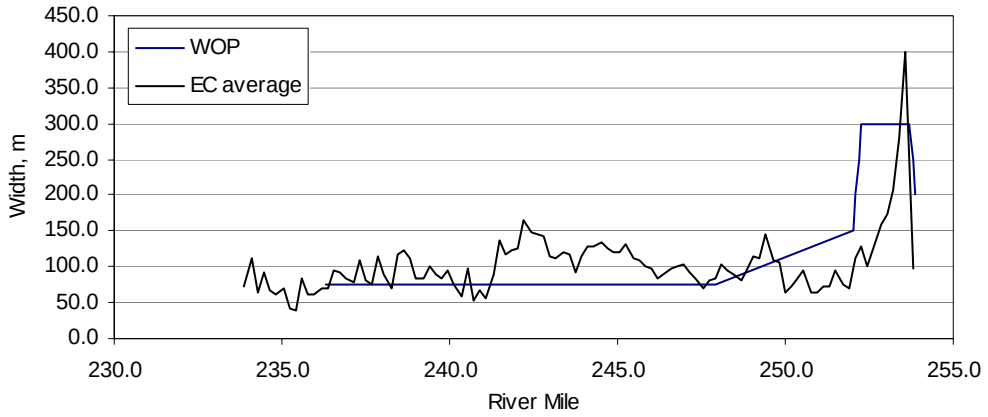


Figure 235. WOP scenario river widths for the Lake Ewauna to Keno Dam river reach

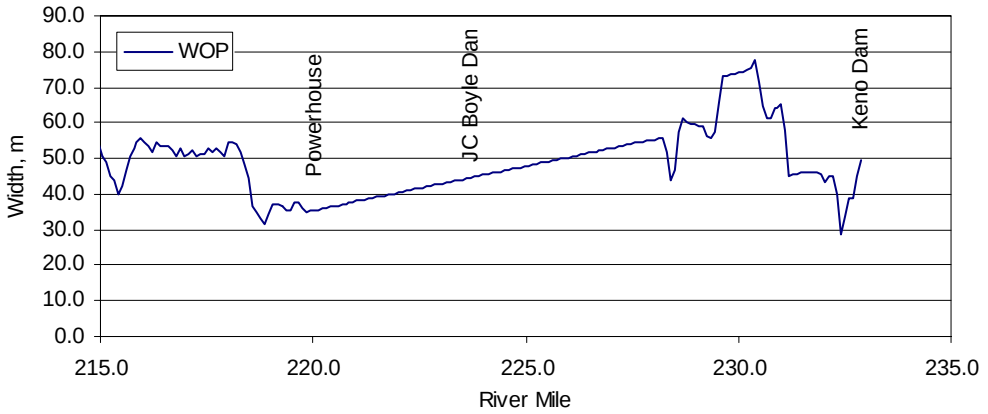


Figure 236. WOP river widths for J.C. Boyle Reservoir and surrounding river reaches

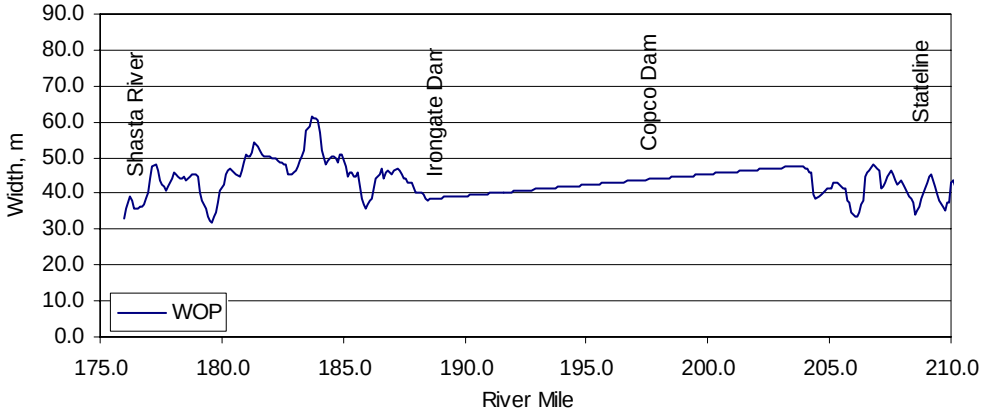


Figure 237. WOP river widths for Copco Reservoir, Irongate Reservoir and surrounding river reaches

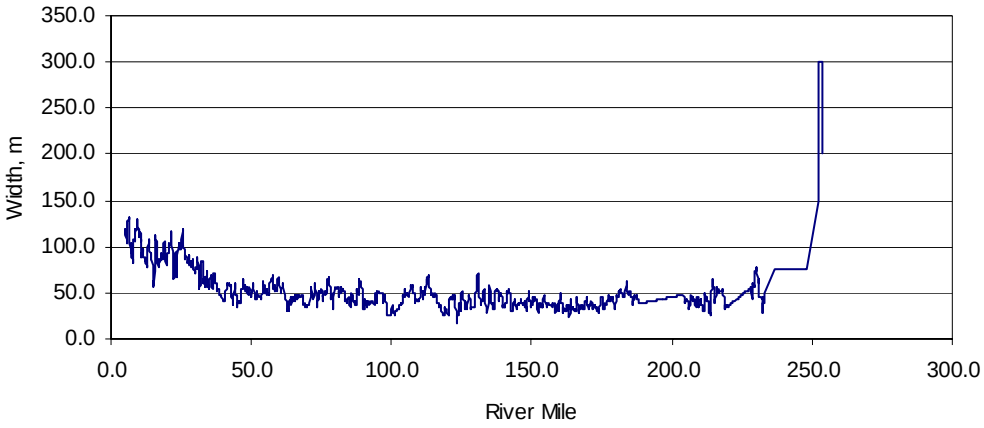


Figure 238. WOP river widths from Link Dam to Turwar

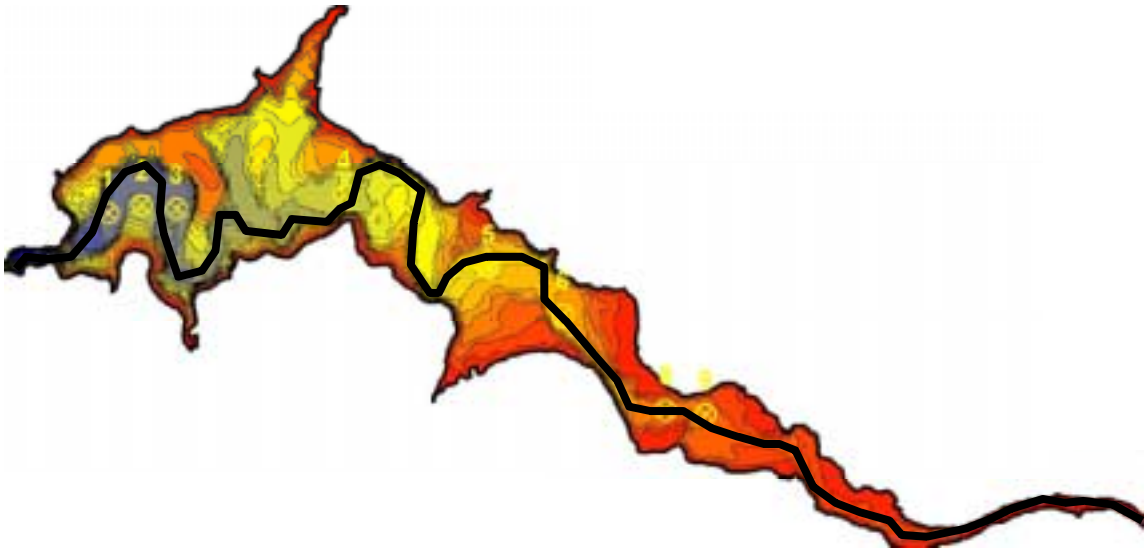


Figure 239. Example of river element orientation from Copco Reservoir bathymetry. Note the black line running through the reservoir in the deepest parts.

4.5.2 Meteorology

The meteorology for each reach of the without project scenario followed the basic modeling framework outlined in the implementation documentation.

4.5.3 Hydrology

The hydrology for boundary conditions for each reach of the without project scenario followed the basic modeling framework outlined in the implementation documentation.

4.5.4 Water Quality

The water quality data for boundary conditions for each reach of the without project scenario followed the basic modeling framework outlined in the implementation documentation.

4.5.4.1 Sediment Oxygen Demand

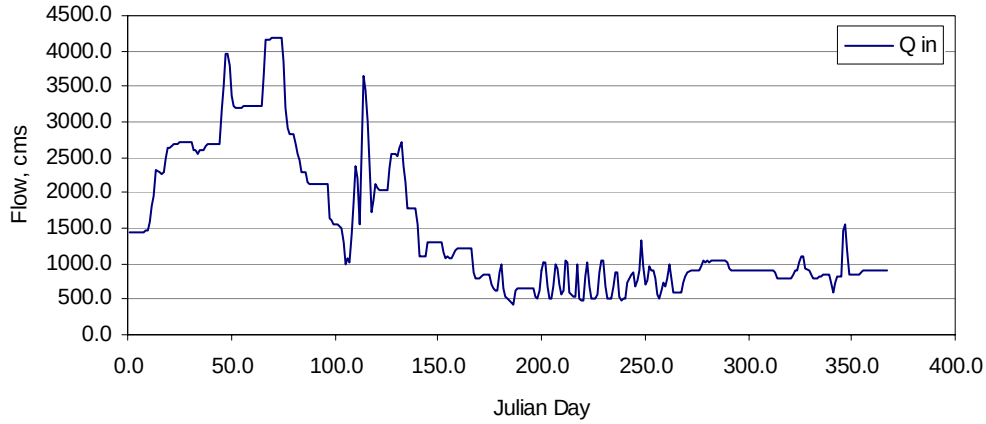
Unlike the sediment oxygen demand exerted in the reservoirs, there is little oxygen demand in the river bed due to scouring. Therefore the SOD which is present in the Existing Conditions scenario is not present in the form of bed BOD in the WOP scenario. Sensitively testing using the modeling framework illustrates that low dissolved oxygen conditions in the Lake Ewauna/Keno reach are most likely due to the oxygen demand imparted on the system from Upper Klamath Lake, and the response is more akin to an oxygen sag in this reach than overwhelming SOD load. SOD plays a role in water quality conditions; however, at this time it is generally presumed to be modest compared to inputs from Upper Klamath Lake.

4.5.5 Operations

No project operations were present in the without project scenario as all projects had been removed.

4.6 Without Project II Scenario (WOPII)

All conditions in the without project II scenario are the same as the WOP scenario with exception of the hydrology. The primary purpose of this scenario was to smooth out the flow variability that was being routed down the river during summer periods (Figure 240). These variations, which are most prominent between Julian day 200 and 250, are born out of US Bureau of Reclamation project operations and maintenance of Keno Reservoir at a stable water surface elevation during operations. The fluctuation over the span of a few days can exceed 500 cfs. The original WOP scenario assumed that all US Bureau of reclamation project operations were consistent with historic conditions – in which case the flow variations that occurred were historically "re-regulated" by system reservoirs were routed down the river. Stakeholder input identified this as an unrealistic without project operation and requested that attempts be made to smooth the hydrograph that was routed down the river.



Keno Dam WOP original flow 2000

Figure 240. Keno Dam WOP flow, 2000

To address this issue, a seven day running average flow was calculated at Keno Dam (Figure 241). Using a water balance on the Link Dam to Keno Dam reach, several

attempts were made to identify flow boundary conditions within this reach to achieve a smooth hydrograph at Keno Dam. These attempts failed to attain a hydrograph that was acceptable. Challenges include the variable transit times through the reach from the various inflow points (Link Dam, Lost River Diversion Channel, Klamath Straits Drain, return flow location), a process further confounded by the impacts on transit time due to diversions from various points. Lumping inputs and outputs was initially considered to simplify the transit time issue, but due to the variable timing and water quality of the various waters, this was deemed unacceptable because the results would be difficult to interpret and the results could not be readily compared with the other global scenarios.

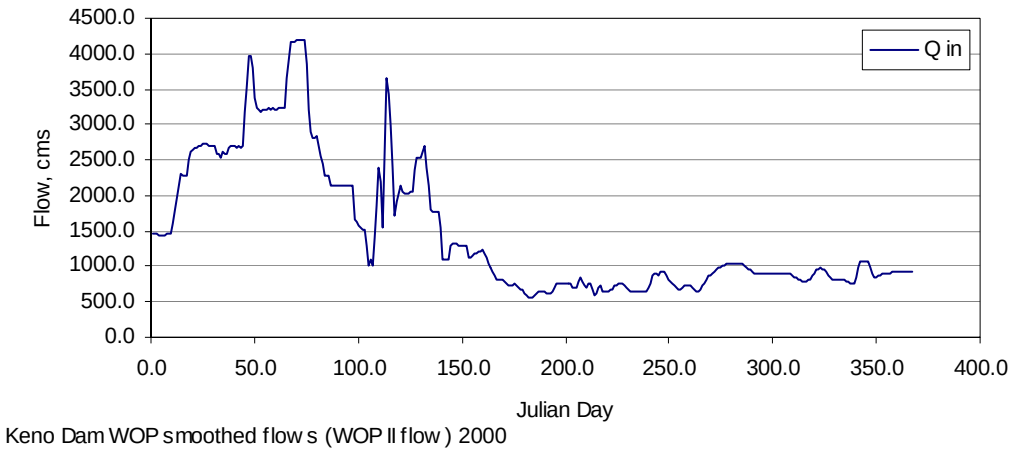


Figure 241. Keno Dam WOPII flow (smoothed), 2000

In the interest of time, and with stakeholder input, it was decided to use WOP scenario water quality conditions at Keno Dam and route those results down the river from Keno Dam to Turwar using the smoothed hydrograph presented in Figure Y. This assumption presumes that the results with a smoothed hydrograph are similar to those without smoothing. (The flow and water quality results for all locations above Keno Dam are identical). It is critical that the reader understand this assumption and interpret the results accordingly.

WOP and WOPII flows at Keno Dam for 2001 are presented in Figure 242 and Figure 243. The impacts of smoothing in 2001 were modest because US Bureau of Reclamation operations were offline.

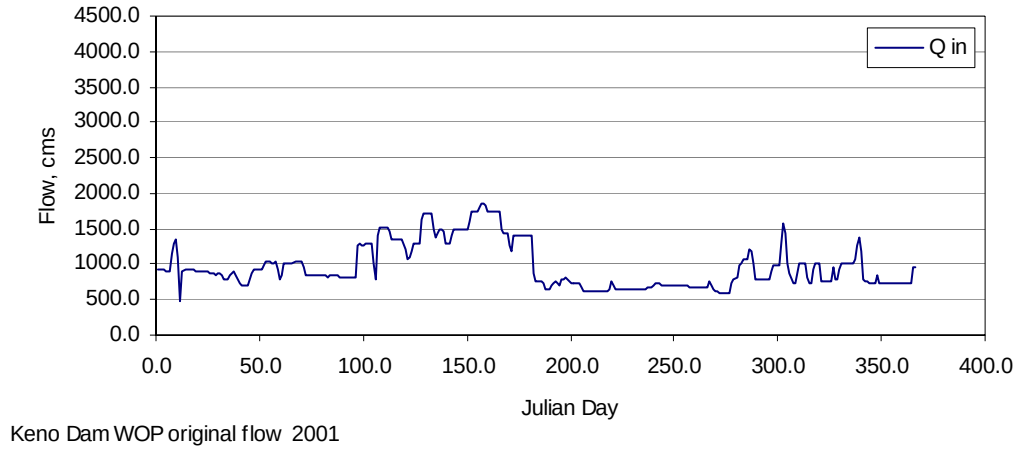


Figure 242. Keno Dam WOP flow, 2001

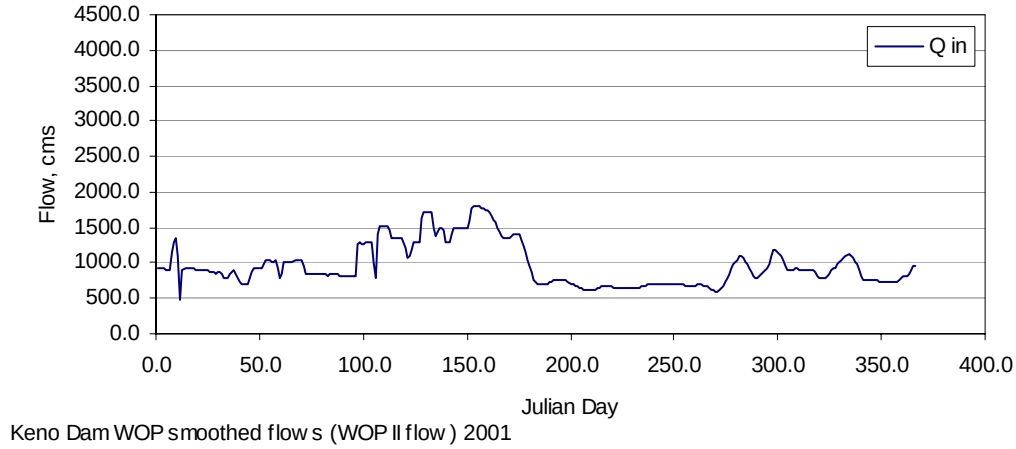


Figure 243. Keno Dam WOPII flow (smoothed), 2001

4.7 Presentation of Results

The model framework produces a substantial amount of information. To effectively provide information to the stakeholders, regulators, and various analysts, input was solicited via the monthly PacifiCorp meetings. Specific locations were identified where model output was desired, as well as parameters and summary statistics. Data was produced for 29 locations, primarily for flow, water temperature, and dissolved oxygen. The reporting locations are presented in Table 77. The information is available in tabular form and graphical form. The current graphical output includes:

For Existing Condition, Steady Flow, and Without Project:

- time series (one-hour data) of water temperature and dissolved oxygen
- daily maximum, mean, and minimum of water temperature and dissolved oxygen

- Longitudinal profiles for river reaches (Bypass/Peaking and Iron Gate Dam to Turwar) for the first of each month from April through November) of water temperature and dissolved oxygen
- Daily mean flow and water temperature (double y-axis plot)
- Daily mean flow and dissolved oxygen (double y-axis plot)

Comparisons of:

- Daily mean water temperature (EC vs. other scenarios)
- Daily mean dissolved oxygen (EC vs. other scenarios)
- Longitudinal profiles for the entire river from Link Dam to the Klamath River near Turwar for the first of each month from April through November) of water temperature and dissolved oxygen.

Table 77. Reporting locations for the Klamath River model simulations

Reach	Location	River Mile	Node (Seg) for EC and SF	Node For WOP
Link River	Link Dam	253.9	1	1
	Link River at Lake Ewauna	252. 7	25	10
Lake Ewauna to Keno Dam Reach	Link River at Lake Ewauna	252.7	(2)	77
	RM 248	248.0	(26)	131
	RM 243	243.0	(53)	185
	RM238	238.0	(79)	227
	Keno Dam	232.9	(107)	
Keno River	Keno Dam	232.9	1	1
	Above J.C. Boyle	227.6	110	55
J.C. Boyle Reservoir	J.C. Boyle Dam	224.3	-	94
Bypass / Peaking Reach	bel J.C. Boyle Dam	224.3	1	94
	Above Powerhouse	220.0	94	138
	Below Powerhouse	221.0	103	144
	Stateline	209.2	332	259
	Above Copco	203.6	448	309
	Copco Reservoir headwaters		453	
Copco Reservoir	Copco Dam	198.6	-	387
Iron Gate Reservoir	Irongate Dam	190.5	-	473
Irongate to Turwar Reach	Irongate Dam	190.5	1	1
	Above Shasta River	177.5	141	141
	At Walker Bridge	156.6	369	369
	Above Scott River	143.6	510	510
	At Seiad Valley	129.0	672	672
	Above Clear Creek	99.0	994	994
	Above Salmon River	67.1	1354	1361
	At Orleans	57.6	1441	1441
	Above Bluff Creek	50.0	1545	1545
	Above Trinity River	43.5	1609	1609
	At Martins Ferry	39.5	1649	1649
	At Blue Creek	16.9	1901	1901
	At Turwar	5.6	1974	1974

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Personal Communications

Todd Olson, PacifiCorp

Appendix A: Modeling Framework

Appendix B: Model Descriptions

Appendix C: River Geometry

Appendix D: Flow Data

Appendix E: Meteorological Data

Appendix F: Water Quality Data

Appendix G: Data processing for Calibration / Validation

Appendix H: 2001 Lake Ewauna/Keno Reach Boundary Conditions – Graphical and Tabular Presentation