APPENDIX 1

STAFF REPORT
for the
PROPOSED
SITE SPECIFIC DISSOLVED OXYGEN OBJECTIVES
for the
KLAMATH RIVER IN CALIFORNIA

March 2010

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EXECUTIVE SUMMARY

Ambient water quality objectives for the Klamath River are contained in Table 3-1 of the *Water Quality Control Plan for the North Coast Region* otherwise known as the Basin Plan. The existing site specific objectives (SSOs) for dissolved oxygen (DO) in the Klamath River were developed based on grab sample data collected during the 1950s and 1960s and represent the elevated, sometime supersaturated, DO conditions typically found during the day when photosynthesis is active. Twenty four-hour DO data collected using DataSonde data probes can not reasonably be compared to the existing SSOs for DO. Further, conditions of barometric pressure and temperature prevent the attainment of the existing SSOs for DO in some locations during some times of the year. Finally, the T1BSR natural conditions run of the *Klamath TMDL model* indicates that under natural conditions, the ambient DO concentrations are frequently less than the existing SSOs for DO.

This Staff Report assesses the DO objectives for the mainstem Klamath, analyzes new DO information, evaluates several alternative methods for recalculating the SSOs for DO, and proposes a recalculated SSO for DO in the mainstem Klamath River. The proposed recalculated SSOs for DO are achievable under natural conditions and are protective of the beneficial uses of the watershed. The proposed recalculated SSOs for DO are based on the natural DO conditions in the basin as estimated using percent saturation and natural receiving water temperatures. Based on natural conditions, the recalculated SSOs for DO necessarily protect any beneficial uses which naturally are or were present in the basin prior to anthropogenic disruption. In a memorandum dated November 5, 1997, Tudor Davies, Director of the Office of Science and Technology at USEPA headquarters in Washington, D.C. corroborates this approach by saying: “For aquatic life uses, where the natural background concentration for a specific parameter is documented, by definition that concentration is sufficient to support the level of aquatic life expected to occur naturally at the site absent any interference by humans.” (p. 2)

The proposed alternative is Alternative 3 which is summarized below. It is to apply to the maximum extent allowed by law. To the extent that the State lacks jurisdiction, the proposed SSO is extended as a recommendation to the applicable regulatory authority."

Location	**Percent DO Saturation Based on natural receiving water temperatures**	**Time period**
Stateline to Scott River	90%	October 1 through March 31
	85%	April 1 through September 30
Scott River to Hoopa	90%	Year round
Hoopa to Turwar	90%	September 1 through May 31
	85%	June 1 through August 31
Upper and Middle Estuary	80%	August 1 through August 31
	85%	September 1 through October 31 and June 1 through July 31
	90%	November 1 through May 31
Lower Estuary	For the protection of estuarine habitat (EST), the dissolved oxygen content of the lower Klamath estuary shall not be depressed to levels adversely affecting beneficial uses as a result of controllable water quality factors.	

Table 7.4 of the Staff Report presents the DO concentrations corresponding to the percent saturation criteria as based on estimates of natural receiving water temperatures contained in the *Klamath TMDL model.*

National Criteria for the protection of early life stages of coldwater organisms require: 9.5 mg/L DO as a 7-day mean in the water column, 6.5 mg/L as a 7-day mean in the intergravel environment, 8.0 mg/L as a 1-day minimum in the water column and 5.0 mg/L as a daily minimum in the intergravel environment. For the protection of other life stages of coldwater organisms, the National Criteria require 6.5 mg/L DO as a 30-day mean, 5.0 mg/L as a 7-day mean of the daily minima, and 4.0 mg/L as a 1-day minimum. US Environmental Protection Agency (USEPA 1986) provides guidance on the development of alternate aquatic life criteria for DO based on the degree to which local criteria must protect against any production impairment, or can allow for slight or moderate production impairment. USEPA (1986) also allows that "where natural conditions alone create dissolved oxygen concentrations less than 110 percent of the applicable criteria means or minima or both, the minimum acceptable concentration is 90 percent of the natural concentration." (p. 35)
Staff compared simulated DO concentrations under natural conditions as produced by the T1BSR natural conditions run of the *Klamath TMDL model* to the National Criteria. Simulated DO concentrations under natural conditions meet a 4.0 mg/L daily minimum all year long, as well as 6.5 mg/L as a 30-day mean. From October to March, simulated natural DO concentrations also meet an 8.0 mg/L daily minimum protecting incubating salmonids. An 8.0 mg/L daily minimum is even met from September through May with exceptions from a location upstream of Iron Gate Dam to a location upstream of the Shasta River. The spawning and incubation period in the Klamath mainstem is generally estimated to last from October 1 through April 30, with the possibility of inter-annual variation.
The DO modeling output does not provide a convenient way of assessing consistency with the 7-day mean National Criteria. But, if the 9.5 mg/L DO criteria is increased to 10.0 and applied as a 30-day mean, simulated DO concentrations under natural conditions as produced by the T1BSR natural conditions run of the *Klamath TMDL model* meets the criteria from November 1 through March 31 at all locations and from October 1 through April 1 at all locations from Seiad to the Lower Estuary.

While simulated natural DO concentrations generally meet the National Criteria, staff believe that the threatened and endangered status of salmonids in the basin require the establishment of DO objectives based on protection against any further production impairment. The T1BSR run of the *Klamath TMDL model*, however, demonstrates that the mainstem Klamath River under natural conditions does not consistently produce DO consistent with no production impairment, as defined by USEPA (1986). As such, staff proposes DO criteria based on natural conditions. As described by Davies (1997) for aquatic life uses, by definition natural conditions are sufficient to support the level of aquatic life expected to occur naturally at the site absent any interference by humans.

The biochemical processes influencing ambient DO concentrations are complex and difficult to simulate site-specifically with perfect accuracy. As such, staff estimated natural DO conditions using percent saturation and natural receiving water temperatures. Receiving water temperatures can be estimated with greater accuracy than can DO and are comparatively consistent in pattern and range from year to year. The *Klamath TMDL model* simulates percent saturation at various locations throughout the mainstem Klamath as a result of barometric pressure, salinity, and natural temperatures at those locations, as influenced by boundary conditions for percent saturation estimated from historical data. The mainstem Klamath under natural conditions meets a minimum percent DO saturation of 85% throughout its length (with an exception during August in the estuary) and 90% during the winter months.

The proposed recalculated SSOs for DO are protective of the beneficial uses for the following reasons:

- They are based on natural conditions, thereby providing water quality comparable to the water quality in which the beneficial uses naturally exist.
- They result in DO concentrations that vary with the seasons, thereby ensuring greater DO concentrations in the winter months when salmonids embryos and alevin reside in the gravels.
- They result in daily minimum DO concentrations greater than 4.0 mg/L throughout the year (National Criteria).
- They result in daily minimum DO concentrations greater than 8.0 mg/L at all locations and throughout all of the identified incubation season (National Criteria).
- They result in 30-day means greater than 6.5 mg/L DO all year and greater than 10.0 mg/L at most locations during the identified spawning and incubation season (National Criteria).
- The transfer of DO from the water column to the intergravel environment may be more efficient than predicted by USEPA (1986) indicating a difference between the water column and intergravel environment of less than 3.0 mg/L, on average. Monitoring data should be collected to determine the relationship between water column DO and intergravel DO at key locations throughout the mainstem Klamath. In this way, staff could better define the DO conditions required in the water column to ensure no production impairment in the intergravel environment.
- They include protections, through the implementation of the Klamath River TMDLs of thermal refugia in the tributaries where most of the spawning and incubation in the basin actually occurs. In addition, they are companions to the TMDL load allocations and source control measures, including measures designed to reduce sediment, decrease temperatures, and decrease organic matter and nutrient inputs.
- They are companions to other water quality objectives contained in the Basin Plan such as narrative objectives that protect natural temperature conditions and protect against suspended sediment, turbidity and settleable matter in quantities that harms beneficial uses.

Further, the proposed recalculated SSOs for DO in the mainstem Klamath River are consistent with the Hoopa Valley Tribe's water quality objectives for DO. That is, though the T1BSR run of the *Klamath TMDL model* indicates that natural conditions prevent the attainment of the life cycle-based DO requirements contained in the Hoopa Valley Tribe's Basin Plan, the proposed 90% DO saturation criteria based on natural receiving water temperatures from the Scott River to Hoopa is identical to the natural conditions clause included in Hoopa's Basin Plan. Staff proposes the T1BSR run of the *Klamath TMDL model* as the tool for quantifying natural DO conditions.

This Staff Report incorporates by reference several chapters of the Klamath TMDL Staff Report of which it is a part. For example, Chapters 6 (Implementation Plan), 7 (Monitoring Plan), 9 (CEQA Analysis), 10 (Economic Analysis), and 11 (Public Participation) describe factors related to both the Klamath TMDL and the recalculated SSOs for DO.

CHAPTER 1.
INTRODUCTION

The purpose of this Staff Report is to present the scientific justification for a recalculation of the existing Site Specific Objectives (SSO) for Dissolved Oxygen (DO) in the Klamath River mainstem (Klamath). Staff to the North Coast Regional Water Quality Control Board (Regional Water Board) has:

1. Reviewed the existing SSO for DO in the Klamath;
2. Analyzed new sources of data and information related to DO conditions in the Klamath; and
3. Recalculated an SSO for DO in the Klamath based on a series of water quality models used to establish the Total Maximum Daily Loads (TMDL) for organic matter, nutrients, temperature, dissolved oxygen, and microcystin necessary to achieve water quality objectives, including objectives for DO.

This Staff Report is an appendix to the Klamath River Total Maximum Daily Load (TMDL) Staff Report which includes an implementation plan, monitoring plan, economic analysis, discussion of public participation, and California Environmental Quality Act (CEQA) analysis applicable to both the proposed TMDL and DO SSO basin plan amendments for the Klamath River.

1.1 Description of the Klamath River Watershed

The Klamath River basin[1] is 12,680 square miles in area. The Klamath River originates in southern Oregon and flows 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 to 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 does hydroelectric power provided via a system of five dams operated by PacifiCorp. The basin 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 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 state and federal governments in Oregon and California. Finally, the watershed continues to support what were once historically significant mining and timber industries.

[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.

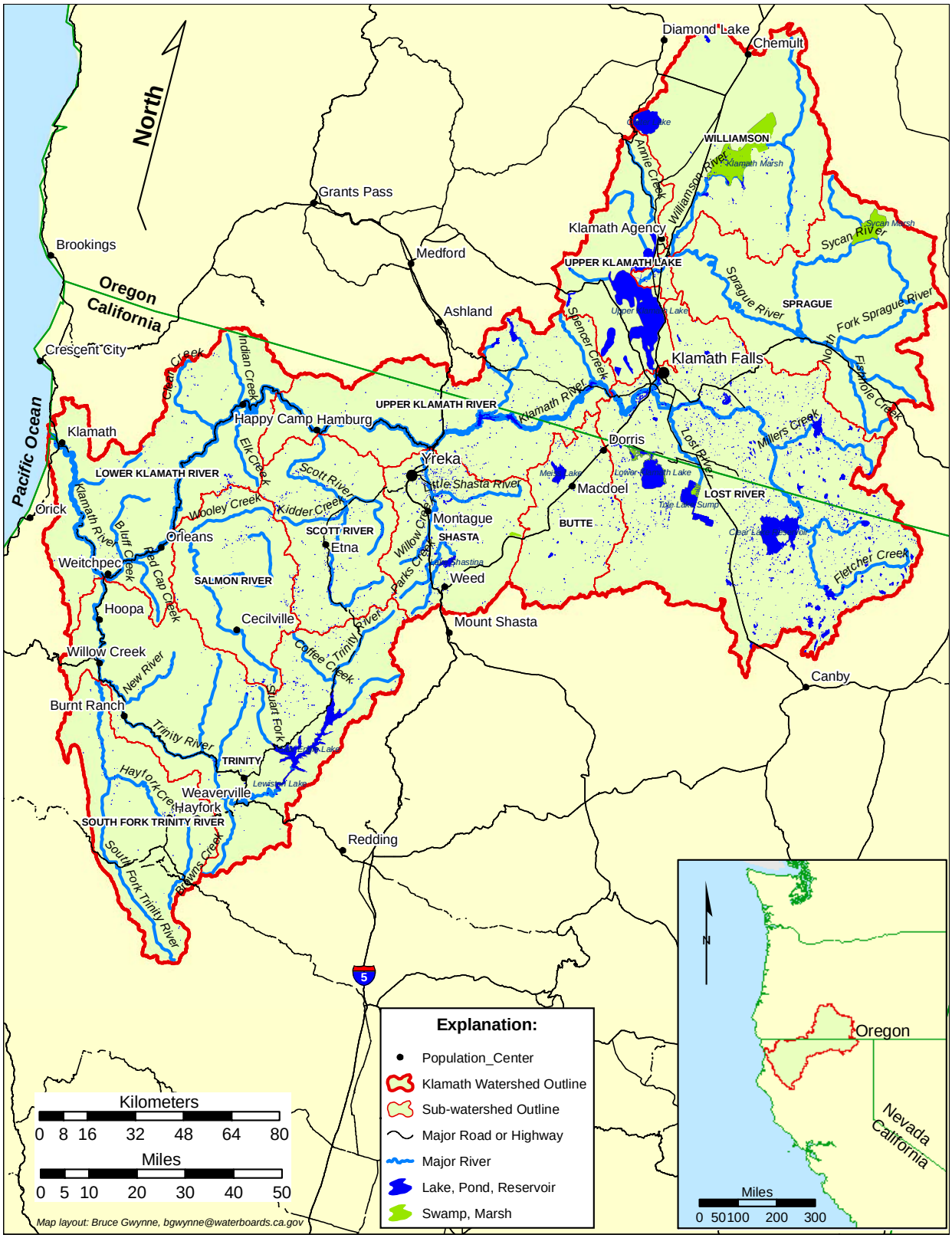

Figure 1-1: Klamath River Basin Showing Rivers, Lakes and Reservoirs, Population Centers, and Major Roads

A decline in the fisheries is one of several indicators of ecological distress in 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 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).

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

The U.S. Environmental Protection Agency (USEPA) Region 9 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 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. Each of these impairments has an effect on ambient DO in the Klamath River mainstem. Table 1.1 summarizes the waterbody-pollutant combinations for the Klamath River in California as identified on the current (2006) section 303(d) List.

A consent decree entered into by the USEPA in March 1997 (*Pacific Coast Federation of Fisherman's Associations et al. v. EPA*) establishes the date by which TMDLs for seventeen northcoast California watersheds must be completed. The Klamath River TMDLs for the listed temperature and nutrient impairments were scheduled for

[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 (HSA) identifies a smaller hydrologic unit within a HA.

completion by 2007. Negotiations between USEPA and the plaintiffs resulted in an extension of that deadline to 2010.

1.2 Summary of the Proposed Action The action proposed in this Staff Report addresses the SSOs for DO on the Klamath mainstem, only. It does not affect any of the tributaries to the Klamath River.

Table 3-1 of the *Water Quality Control Plan for the North Coast Region* (Basin Plan) currently requires Klamath mainstem ambient water quality DO conditions as follows:

1) An instantaneous minimum DO upstream of the Iron Gate Dam of 7.0 mg/L. Half of the monthly mean DO values for the year must be 10.0 mg/L or greater.
2) An instantaneous minimum DO downstream of the Iron Gate Dam of 8.0 mg/L. Half of the monthly mean DO values for the year must also be 10.0 mg/L or greater.

The proposed action is an amendment to the Basin Plan to remove from Table 3-1 the instantaneous minimum and 50% lower limit numeric criteria for DO applicable as follows:

- In the Middle Klamath River HA, Klamath River above Iron Gate Dam including Iron Gate & Copco Reservoirs and Klamath River below Iron Gate Dam; and,
- In the Lower Klamath River HA, Klamath River.

In its place, language is to be inserted requiring that the DO objective for the Klamath River mainstem from the Oregon border to the Pacific Ocean is as depicted below. The percent DO saturation criteria are to be calculated as twelve (12) individual daily minima, one for each calendar month of the year using site salinity, site barometric pressure and natural receiving water temperatures.

Proposed Recalculated SSO for DO in the mainstem Klamath River
(To be applied from the Stateline to the Pacific Ocean except where there is Tribal jurisdiction).

From Stateline to Upper Hoopa Boundary

- 90% DO saturation based on natural receiving water temperatures from October 1 through March 31
- 85% DO saturation based on natural receiving water temperatures from April 1 through September 30

From Lower Hoopa Boundary to Turwar

- 85% DO saturation based on natural receiving water temperatures all year

Upper and Middle Estuary

- 80% DO saturation based on natural receiving water temperatures from August 1 through August 31

- 85% DO saturation based on natural receiving water temperatures from September 1 through July 31

Lower Estuary
For the protection of estuary habitat (EST), the Dissolved Oxygen content of the Lower Klamath Estuary shall not be depressed to levels adversely affecting beneficial uses as a result of controllable water quality factors.

1.3 History of the Proposed Basin Plan Amendment for DO
Regional Water Board staff has been assessing the need to revise the existing DO objectives for several years. In an August 2000 review of Russian River water quality objectives (focusing on DO, temperature, pH, oil and grease, and turbidity) for the protection of salmonid species prepared for the Sonoma County Water Agency, Regional Water Board staff found that the DO and water temperature objectives for the Russian River Basin, among others, did not afford adequate protection for species listed on the State and Federal Endangered Species Acts (CESA/ESA). In order to address this, Regional Water Board staff recommended developing numeric objectives specific to each salmonid life stage.

In 2005, staff distributed for public review a region wide proposal for the revision of both the temperature and DO objectives contained in the Basin Plan. Zabinsky and Azevedo (2005) proposed numeric temperatures objectives and updated numeric DO objectives for the protection of individual life stages of salmonids. A workshop on this subject was held before the Regional Water Board in April 2005.

Shortly thereafter, staff was diverted to the development of the Klamath Total Maximum Daily Loads (TMDL). As a result, the proposal to amend the Basin Plan's temperature and DO objectives was put on hold. As part of the Klamath TMDL, a series of models were developed to estimate water quality conditions, including temperature and DO, in the Klamath River mainstem under varying pollutant loading scenarios. Once the models were validated and calibrated, they were run to estimate natural conditions as the baseline.

One of the important findings of the TMDL natural conditions model run (T1BSR) is that DO fluctuates widely in the Klamath River mainstem due to such natural conditions as elevated summer temperatures, elevated nutrients emanating from the volcanic geology and organic-rich wetland soils of the upper basin, and elevated phytoplankton activity resulting from these natural conditions. As a result of the elevated phytoplankton activity, DO concentrations fluctuate both daily and seasonally. This fluctuation results in periodic noncompliance with the existing SSO for DO in the Klamath, particularly during the night time hours of the summer months. That is, the model demonstrates that under natural conditions, water quality in the mainstem of the Klamath River can not consistently meet the existing SSOs for DO. This is primarily due to the fact that the existing SSOs for DO are based on day time grab sample data and do not reflect the night time minima. This differs from the TMDL modeling which was calibrated and validated using 24 hour day.

After some evaluation, staff determined that the issues associated with the SSOs for DO in the Klamath River are also reflected in the SSOs for DO in the rest of the fifty-eight (58) waterbodies listed in Table 3-1 of the Basin Plan. For this reason, staff picked up the regionwide Basin Plan Amendment again, this time focusing just on DO. A CEQA scoping document was distributed and two scoping meetings held in the fall of 2008. A draft Staff Report was prepared and submitted for peer review. Peer review comments were received and responses drafted. Revisions to the regionwide proposal were prepared as a result of the peer review comments.

In the mean time, the need to establish accurate SSOs for DO in the mainstem of the Klamath River has become more pressing because of a court-ordered deadline for establishing the Klamath River TMDL by December 2010. By regulation, a TMDL must demonstrate that it will achieve applicable water quality objectives for it to be approvable. Staff has taken the concepts of the draft regionwide Basin Plan Amendment and applied them to the mainstem Klamath River as the means of establishing accurate SSOs for DO in the Klamath. This Staff Report documents the approach, including the model results which support this proposal.

After the adoption of recalculated SSOs for DO in the Klamath River, staff will finalize its proposal for amending DO objectives on a regionwide basis and bring it before the Regional Water Board for their consideration in the future.

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CHAPTER 2.
PHYSICAL SETTING OF THE KLAMATH RIVER BASIN

The purpose of this chapter is to establish the location and physical characteristics of the Klamath River basin. The Site Specific Objectives (SSO) for Dissolved Oxygen (DO), as developed in this Staff Report, are intended to apply to those portions of the Klamath River mainstem under the jurisdiction of the State of California: from the Oregon border to the Pacific Ocean, but excluding that portion near Saints Rest Bar which is under the independent jurisdiction of the Hoopa Valley Tribe and that portion downstream of the Trinity River through the estuary under the jurisdiction of the Yurok Tribe. Factors such as landuse, topography, geology, vegetation, climate, and hydrology affect the way in which DO dynamics are expressed in the Klamath River mainstem.

2.1 Population and Land Ownership

The 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 is Klamath Falls in Oregon (19,462 people in 2000) 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.

According to Natural Resources Conservation Service (NRCS) in a report published in 2004, 63% of the Klamath River watershed is in federal, state or tribal ownership; the remaining 37% of the basin in private ownership. While federal, state, and tribal land ownership surpasses private landownership in the California portion of the Klamath watershed, ownership is more evenly divided in Oregon.

Figure 2.1 shows, among other things, federal lands managed as National Forests, National Wildlife Refuges, and National Parks, in addition to lands administered by the Bureau of Land Management (BLM). The Hoopa Valley Tribe owns land, 12 miles by 12 miles, primarily in the Trinity River watershed but intersecting the Klamath River at Saints Rest Bar upstream of the confluence with the Trinity. The Yurok Tribes's land extends from 1 mile on each side of the Klamath River from the mouth upriver for a distance of 44 miles. The 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.

Forestland accounts for about 22% of the private lands in the basin, equally divided between California and Oregon, though the private timber activity in California occurs primarily in the lower Klamath basin (NRCS 2004). Cropland/pasture activities and rangeland activities account for 14% and 21%, respectively, of the private land use in the Klamath River watershed. Private cropland and pasture are concentrated in the upper Klamath watershed; but, private rangeland is more evenly divided throughout the basin (NRCS 2004). Urban development, commercial and industrial lands, and residential

lands account for less than 1% each of the landuse activities occurring on privately owned land in the Klamath River watershed. Urban and commercial/industrial development, such as it is, is concentrated in California while residential lands are concentrated in Oregon (NRCS 2004). Commercial landuse activities such as grazing, mining, and timber harvesting occur on Federal lands managed by the U.S. Forest Service and Bureau of Land Management, as well.

By area, the vast majority of streams and lakes present in the Klamath basin are in Oregon (93%). Only 7% of the area covered by water is made up of streams and lakes found in the California portion of the basin (NRCS 2004).

2.2 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 2.2). Elevations range from 14,179 feet (4,322 meters) at the summit of Mount Shasta to sea level at the river mouth. 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 2.3). 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 (1219 to 1524 meters) 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. Many of these wetlands have been converted to farmland. The volcanic soils are naturally rich in phosphorus, a nutrient of concern in the Klamath TMDLs and important to the DO dynamics in the basin. 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 a line on a map is by necessity a bit arbitrary (Figures 2.3, 2.4). 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 collapsed crater of a volcano that erupted cataclysmically about 7,000 years ago.

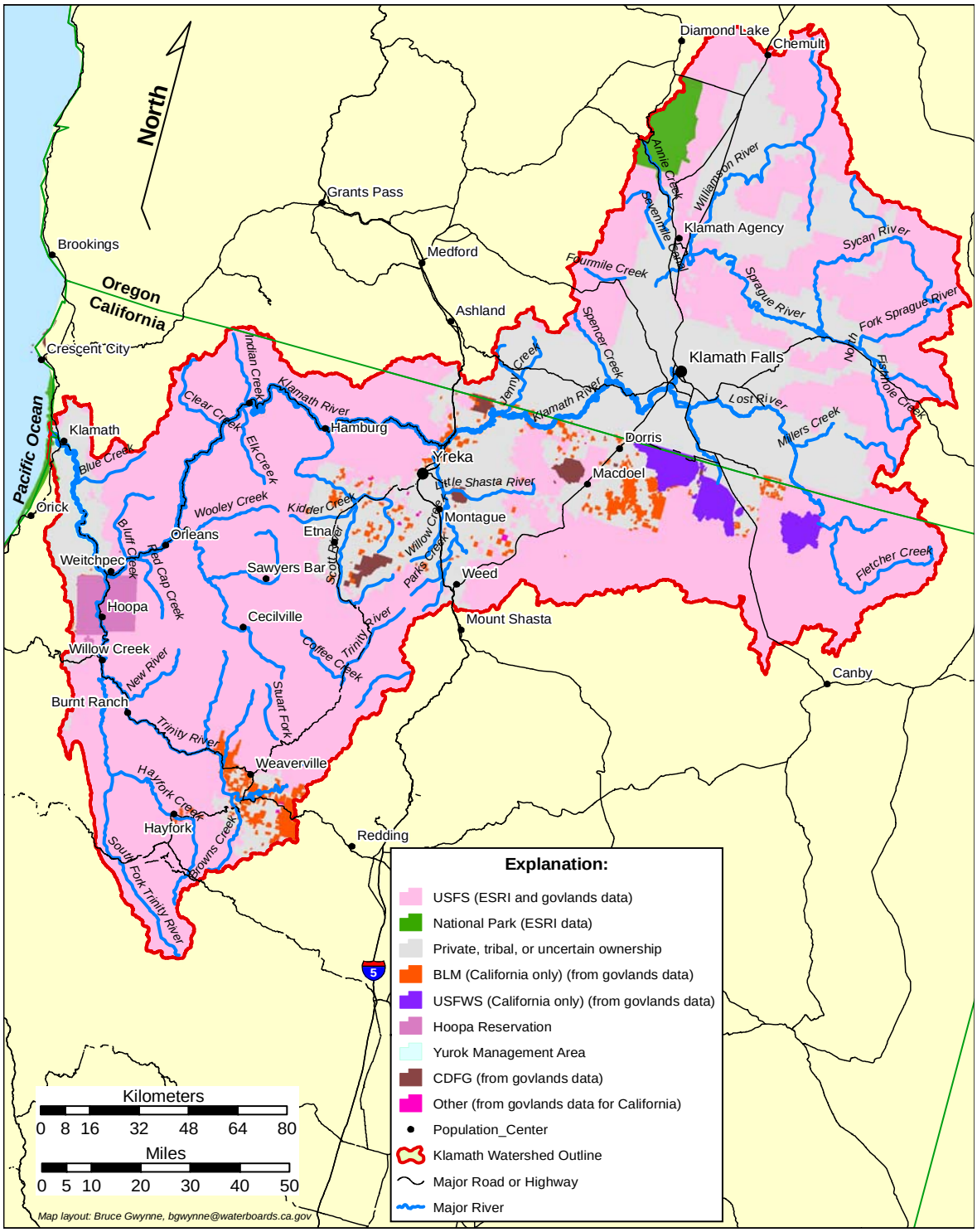

Figure 2.1: Land Ownership in the Klamath River Basin

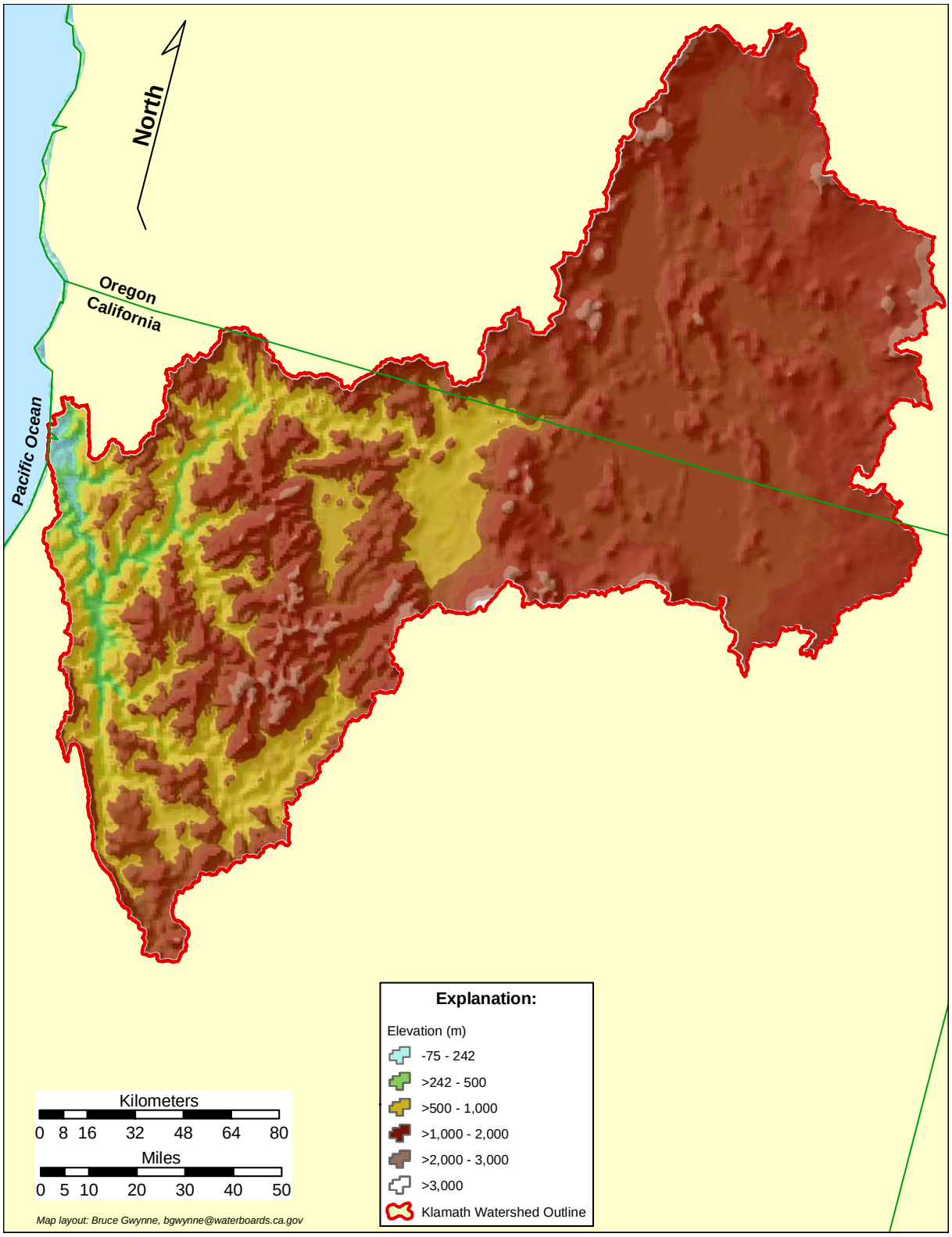

Figure 2.2: Land Elevation in the Klamath River Basin

Figure 2.3: Geomorphic Provinces in the Klamath River Basin - Source: Oakshott 1978

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 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 2.1), 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 2.4) 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 2.3), 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 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 terrain 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 2.2). This unusual gradient is largely the result of geologic uplift in the upstream portion of the river basin in recent geologic time. It is a defining characteristic of the Klamath watershed and strongly influences the nutrient and DO dynamics of the basin.

Figure 2.4: Geologic Map of the Klamath River Basin
Source: Modified from Schruben et al. (1997)

2.3 Vegetation

Vegetation in the Klamath River watershed varies greatly with elevation, precipitation, geology, and degree of disturbance. Figure 2.5 shows the major classifications of vegetation. Conifers dominate in the steep mountains and the higher elevations throughout the watershed and are the major land cover of the basin. Hardwood forest and shrubs are more abundant in the lower country within the Klamath Mountains and Coastal Range Provinces. Grass and brush land, as well as lands converted for agricultural purposes, are abundant in the low gradient landscapes associated with the Scott, Shasta, and Lost River valleys in California, as well as the Lost, Sprague, and Williamson River valleys in Oregon. Wetlands are found throughout Oregon, including around Upper Klamath Lake, as well as in the Lost River valley in California. The wetland habitat present in the Klamath River watershed today represents about 25% of what existed historically (http://www.fws.gov/klamathbasinrefuges/history.html retrieved October 26, 2009). As described above, much of the wetland land cover in the upper watershed has been converted to agricultural use over the last 150 years, significantly altering the natural processes by which organic matter and nutrients are stored and released downstream.

2.4 Climate

The great geographic extent and topographic relief of the Klamath River watershed combine to produce a wide variety of climate conditions (Figure 2.6). 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 2.6).

Figure 2.7 provides a comparison of monthly precipitation values from Orleans, California in the mountainous country of the lower Klamath basin and Klamath Falls, Oregon in the broad valley of the upper Klamath basin as an illustration of rain shadow 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.

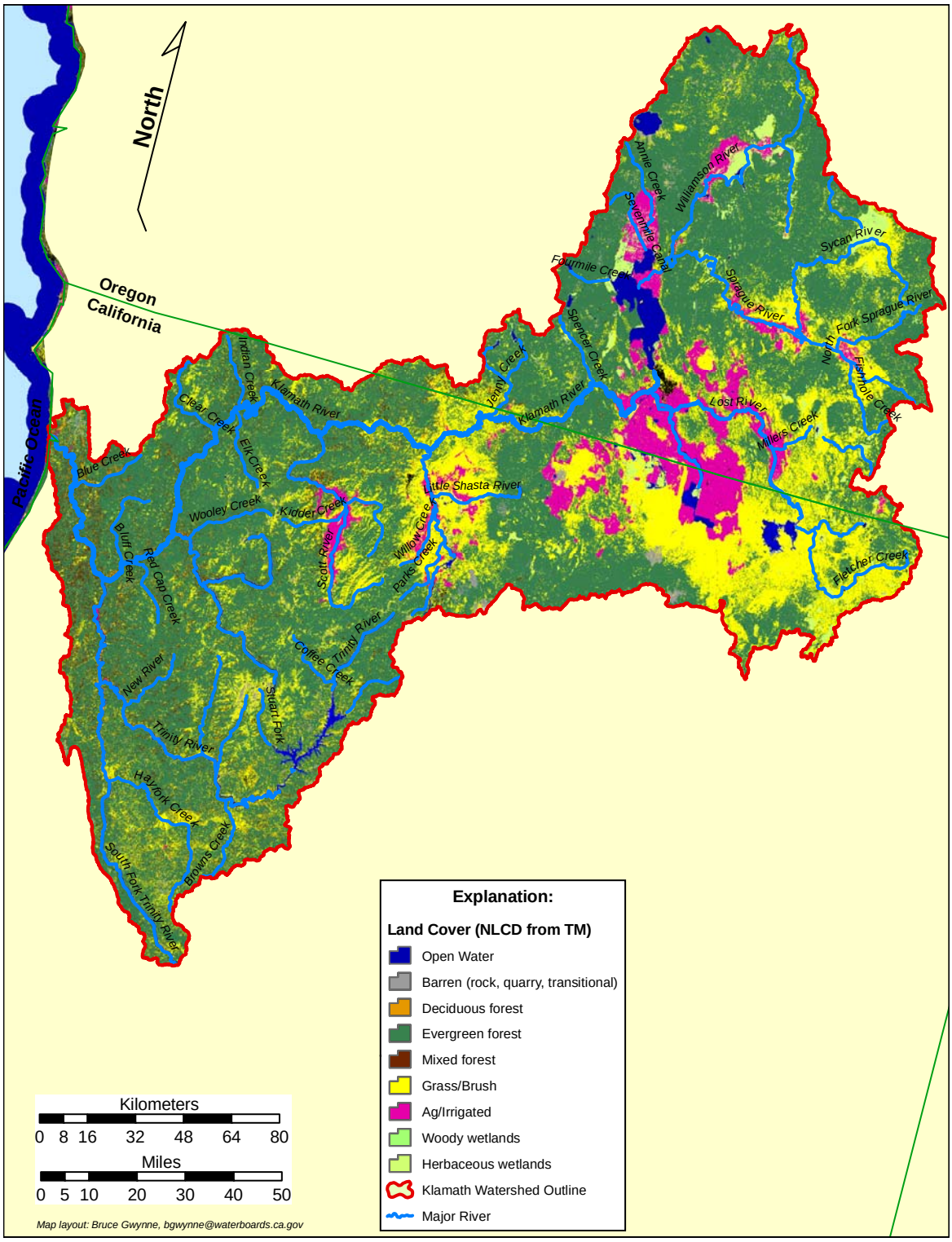

Figure 2.5: Vegetation and Land Cover of the Klamath River Basin, Thematic Mapper GIS database

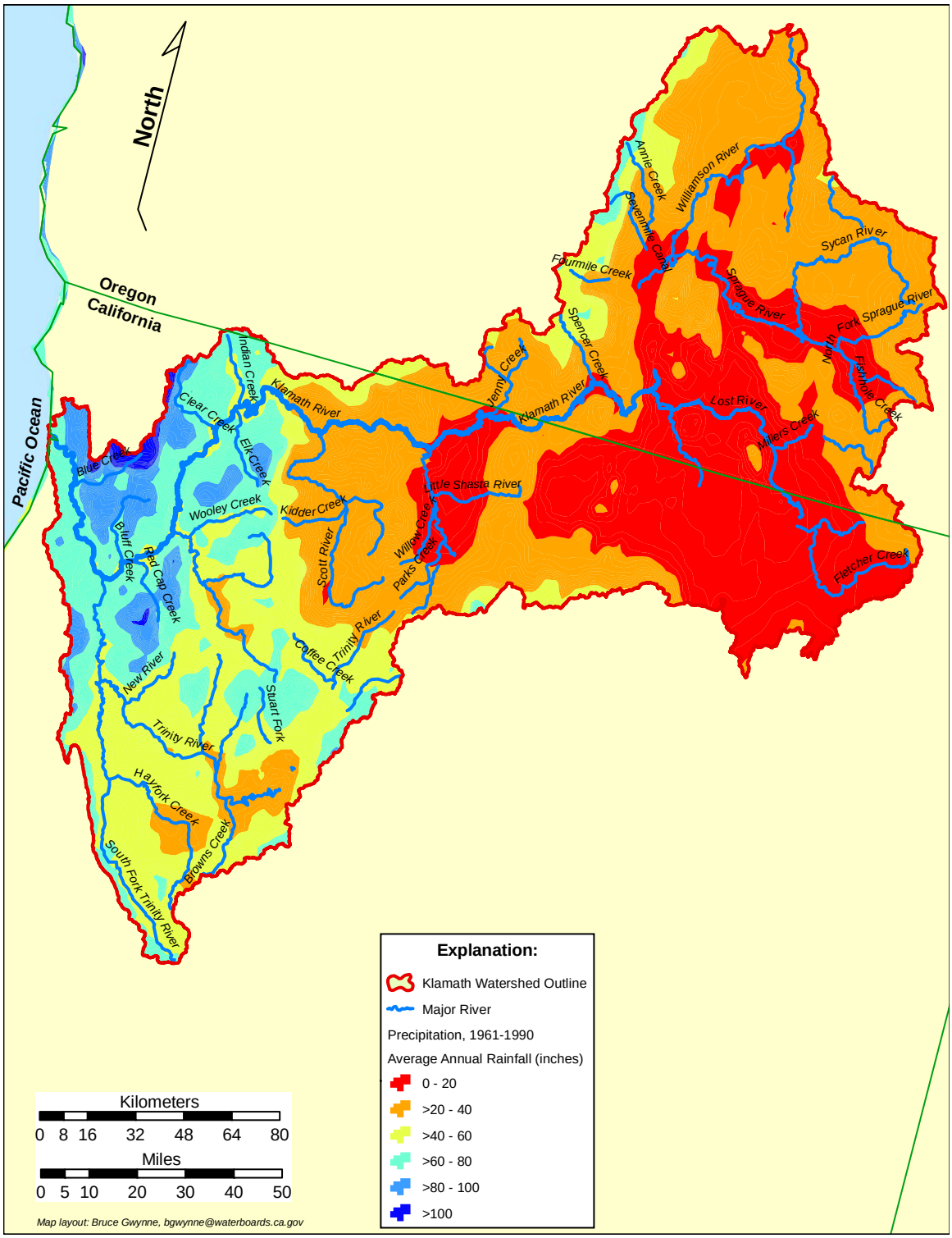

Figure 2.6: Average Annual Rainfall in the Klamath River Basin
Source: United States Department of Agriculture (USDA) Undated

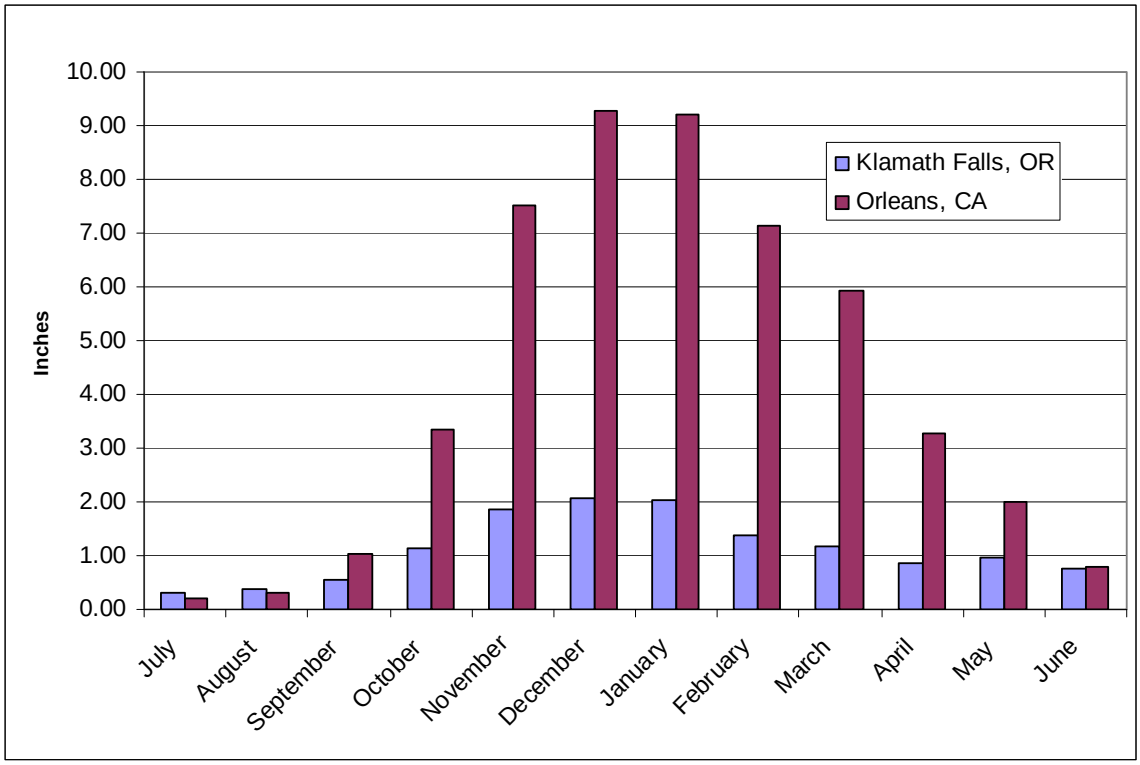

Figure 2.7: Average Monthly Precipitation, 1905-2003, in Klamath Falls, Oregon and Orleans, California
Source: California Data Exchange Center [CDEC] 2006; Oregon Climate Service [OCS] 2006

Klamath Basin air and water temperature data indicate that air and water temperatures have been steadily increasing since at least the 1960s. Bartholow (2005) analyzed air and water temperature records distributed throughout the Klamath basin and evaluated water temperatures simulated using a computer-based water temperature model. The results of Bartholow's analysis strongly suggest a trend of water temperature increases of approximately 0.5 ^{o}C per decade since the 1960s. As described in more detail in Chapter 4.0 of this Staff Report, water temperature is one of three factors controlling DO concentrations at saturation. DO concentrations at saturation are inversely proportional to water temperature. Thus, as water temperatures rise, the DO concentration at saturation decreases.

2.5 Hydrology

Drainage density in the Klamath River watershed is affected by infiltration capacity, tectonics, and underlying bedrock. Figure 2.8 shows dense drainage networks in the

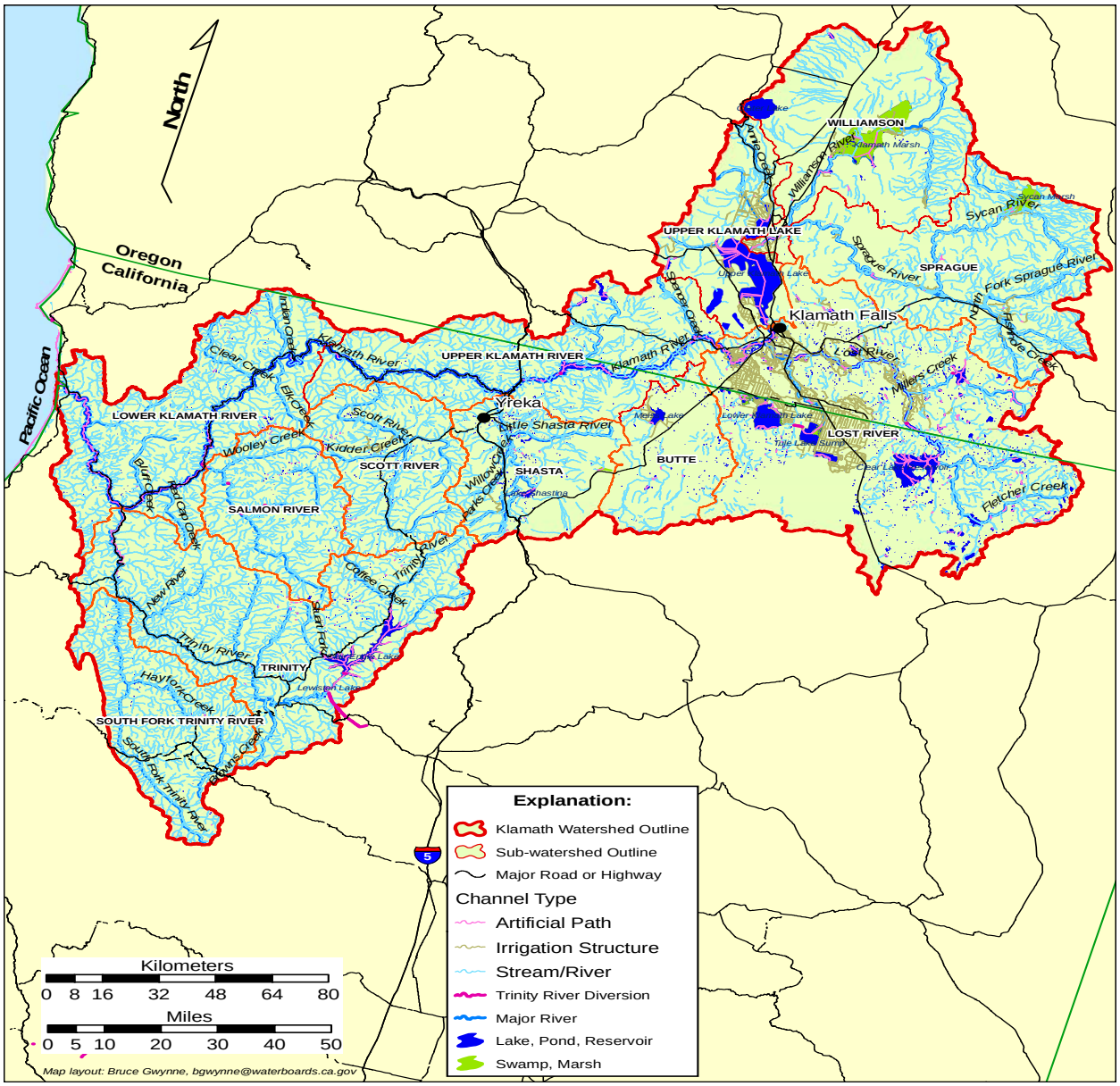

Figure 2.8: Map of Klamath River Basin Emphasizing Subbasins and Surface Drainage

steep, recently uplifted ranges to the west and in the volcanic mountains to the east. The lower, flatter country in the upper Klamath, in the region of Klamath Falls, has a much lower drainage density (though greater percent area covered by water) and is punctuated by lakes and wetlands associated with local tectonic subsidence.

Water yield in the Klamath basin varies by watershed setting. As illustrated in Figure 2.9, approximately half of the February flow measured in the lower watershed at the town site of 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% 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. It is important to recognize that the data presented in Figure 2.9 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.

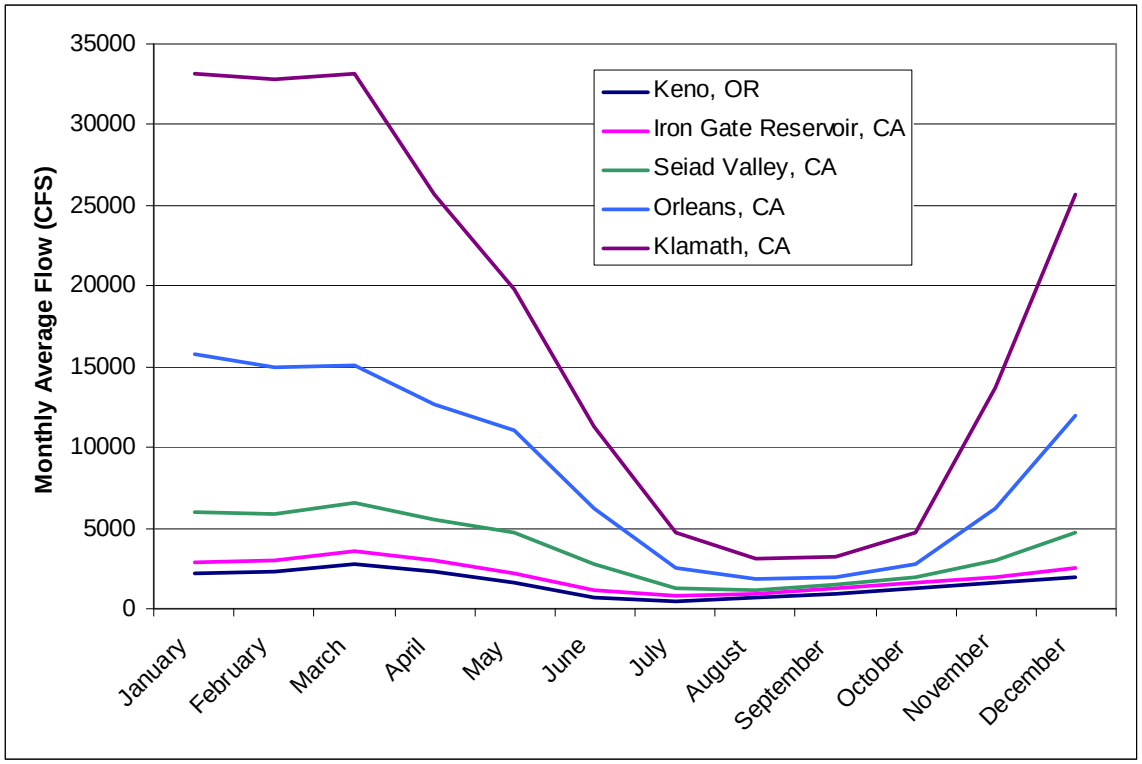

Figure 2.9: Monthly Average Flows at Five Klamath River Locations, Water Years 1963-2005
Source: United States Geological Survey [USGS] 2006

2.6 Summary

The Klamath River watershed has a number of unique physical characteristics which define the water quality dynamics of the basin. Most watersheds in the North Coast Region share a general topographic profile in which the headwaters flow down steep inner gorges, gather in second and third order streams of more moderate slope, and meander gently across a coastal plain before discharging to the Pacific Ocean. The Klamath River, on the other hand, gathers in the gently sloping wetlands and lakes of southeastern Oregon before leaving Upper Klamath Lake at Keno where the stream slope steepens through California and to the ocean. The soils of the upper basin are defined in large part by the volcanic geology of the southeastern part of Oregon and include naturally high levels of phosphorus which were historically stored in the wetland soils and vegetation of the upper basin. The periodic mobilization of excess organic matter and nutrients from Upper Klamath Lake to the free-flowing portion of the Klamath River created a zone of high productivity downstream which slowly dissipates as the stream channel steepens. This phenomenon has earned the Klamath River its nickname: "the River of Renewal."

The Klamath River watershed includes mountain ranges of higher elevation than most other watersheds in the North Coast Region. Many of the watersheds in the North Coast show a pattern of stream flow that closely mimics rainfall and can be quite flashy during and immediately after large storms. In the Klamath River; however, winter precipitation is stored as snow at the higher elevations. Thus, stream flow increases in the fall as a result of rainfall and is extended through the spring as the winter snows melt. (Though, rain-on-snow events can mobilize stored water quickly and catastrophically).

As is true of most other watersheds in the North Coast Region, the Klamath River is fundamentally a rural watershed, particularly within the boundaries of California. Thus, the water quality impacts associated with human activity in the Klamath River basin have little to do with point source discharges. In fact, point source discharges are prohibited in the California portion of the Klamath River watershed as is described in more detail in Chapter 5.0[1]. The much more significant cause of water quality impact in the Klamath River basin is the modification of *natural* water quality dynamics that has occurred due to human caused alterations of the landscape such as altered: flows and flow pattern; slope and stream channel stability; vegetation type, age, and density; and nutrient and organic matter availability, as examples.[2]

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[1] The Regional Water Board has granted one exception to the prohibition against the point source discharge of waste to the Klamath River. The exception is granted to Iron Gate Hatchery, a fish rearing facility operated jointly by the Department of Fish and Game and PacifiCorp. They are issued a permit restricting the volume and quality of waste which can be discharged.

[2] The effects of mining on the Klamath River are an exception to this general description, with large scale discharges of sediment resulting from hydraulic mining and toxics discharged from leach and tailings piles.

CHAPTER 3.
FISHES OF THE KLAMATH REGION

The proposed Site Specific Objectives (SSO) for dissolved oxygen (DO) in the mainstem Klamath River are designed to protect the beneficial uses of the mainstem. As such, the purpose of this chapter is to provide a review of the native fishes of the mainstem Klamath River that are at risk of extinction and identify their dissolved oxygen (DO) requirements. Staff focuses on the native fishes at risk of extinction because of their unique vulnerability. The Cold Freshwater Fishery (COLD) (i.e. salmonids) is identified as the most sensitive beneficial use of the Klamath River, the spawning and incubation of salmonids the most sensitive life stages.

The DO requirements of salmonids are identified in a series of review papers analyzing the relationship between DO and various fish health parameters as described in numerous laboratory and field studies. The review papers span 20 years, beginning with the 1986 DO guidance document published by the USEPA and including reviews conducted by the states of Oregon and Washington, as well as an in-house Regional Water Board review conducted by staff in 2005 (Carter 2005).

Water quality conditions in the mainstem Klamath River have been modeled as part of a Regional Water Board effort to establish Total Maximum Daily Loads (TMDLs) for dissolved oxygen, temperature, nutrients, and microcystin. The models indicate that under natural conditions, the Klamath River mainstem does not consistently produce the ideal DO conditions as defined by the laboratory and field studies of the last several decades. This has led staff to ponder the means by which salmonids have historically coped with less than ideal mainstem conditions. One well-accepted view is that they seek refuge in cool tributary streams and deep mainstem pools (thermal refugia). A listing of existing thermal refugia is also included in this chapter (Figure 3.2).

<u>Upper and Lower Klamath Subprovinces</u>

As described by Moyle (2002), the North Coast Region is divided into two zoogeographic provinces representing two distinct fauna: the Klamath Province and the North Coast Province. The Klamath Province is divided into 4 subprovinces, including the Upper and Lower Klamath through which the Klamath River flows.

Moyle (2002) describes the native fishes of the Upper Klamath Subprovince as primarily freshwater dispersants "most having their closet relatives in the Great Basin." A *freshwater dispersant* is a species that arrived in its present location from a freshwater route or has evolved in place from a distant saltwater ancestor (Moyle 2002). Freshwater dispersants in the Upper Klamath Subprovince arrived from the Great Basin during a time in geologic history when an ancestor of the Snake River, now draining through the Columbia River, previously flowed through the Klamath Region (Aalto et al. 1998 as cited by Moyle 2002). The native fishes of the Upper Klamath Subprovince include three species of sucker; three species of cyprinids (i.e., blue chub, Klamath tui chub, speckled dace); three species of sculpin; several species of salmonid (e.g., bull trout, rainbow trout, redband trout, coastal rainbow trout, and the now extinct Chinook salmon); and three species of lamprey (Moyle 2002). Of these, the Klamath River lamprey, Lost River

sucker, shortnose sucker, and slender sculpin are at risk of extinction (Moyle 2002). The slender sculpin, however, only occurs in Klamath and Agency lakes in Oregon and is not discussed here.

The Lower Klamath Subprovince includes 21 native species of fish including: three species of lamprey, two species of sturgeon, one cyprinid (speckled dace), one sucker, two species of smelt, six species of salmonid (the pink salmon now extinct), one stickleback, four species of sculpin, and one flounder. Of these, the river lamprey, green sturgeon, eulachon, longfin smelt, chum salmon, coho salmon, and cutthroat trout are at risk of extinction (Moyle 2002).

What follows is a discussion of the individual life histories and DO requirements, to the degree that they are known, of the native fishes at risk of extinction in the Klamath River. Predictably, the DO requirements of salmonids are the most well understood and represent the largest part of the discussion. Because coldwater DO objectives have generally been developed based on the requirements of salmonids, the information below is intended to confirm that DO objectives developed to protect salmonids will protect the other fishes at risk, as well.

3.1 Salmonids

The present distribution and abundance of salmonids "has been strongly shaped by Pleistocene events. In northern and mountain areas, they followed the advance and retreat of continental glaciers, rapidly colonizing new streams and lakes" (Moyle 2002). Moyle (2002) asserts that salmonids thrive in dynamic environments. But, the water must be fairly cool (<22°C maximum) and well oxygenated (Moyle 2002). Moyle (2002) opines that because they have twice as much genetic material as most fishes, salmonids respond rapidly to evolutionary pressures.

Salmonids are anadromous fish, born in freshwater, migrating to the ocean where they feed and mature, and returning to their natal freshwater stream to reproduce. Salmonids typically die after spawning in fresh water, trout and steelhead being exceptions. Salmonid eggs are laid in a nest (i.e., redd) that the female digs in the gravel. The eggs are fertilized externally and the developing embryos covered with gravel as protection. After the yolk sac fry or alevin hatch, they remain in the interstices of the gravel until ready for emergence to the water column. Juvenile fish grow in freshwater until ready for outmigration to the ocean. They remain in the estuary where they develop osmoregulation facilities capable of life in the ocean. Once in the ocean they feed and grow before reaching sexual maturity. Some salmonids complete their sexual maturation in the freshwater of their natal stream. Others return to their natal stream ready to spawn.

Salmonid species differ in the timing of their life cycle stages, as well as the specific habitat niches they inhabit while in the freshwater environment. For example, spring-run Chinook enter a river system in the spring and hold over in cold water tributaries and deep pools until spawning in the fall. Fall-run Chinook enter a river system in the fall, immediately ready to spawn. However, both species wait until water flows increase and water temperatures decline in the fall before building redds and laying eggs. Other

salmonid species arrive throughout the fall and winter for spawning. By June, the fry of all salmonid species have emerged from the gravel and begun their life in the water column. The length of time juvenile fish remain in freshwater before outmigrating to the ocean varies from several months to several years.

Endangered Species Act (ESA) listed salmonids may be present in some locations in the mainstem Klamath river during the entire year. At the Klamath River Fish Health (KRFH) Conference held in 2007, the participants in the "Panel Discussion on the Cultural, Economic, and Management Implications of Fish Disease in the Klamath River" described the Klamath River as historically being dominated by spring-run Chinook; but, population trends have shifted to favor fall-run Chinook. Carter and Kirk (2008) describe in some detail the causes of this shift and the reader is directed to Appendix 5 of the Klamath TMDLs Staff Report for a copy. Rebecca Quinones of the U.S. Fish and Wildlife Service reported at the 2007 KRFH Conference that the population of fall-run Chinook is looking stable; though, hatchery fish spawning is increasing. She also reported that spring-run Chinook are only found in the Salmon River and periodically in Beaver Creek. Coho populations have decreased by 90-95% from historical levels and populations are trending downwards in the Shasta River; though, returns to the Iron Gate Hatchery are increasing (Quinones, KRFH Conference, 2007).

3.1.1 Individual Species Descriptions

Coho Salmon

In California, coho salmon (*Oncorhynchus kisutch*) have a fairly strict 3 year life cycle with about half of its life spent in freshwater and the other half in the ocean (Moyle 2002). Coho adults migrate upstream for spawning after heavy fall or winter rains breach the sandbars of coastal streams allowing the fish to enter. Coho choose smaller coastal streams or the tributaries of larger coastal streams for spawning. They continue upstream when stream flows are rising or falling; though, not necessarily when the streams are in full flood (Moyle 2002). Redd locations generally are at the head of riffles, just below a pool, "where water changes from smooth to turbulent flow and there is abundant medium to small gravel" (Moyle 2002). Embryos hatch after 8-12 weeks of incubation, time being "inversely related to water temperature" (Moyle 2002).

After emergence, fry find quiet stream margins to feed and shelter before establishing territories. Nielsen (1992a, 1992b, and 1994) as cited by Moyle 2002, documented a complicated division of territories amongst coho juveniles, including distinctions between those she called estuarine, margin, thalweg, and early pulse juveniles. All are as their name implies. "Early pulse juveniles show two pulses of growth, one in spring and one in autumn." (Moyle 2002)

The outmigration of juveniles begins between March and May. The triggers include: "rising or falling water levels, day length, water temperature, food densities, phase of the moon, and dissolved oxygen levels" (Moyle 2002). Migrants transform into silvery smolts often lingering for a period in the estuary while adjustments are made to their osmoregulatory system (Moyle 2002).

The National Marine Fisheries Service (NMFS) issued a biological opinion on the Klamath Project Operations dated May 31, 2002. In it, NMFS (2002) reports "adult and juvenile coho salmon are observed in tributaries and the main stem of the Klamath River." Coho populations are found in the Klamath River mainstem year round and in Klamath tributaries as listed in Table 3-1 below.

Table 3-1: From NMFS (2002) Biological Opinion on the Klamath Project Operations

Klamath River Tributaries in which coho populations are present	
Between Iron Gate Dam and Seiad Valley	
Bogus Creek	Empire Creek
Little Bogus Creek	Beaver Creek
Shasta River	Horse Creek
Humbug Creek	Scott River
Little Humbug Creek	
Between Seiad Valley and Orleans	
Seiad Creek	China Creek
Grider Creek	Fort Goff Creek
Indian Creek	Portuguese Creek
Elk Creek	Swillup Creek
East Fork Elk Creek	Independence Creek
Clear Creek	Ukonom Creek
Dillon Creek	Salmon River
Between Orleans and Klamath (mouth of the river)	
Camp Creek	Waukell Creek
Trinity River	McGarvey Creek
Turwar Creek	Tarup Creek
Blue Creek	Omagaar Creek
West Fork Blue Creek	Pularvasar Creek
Nickowitz Creek	Ah Pah Creek
One-Mile Creek	Bear Creek
Crescent City Fork	Little Sulfur Creek
Tectah Creek	Johnson Creek
Hunter Creek	Pecwan Creek
East Fork Hunter Creek	Roach Creek
Mynot Creek	Mettah Creek
Hoppaw Creek	Tully Creek
Saugep Creek	Pine Creek

Shaw et al. (1997) studied the life stage periodicities for Chinook, coho, and steelhead in the Klamath River basin from Iron Gate Dam to Seiad Creek. "USFS and USFWS personnel both agree that coho spawning does occur in the mainstem Klamath River (Shaw et al. 1997)." Though not measured, Shaw et al. (1997) believe that coho spawning occurs from November through January in the Klamath system, mostly within tributaries and quiet mainstem habitats. Emergence occurs from late February through April (Shaw et al. 1997). "Coho fry were observed outmigrating from tributaries from early March through late June (Shaw et al. 1997)." Shaw et al. (1997) believe that coho rear in the study area year round.

Coho are listed under the Endangered Species Act as a threatened species in the Southern Oregon/Northern California Coast Ecologically Significant Unit (ESU). The Klamath is listed under the Magnusen Stevens Fishery Conservation and Management Act as Essential Fish Habitat (EFH) for coho.

Chinook Salmon

In California, Chinook salmon (*Oncorhynchus tshawytscha*) are often described by the timing of their freshwater migration: fall-run, late fall-run, winter-run, and spring-run (Moyle 2002). Widely recognized runs in the North Coast Region include: Smith River fall and spring run, Klamath-Trinity fall run, Klamath-Trinity spring run, Klamath late fall run, Redwood Creek fall run, Little River fall run, Mad River fall run, Humboldt Bay tributary fall run, Eel River fall run, Bear River fall run, Mattole River fall run, and Garcia River fall run (Moyle 2002). As described by Moyle (2002), the Klamath-Trinity system has the largest diversity of Chinook salmon runs.

Stream-type Chinook are fish that migrate upstream before reaching sexual maturity, as well as juveniles that spend more than 1 year in freshwater before outmigrating (Moyle 2002). Ocean-type Chinook are fish that spawn immediately upon migrating upstream, as well as juveniles that spend less than 1 year in freshwater before outmigrating (Moyle 2002).

A fall-run Chinook is an ocean-type Chinook, entering the big rivers of the Klamath and North Coast Provinces in the late summer and early fall, and spawning in the lowland reaches within a few days to weeks of arrival (Moyle 2002). Juveniles emerge from the gravel in spring and move downstream within a few months to rear in the mainstem or estuary before going out to sea (Moyle 2002).

A spring-run Chinook is a stream-type Chinook, entering the Smith, Klamath or Eel River in the spring or early summer, going as far upstream as it can, and holding in deep, cold pools until spawning in the early fall (Moyle 2002). The juveniles rear for 3-15 months depending on flow conditions (Moyle 2002). Spring-run Chinook in the Klamath River are considerably less abundant than fall-run Chinook because of the presence of dams, blocking much of their historical mid-elevation habitat (Moyle 2002). Shaw et al. (1997) reports that spring-run Chinook migrate up the Klamath River mainstem beginning in June, tailing off in the Trinity River by mid-September. They hold over until the fall when they spawn primarily in the tributaries. Historically, spring-run Chinook returned to the Iron Gate Hatchery throughout July and August. But, whether or not spring-run Chinook ever spawned in the mainstem is unknown.

Shaw et al. (1997) report that fall-run Chinook enter the Klamath in September with peak migration occurring in October; though, historically they entered as early as August. "Spawning in the mainstem Klamath begins during the second week of October, peaks during the last week of October and declines by the end of November (Shaw et al. 1997)." Fall-run Chinook spawn in the lower reaches of tributaries and in the mainstem Klamath River, although less than 33% spawn in the mainstem (Carter and Kirk 2008). Juveniles emerge from early February through the end of April, depending on water

temperatures. Peak juvenile emigration from the tributaries occurs in mid-March. "Juveniles may emigrate directly to the estuary or remain in the mainstem and emigrate as yearlings (Shaw et al. 1997)."

The Klamath River is listed under the Magnusen Stevens Fishery Conservation Management Act as essential fish habitat for Chinook salmon.

Chum Salmon

In California, small runs of chum salmon were historically present in streams from the Sacramento River north (Moyle 2002). Today, small runs of chum salmon continue in the Smith, Klamath and Trinity Rivers. Hamilton et al. (2005) reports that chum salmon were historically present in the Klamath River basin well below Iron Gate Dam. Chum salmon are generally ocean-type salmon, spending little time in freshwater, and most of that often in the estuary. Chum salmon enter freshwater in the late fall with optimal spawning temperatures of 7.2-12.8 °C and oxygen levels greater than 80% saturation (Moyle 2002). NRC (2004) reports that chum in the Klamath basin are at the southern-most end of their existing range.

Cutthroat Trout

In California, coastal cutthroat trout live in the coastal drainages from the Eel River north (Moyle 2002). Coastal cutthroat trout are more strongly tied to fresh water than most anadromous fishes, leaving freshwater only in the summer months, if at all, and returning to overwinter in freshwater (Moyle 2002). They live primarily in small, low-gradient coastal streams and estuaries where temperatures are cool (<18 °C), well-shaded, and there is abundant cover (Moyle 2002). They especially avoid waters with DO <5 mg/L (Moyle 2002). Embryo survival can be reduced to less than 10% with DO levels lower than 6.9 mg/L (Moyle 2002).

Cutthroat trout migrate upstream in August-October following the first substantial rainfall (Moyle 2002). Cutthroat trout have a prolonged spawning period, lasting as long as September through April (Moyle 2002). Embryos hatch after 6-7 weeks of incubation and alevin remain in the gravel for an additional 1-2 weeks (Moyle 2002), emerging from March to June (Moyle 2002). Juveniles grow in the stream 1-3 years before going to sea (NRC 2004). They spawn 2-4 times. In the Klamath River basin, they occur primarily in the smaller tributaries to the main stem within about 22 miles of the estuary (NRC 2004).

Voight and Gale (1998) "found juvenile and/or adult coastal cutthroat in 13 of the 19 tributaries downstream of and including Johnsons Creek in the lower Klamath River." In several of the tributaries where they were found, cutthroat dominated the electrofishing catch. Voight and Gale (1998) suggest cutthroat trout maybe more abundant in headwater streams than historically because they have become resident above migration barriers. Gale et al. (1998) report large numbers of adult cutthroat in Blue Creek where they seek refuge from inhospitable conditions in the mainstem.

3.1.2 DO requirements of salmonid species

Regional Board staff has relied primarily on four surveys of the scientific literature associated with the DO requirements of salmonids. The first is USEPA's guidance on the development of DO criteria (USEPA 1986). The second is a review conducted by members of the Dissolved Oxygen Technical Advisory Committee (DOTAC) and staff of the Oregon Department of Environmental Quality and published in 1995 (Oregon 1995). The third is a review conducted by staff of the Washington State Department of Ecology and published in 2002 (Washington 2002). And, the fourth is an in-house literature survey conducted by Katharine Carter, peer reviewed, and published in 2005 (Carter 2005). The following discussion is derived primarily from these literature surveys. For a discussion of the original literature from which these conclusions were drawn, the reader is directed to the four above mentioned surveys.

DO criteria for salmonids are generally divided into two categories: those designed to protect early life stages and those designed to protect other life stages. The early life stages of salmonids face specific environmental issues not otherwise confronting other life stages of salmonids, namely relative immobility and life within the intergravel environment. As such, the DO criteria designed to protect the early life stages take into account the inability of embryos to find refuge from inhospitable DO conditions and the difficulty with which fry and alevin avoid inhospitable intergravel DO conditions. They also take into account the reduction in DO concentration that occurs as water from the water column passes through the intergravel environment.

3.1.2.1 Intergravel Dissolved Oxygen (IGDO) Requirements of Early Life Stages of Salmonids

Intergravel dissolved oxygen (IGDO) is the result of a balance between the rate of respiration among gravel dwelling organisms and the rate of oxygen supply. The rate of oxygen supply, in turn, is dependent on the rate of water percolation and convection, as well as oxygen diffusion (USEPA 1986). IGDO has been correlated to embryo survival in some studies, as has apparent velocity and temperature (USEPA 1986, Oregon 1995, Washington 2002). However, the influence of these parameters, one on the others, can not always be separated (Oregon 1995, Washington 2002). A clear relationship between IGDO and alevin growth and development, however, is observable (USEPA 1986, Oregon 1995). Researchers hypothesize that smaller alevin and alevin that hatch later, as a result of depressed IGDO, may be 1) less successful in their competition for food and space as fry and 2) more susceptible to predation (USEPA 1986, Oregon 1995).

USEPA (1986) concludes that the DO requirements of the early life stages of salmonids (i.e., embryo-to-fry emergence from the gravels) are not appreciably different from adult salmonids. In short, a daily minimum of 6.0 mg/L and an average (weekly or monthly) of 8.0 mg/L DO is sufficient to protect the early life stages of salmonids while they reside in the intergravel environment (USEPA 1986). Washington (2002) notes that alevin selectively prefer oxygen concentrations from 8-10 mg/L and will move through the gravel interstices to find favorable DO conditions. Above 7.8 mg/L DO, there may be no size and survival benefit (Washington 2002).

The outstanding question is how to predict from water column DO measurements, the DO available in the intergravel environment. IGDO can be expected to vary widely within redds and between redds (USEPA 1986, Oregon 1995). Yet, USEPA (1986) assumes an average 3 mg/L DO difference between the water column and intergravel environment based on two studies in which the minimum IGDOs were an average of 3 mg/L less than the DO of the overlying water. Early life stage DO requirements as measured in the water column, then, should be 9.0 mg/L as a daily minimum (i.e., 6.0 mg/L + 3.0 mg/L) and 11.0 mg/L as an average (i.e., 8.0 mg/L + 3.0 mg/L). These criteria are intended to apply to unimpaired settings, only. Locations in which sedimentation, elevated temperatures, or reduced flows are complicating factors, the difference between the overlying water and intergravel environment may be substantially more (Oregon 1995).

For comparison, data collected from two streams in Oregon showed IGDO consistently higher than 8.0 mg/L with the IGDO typically less than 1.0 mg/L below surface water measurements (Oregon 1995). In these streams, the observed surface measures fell below 9.0 mg/L and 11.0 mg/L and yet the intergravel data indicated no measureable impairment (Oregon 1995). A 3.0 mg/L difference between water column DO and IGDO, therefore, may sometimes be overly protective and/or unattainable. Washington (2002) identifies from studies a range of 0.5 to 7.2 mg/L difference in DO from the water column to the intergravel environment; but, suggests that 1-3 mg/L difference is the "typical" range and should be used in setting water quality criteria.

Oregon (1995) recommends that in impaired streams, monitoring protocol should be to collect test and control samples, either from paired watersheds; upstream and downstream of a site; or before and after an activity. Reduction in sedimentation through cessation of activity or stream restoration is correlated to improvement in IGDO, either through improvement in apparent velocity and/or reduction in sediment oxygen demand (Oregon 1995).

3.1.2.2 DO Requirements of Other Life Stages of Salmonids

Once fry emerge from the gravels, they enter the water column where they will reside throughout the rest of their freshwater tenure. As young-of-year, salmonids must put on weight, compete for food, and find shelter from predators and adverse environmental conditions. At issue is the effect of DO on swimming performance; growth; avoidance behavior; and synergistic relationship with toxics, temperature, and disease.

Swimming Performance

Laboratory studies demonstrate that any reduction from saturation in DO concentrations can result in reduced swimming performance (USEPA 1986, Oregon 1995, Washington 2002). Salmonids conserve their energy when DO is depressed and remain more active when DO is fully saturated. While the importance of top swimming performance to the health and survivability of salmonids has not been established, it is hypothesized that it is important during spawning and to avoid predators (USEPA 1986, Washington 2002, Carter 2005). With these exceptions, USEPA (1985) concludes that "the moderate levels

of swimming activity required by salmonids are apparently little affected by concentrations of dissolved oxygen that are otherwise acceptable for growth and reproduction." Oregon (1995) suggests that reduction in swimming speed may act as a surrogate measure of the effect of chronic stress, a phenomena that influences natural populations, but is not directly measurable.

Growth

Researchers hypothesize that food conversion efficiency is influenced by a number of factors, including DO concentration. Constant exposure studies indicate that when food resources are abundant and temperatures are warm but not lethal, there is a significant correlation between salmonid growth and DO concentration (USEPA 1986, Oregon 1995); though the statistical significance is less universal amongst the studies evaluated for DO concentrations in the range of 5-8 mg/L (USEPA 1986, Washington 2002). Washington (2002) reports a loss of growth when DO concentrations fluctuate from high (>10.0 mg/L) to low concentrations (<5.3 mg/L). Oregon (1995) reports better growth for fish exposed to intermittently low concentrations as compared to those exposed to continuously low concentrations.

In the natural environment, where food resources, temperatures and DO concentrations vary episodically, one expects growth rates less robust than those of fish held under constant, ideal, laboratory conditions. Still, USEPA (1986) concludes that "the attainment of critical size is vital to the smolting of anadromous salmonids and may be important for all salmonids if size-related transition to feeding on larger and more diverse food groups is an advantage." USEPA's (1986) survey of the literature indicates: 1) no reduction in the growth rates of salmonids at temperatures ranging from 12-18 °C and DO ≥8 mg/L, and 2) <10% reduction in growth in the same temperature range and with DO ≥ 6mg/L. Washington (2002) concludes that growth rates may become independent of DO concentrations well below saturation when food availability is low, particularly when temperatures are cool. Washington (2002) notes a general trend for growth rates, even in highly fed salmonids in warm waters, to commonly be indistinguishable from controls at concentrations above 8 mg/L. USEPA (1986) recommends a DO concentration of 8.0 mg/L to ensure no production impairment of other life stages of salmonids and 6.0 mg/L to ensure only slight production impairment. Washington (2002) observes that the highest levels of protection against growth effects are demonstrated under DO conditions ranging from 7.9 to 9 mg/L.

Avoidance Behavior

Juvenile salmonids have the ability to detect areas of substandard DO and avoid them (USEPA 1986, Oregon 1995, Washington 2002, Carter 2005). This is an ability that apparently refines as fry grow and age (Oregon 1995). Even alevin will position themselves in the gravel interstices to avoid DO in the range of 4.5-7 mg/L, showing a selective preference for waters in the range of 8-10 mg/L DO (Washington 2002). Within the water column, studies indicate an avoidance behavior that is triggered by DO conditions below 5-6 mg/L (USEPA 1986, Washington 2002); though, the early avoidance studies for coho typically only tested up to 6 mg/L DO (Oregon 1995). "Later tests conducted at concentrations of 7 mg/L indicated no (coho) avoidance; however, the

test temperatures were much cooler which, if reactions are similar to those observed for Chinook juveniles, would be expected to reduce avoidance (Oregon 1995)."

Synergistic Relationships

Salmonids may be exposed to any number of toxicants and/or disease organisms during their time in freshwater, depending on the watershed and the associated anthropogenic activities. Oregon (1995) reports evidence that DO concentrations below saturation act to increase the response of fish to toxicants. Oregon (1995) describes the mechanisms by which adverse actions of a toxicant might be increased by low DO:

1. Increased ventilation of the gill associated with low DO can increase uptake of waterborne toxics;
2. Any toxic which damages the gill epithelium and decreases efficiency of oxygen uptake can thereby increase sensitivity to low DO; and
3. A number of toxics such as pentachlorophenol increase oxygen consumption due to interference with oxidative phosphorylation.

Washington (2002) concludes that maintaining high (>8.5 mg/L) oxygen levels provides added protection from the effects of several very common pollutants.

Washington (2002) also notes the synergistic effects of temperature on the toxicity of pollutants. For several salmonid species, the resistance to lack of oxygen decreases with increasing temperature (Oregon 1995). This is combined with the physical fact that as temperatures rise, the DO concentration at saturation decreases such that less DO is available to aquatic biota in warm water than in cold water. These combined phenomena indicate the importance of cold water refugia, to the success of many salmonids, particularly when summer temperatures otherwise approach levels of concern. Cold water refugia such as deep mainstem pools and tributary streams have the benefit of providing the cool temperatures necessary to many species of salmonids; but also provide DO concentrations at saturation greater than those in the warmer mainstem channel. Without access to cold water refugia, salmonids are confronted with an accelerated metabolism (driven by warmer temperatures) and a reduced ability to swim and feed (driven by lower DO).

In order to identify the locations of known thermal refugia in the Klamath River basin, Regional Water Board staff solicited information from fisheries biologists working in the Klamath through a formal request in April 2009. Based on the information staff received, as well as review of the available reports on the topic, staff compiled a list of the known thermal refugia in the Klamath River basin in California (Table 3-2). The listed tributaries provide thermal refugia at their confluence with the Klamath River mainstem. Maps showing the locations of these creeks in the Klamath River basin are provide in Appendix B. The implementation plan for the Klamath River TMDL and SSO for DO includes a provision to restrict discharges within a buffer zone associated with known thermal refugia (see Chapter 6 of the Klamath TMDL Staff Report).

Table 3-2: Tributaries to the Klamath River Known to Provide Thermal Refugia In and Around Their Confluence.

Tributaries		
Aikens Creek	Halverson Creek	Pine Creek
Aubrey Creek	Hopkins Creek	Portuguese Creek
Barkhouse Creek	Horse Creek	Red Cap Creek
Beaver Creek	Humbug Creek	Reynolds Creek
Blue Creek	Hunter Creek	Roach Creek
Bluff Creek	Ikes Creek	Rock Creek
Bogus Creek	Independence Creek	Rogers Creek
Boise Creek	Indian Creek	Rosaleno Creek
Boulder Creek[1]	Irving Creek	Sandy Bar Creek
Cade Creek	Kelsey Creek[1]	Salt Creek
Camp Creek	King Creek	Seiad Creek
Canyon Creek[1]	Kohl Creek	Slate Creek
Cappell Creek	Kuntz Creek	Stanshaw Creek
Cheenitch Creek	Ladds Creek	Swillup Creek
China Creek	Little Horse Creek	Ten Eyck Creek
Clear Creek	Little Humbug Creek	Thompson Creek
Coon Creek	Little Grider Creek	Thomas Creek
Crawford Creek (Humboldt Co.)	Lumgrey Creek	Ti Creek
Crawford Creek (Siskiyou Co.)	McGarvey Creek	Titus Creek
Dillon Creek	Mill Creek	Tom Martin Creek
Doggett Creek	Miners Creek	Trinity River
Dona Creek	McKinney Creek	Tully Creek
Donahue Flat Creek	Nantucket Creek	Ukonom Creek
Elk Creek	Negro Creek	Ullathorne Creek
Elliot Creek	Oak Flat Creek	Walker Creek
Empire Creek	O'Neil Creek	West Grider Creek
Fort Goff Creek	Pecwan Creek	Whitmore Creek
Grider Creek	Pearch Creek	Wilson Creek

[1] Scott River tributary

Poor water quality conditions have been at least partially responsible for a number of documented fish kills in the Klamath River mainstem downstream of Iron Gate Dam through to the estuary from 1994 to 2004. Juvenile fish kills are thought to be fairly common in the mainstem; but, they often go undetected (NCRWQCB, 2009). Low DO was identified as a contributing stressor in the juvenile fish kills documented in 1997, 1998, and 2000. It was also identified as a contributing stressor in the adult fish kill of 1997.

The adult fish kill of 2002 killed a recorded 33,000 adult salmonids. 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, USFWS 2003). Subsequent study has identified other diseases affecting salmonid populations in the Klamath River.

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. Two of the factors associated with the presence of *C. shasta* appear to be the presence and abundance of the polychaete in the Klamath River (Bartholomew and Bjork 2007).

There may be a linkage between the proliferation of *C. shasta* in the mainstem Klamath River, elevated nutrient concentrations, and subsequent increases in the diurnal fluctuation of DO. Elevated nutrient concentrations result in increased periphyton and increased suspended algae and blue-green algal growth in the river, which have been identified as prime habitat for the polychaete. Increased habitat leads to an increased abundance of the polychaete, 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*. *C. shasta* is commonly found in salmonid streams. But, large scale outbreaks of disease are rarely observed unless, as shown in the Figure 3-1, there is an increase in both parasite spores and environmental stressors, including low DO. Oregon (1995) reports that generalized stress causes increased releases of cortisol in salmonids which suppresses immune function and disease resistance, as appears to have been happening in the Klamath River.

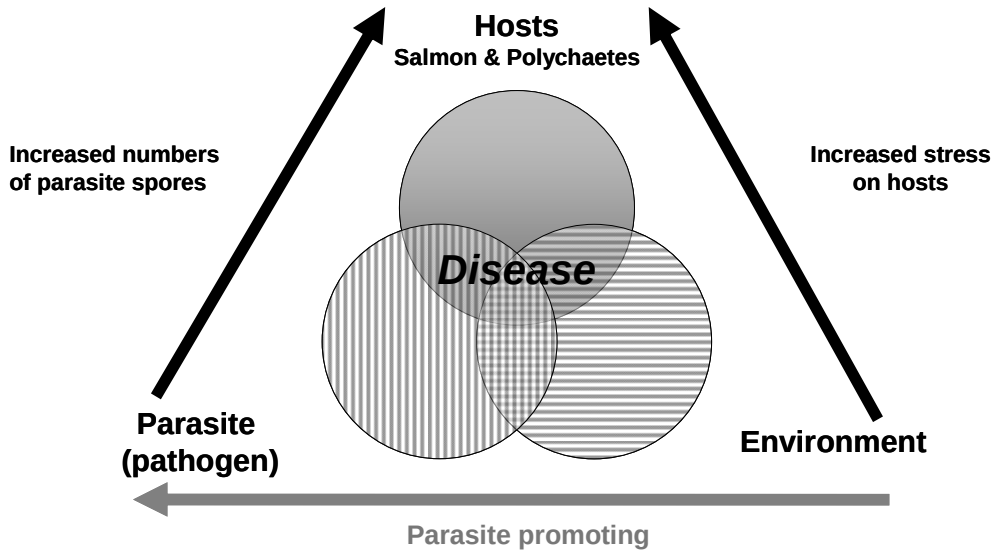

Figure 3-1: Severity of *Ceratomyxosis* in Klamath River suggests a shift in the host/parasite balance towards *C. shasta*
Source: Bartholomew personal communication 2008

3.1.2.3 Summary of Salmonid DO Requirements

USEPA (1986), Oregon (1995) and Washington (2002) each provide technical recommendations for appropriate DO criteria for the protection of salmonids. Table 3-3 represents USEPA's (1986) recommendations derived from it's synthesis of scientific studies but primarily relying on 1) growth data and 2) information on temperature, disease, and pollutant stresses (USEPA 1986). USEPA (1986) proposes national coldwater criteria for the protection of early life stages of 9.5 mg/L DO in the water

column as a 7-day mean and 8.0 mg/L DO in the water column as 1-day minimum. For other life stages, USEPA (1986) recommends 6.5 mg/L DO as a 30-day mean, 5.0 mg/L DO as a 7-day mean minimum, and 4.0 mg/L DO as a 1-day minimum.

However, "if slight production impairment or a small but undefinable risk of moderate production impairment is unacceptable, then continuous exposure conditions should use the "no production impairment values" as means and the "slight production impairment values" as minima (USEPA 1986)." The Klamath River is a system in which even slight production impairment is unacceptable because of the threatened and endangered status of several of the basin's native fish species. For a river such as the Klamath, then, USEPA (1986) would recommend (see Table 3-3) for early life stages 11 mg/L DO in the water column as a 7- or 30-day mean (8 mg/L IGDO) and 9.0 mg/L DO in the water column as a 1-day minimum (6.0 IGDO). For other life stages, USEPA (1986) would recommend 8.0 mg/L as a 7- or 30-day mean and 6.0 mg/L as a 1-day minimum.

Table 3-3 from USEPA (1986) Ambient Water Quality Criteria for Dissolved Oxygen

	No Production Impairment (mg/L)	**Slight Production Impairment** (mg/L)	**Moderate Production Impairment** (mg/L)	**Severe Production Impairment** (mg/L)	**Limit to Avoid Acute Mortality** (mg/L)
Salmonid Waters-- Embryo and larval stages	11* (8)	9* (6)	8* (5)	7* (4)	6* (3)
Salmonid Waters--Other life stages	8	6	5	4	3
Nonsalmonid Waters— Early life stages	6.5	5.5	5	4.5	4
Nonsalmonid Waters— Other life Stages	6	5	4	3.5	3
Invertebrates	8	5			4

* These are mean water column concentrations recommended to achieve the required intergravel DO concentrations shown in parentheses. The recommended water column concentrations are based on the assumption that there is a 3 mg/L difference between water column and intergravel DO, on average.

USEPA (1986) also considers waterbodies in which natural conditions produce DO in noncompliance with the given criteria. USEPA (1986) recommends that "if natural conditions alone create dissolved oxygen concentrations less than 110 percent of the applicable criteria means or minima or both, the minimum acceptable concentration is 90 percent of the natural concentration (USEPA 1986)." The Klamath River is a productive river which under natural conditions produces DO in noncompliance with the recommended criteria (see Chapter 6.0 of this Staff Report). As such, USEPA's (1986) guidelines suggest that 90% of the natural DO concentrations will provide adequate protection of the beneficial uses.

Oregon (1995) also includes several recommendations with respect to DO criteria suitable to protect salmonids. The Oregon Department of Environmental Quality assembled a Dissolved Oxygen Technical Advisory Committee (DOTAC) for the purpose of reviewing the existing standards, reviewing the current state of the scientific literature associated with the DO requirements of salmonids and other aquatic species, and developing findings and recommendations. The DOTAC was chaired by Dr. Gary Chapman of the USEPA who also authored the USEPA's 1986 guidance on ambient water quality criteria for DO. The DOTAC conducted its review of Oregon standards from 1992-1994. Their findings and recommendations were published in 1995. The DOTAC found that:

1. "The "natural" conditions in some streams will cause dissolved oxygen levels to fall below the numerical criteria, especially the conservative 90-95 percent criteria when interpreted as absolute minimums.
2. Saturation criteria may result in inadequate protection at high temperatures and greater than necessary criteria at low temperatures, often inversely related to the needs of the resource. Because of the high level of protection warranted for salmonid spawning, concentration and saturation criteria would be similar for this use.
3. Current criteria recognize that situations will occur where the achievement of dissolved oxygen standards will not be possible due to naturally occurring conditions or due to human activities which are beyond regulatory control. In these cases, the background conditions become the criteria and no further degradation is permitted. Other states, such as Washington, provide an allowance on the order of 0.20 mg/L for further degradation under similar conditions.
4. 10% of the reference sites and 24% of the Regional Environmental Monitoring and Assessment Program (REMAP) sites in the coast range would violate a 90% saturation criterion, even though they meet a no measureable impact to cold-water fish criteria of 8.0 mg/L.

The DOTAC and staff at the Oregon Department of Environmental Quality jointly reviewed scientific literature related to DO criteria. They reviewed literature associated with salmonid physiology, early life stages and intergravel DO, relationship between intergravel DO and solids, natural range and variation in intergravel DO, swimming performance, fish growth, oxygen cycles, supersaturation; avoidance and behavioral changes; toxics and disease; water temperature; field studies; estuarine criteria; and relationship between pH, CO_2, and DO. From this review, the DOTAC recommended that:

1. Criteria should be related to the biological resources that are to be protected.
2. There should be consistency between the criteria for different river basins.
3. Critical compliance issues related to temperature and dissolved oxygen need to be analyzed. The State needs to manage its aquatic resources much more broadly than by single parameter or by point-source pollution control.
4. Concentration criteria should be used rather than percent of saturation for other life stages of cold-water biological resources, with the exception of

5. Statistical criteria with associated duration period should be used.
6. Statistical criteria should be applied only when adequate data are available.
7. The early life stages criteria for salmonid protection should apply during the latter stages of incubation of embryos and fry, until after fry emerge from the gravels. The protective criteria need only apply to areas of salmonid spawning.
8. The state should establish intergravel dissolved oxygen criteria for protection of the early life stages of salmonids. For unimpaired watersheds, the expected loss of an average of 3.0 mg/L DO from surface to the gravels provides the method for determining minimum surface-water concentrations. The assumption of a 3.0 mg/L loss between surface and intergravel environments may underestimate the loss that occurs in highly impacted spawning areas.
9. The importance of nutrient and sediment runoff and removal of the riparian canopy as major cause of DO depletion in streams and lakes should be recognized.
10. The impact of stream flows on temperature changes and therefore on DO should be recognized**.**

In 2002, the State of Washington published the findings and recommendations resulting from its review of the State's DO criteria and the current scientific literature. It notes that any depression of oxygen from saturation will produce some reduction in the performance of fish (Washington 2002). It also notes that statistically significant changes to growth, swimming speed, etc. do not occur until oxygen levels are depressed to levels that are sometimes well below the saturation value (Washington 2002).

Table 3-4 captures the technical recommendations of USEPA (1985), Oregon (1995), and Washington (2002) with respect to DO criteria suitable for the protection of salmonids and other aquatic life.

3.2 Lamprey

Lamprey are a jawless fish from the family *Petromyzontidae* that generally feed on the blood and body fluids that they extract with their sucker-like mouth from live fish (Moyle 2002). This "predatory" phase of the Pacific lamprey is spent in the ocean, except for those species that are landlocked (Moyle 2002).

Pacific lamprey spawning usually begins in early March and lasts through late June (Moyle 2002). There are variations to this schedule. And, in the larger rivers (Klamath, Trinity, and Eel) there may be both spring and fall runs, similar to salmon (Moyle 2002).

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Table 3-4: Recommendations of USEPA (1986), Oregon (1995), and Washington (2002)

	USEPA (1986)—mg/L		Oregon (1995)—mg/L		Washington (2002)—mg/L	
Incubation through emergence[1]	≥11	7- or 30-day mean	≥11[2]	7-day mean	≥9.0-11.5[3,4]	30- to 90-day average of daily minima
	≥9	1-day minimum	No comment			
	≥8 IGDO	7- or 30-day mean	No comment			
	≥6 IGDO	1-day minimum	≥6 IGDO	1-day minimum		
Growth of Juvenile Fish	≥8	7- or 30-day mean	≥8[5]	30-day mean	≥8.0-8.5	30-day daily minimum
	≥6	1-day minimum	No comment		≥5.0-6.0	1-day minimum
Swimming Performance	No comment		No comment		≥8.0-9.0	1-day minimum
Avoidance	No comment		No comment		≥5.0-6.0	1-day minimum
Acute Lethality	No comment		No comment		≥4.6	7- to 30-day average of daily minima
	No comment		No comment		≥3.0	1-day minimum
Macro-Invertebrates	≥8	7- or 30-day mean	No comment		No comment	
	≥5	1-day minimum	No comment		≥8.5-9.0[6]	1-day minimum or average
					≥7.5-8.0[7]	1-day minimum or average
					≥5.5-6.0[8]	1-day minimum or average
Synergistic Effect Protection	≥8	7- or 30-day mean	No comment		No comment	
	No comment				≥8.5	1-day average
	6	1-day minimum			No comment	
To ensure no risk	No comment		No change from natural		No comment	

[1] Applies only during the period of incubation through emergence and only in those locations in which spawning occurs.
[2] If conditions of altitude and natural temperature preclude achievement of 11 mg/L, then 95% saturation applies.
[3] No measureable change when waters are above 11°C (weekly average) during incubation.
[4] Applies throughout the period from spawning through emergence and assumes 1-3 mg/L will be lost between the water column and the incubating eggs.
[5] If conditions of altitude and natural temperature preclude achievement of 8 mg/L, then 90% saturation applies.
[6] To be applied in mountainous headwater streams
[7] To be applied to mid-elevation streams, lakes, and non-salmonid water
[8] To be applied to low-elevation streams, lakes and non-salmonid water

Adult lamprey migrate from the ocean to freshwater where a male and female build a nest together in the gravel (Moyle 2002). After the eggs are laid and fertilized, embryos develop and hatch in about 19 days at 15 °C (Moyle 2002). The ammocoetes are washed downstream to a muddy or sand-bottomed backwater where they burrow in the sediment, tail down (Moyle 2002). They remain in the sediment as filter feeders while they undergo a metamorphosis to become adult lamprey (Moyle 2002). Metamorphosis takes from 5-7 years (Moyle 2002).

There is some evidence of temperature requirements of lamprey. But, little information is available regarding dissolved oxygen requirements, though ammocoete development is impaired under very low DO concentrations (Goodman 2008). Of primary concern to lamprey conservation are activities that may directly disturb ammocoetes, result in sedimentation of quiescent stream reaches, or cause localized dewatering (USFWS 2007a). Data on optimal DO conditions for lamprey are not available; however, DO conditions suitable to support salmonids are believed to be adequate for lamprey, as well (Goodman 2008).

3.3 Sucker

The Lost River sucker (*Catostomus luxatus*) and shortnose sucker (*Chasmistes brevirostris*) are two native fish species of the upper Klamath basin. Both sucker species are endangered and belong to a "part of a group of suckers that are large, long-lived, late-maturing, and live in lakes and reservoirs but spawn primarily in streams; collectively, they are commonly referred to as lake suckers" (NRC 2004). Lake suckers differ from most other suckers in having terminal or subterminal mouths that open more forward than down, an apparent adaptation for feeding on zooplankton rather than suctioning food from the substrate (Scoppettone and Vinyard 1991 as cited by NRC 2004). Historically, Lost River suckers and shortnose suckers occurred in the Lost River and upper Klamath River and their tributaries, especially Tule Lake, Upper Klamath Lake, Lower Klamath Lake, Sheepy Lake, and their tributaries (Moyle 2002 and USFWS 2002 as cited by NRC 2004).

The adult suckers reach sexual maturity between years 4 and 6 for the shortnose sucker (USFWS 2007c) and 5 and 14 for the Lost River sucker (USFWS 2007b). They spawn in river riffle and run habitat from February through May in gravel and cobble substrate with moderate flows and depths less than 4 feet (USFWS 2007b and 2007c). Sucker larvae move out of the gravel soon after hatching and generally drift downstream to the lake environment where they disperse in the near shore areas (Cooperman and Markle 2004 as cited by USFWS 2007a; USFWS 2007b). Larval habitat is best described as shallow, nearshore, and vegetated in both rivers and lakes, except Clear Lake and Gerber Reservoir which lack vegetation (Klamath Tribe 1991, Markle and Simon 1994, and Reiser et al. 2001 as cited by NRC 2004). Adult suckers select water depths of 3-15 feet, their strongest preference appears to be for 5-11 feet (Reiser et al. 2001 and USFWS 2002 as cited by NRC 2004). Adult Lost River suckers have been aged to 43 years while shortnose suckers have been aged to 33 years (NRC 2004). The lake suckers spawn numerous times over their life time producing millions of eggs, a life history strategy

necessary due to the high natural mortality of the young fish and the low natural mortality of the older adult fish (NRC 2004).

With respect to water quality, Woodhouse et al. (2004) synthesized several studies in the Lost River basin to determine appropriate thresholds for Lost River and shortnose suckers. They were unable to identify appropriate criteria for the protection of suckers; but, did identify acute lethality thresholds, as follows:

- DO < 2.3 mg/L (based on LC_{50} in shortnose sucker larvae);
- pH > 9.5 (based on critical maxima in shortnose sucker adults);
- Water temperature < 30.3 ºC (based on LC50 in shortnose sucker juveniles);
- Un-ionized ammonia < 0.48 mg/L (based on LC_{50} in Lost River sucker larvae and shortnose sucker juveniles).

Comparing to the lethality thresholds for salmonids as described by USEPA (1986), Oregon (1995), Washington (2002), staff concludes that DO conditions suitable for the protection of salmonids will adequately protect suckers, as well.

3.4 Green Sturgeon

The green sturgeon (*Acipsenser medirostris Ayres*) is a long-lived anadromous fish that spends most of its time in ocean waters with feeding forays to bays and estuaries (NMFS 2009). Both adults and juveniles are benthic feeders eating shrimp, mollusks, amphipods and small fish (Moyle 2002). The green sturgeon migrates into freshwater systems to spawn. In the North Coast Region, green sturgeon are primarily found in the Klamath and Trinity rivers; though, they will occasionally be seen in the Eel River which once supported a spawning run (Moyle 2002).

Green Sturgeon in the Klamath River system are likely to be part of the Northern Distinct Population Segment (DPS) which is a Federal ESA species of concern, commonly referred to as a candidate species. Adults of the Southern DPS may also enter the river, particularly the estuary to forage; and, they are listed as a threatened species under the Federal ESA. Green sturgeon enter the Klamath River system between February and late July with a spawning period of March to July and a peak from mid-March to mid-June (Moyle 2002). They spawn in deep, fast water where eggs are broadcast and externally fertilized (Moyle 2002). Juveniles remain in freshwater for up to 3 years before migrating to the ocean. Water quality requirements for the green sturgeon are unknown; but, a small amount of silt will prevent the eggs from clumping together and thus reduce viability (Moyle 2002).

Gulf of Mexico sturgeon were found in locations in the Suwannee River estuary ranging from 6.0 to 9.8 mg/L DO with an average of 7.5 mg/L DO (Harris et al. 2005). Eggs were found in areas of the Suwannee River with DO exceeding 5.0 mg/L (Sulak and Clugston 1998). Campbell and Goodman (2004) exposed juvenile shortnose sturgeon, an Atlantic species, to varying laboratory conditions and derived LC50s ranging from 2.2-3.1 mg/L DO depending on the accompanying salinity, temperature, and age of the fish. Younger fish were more sensitive to low DO than older fish.

NMFS 2009 lists as threats to California's green sturgeon:

- ✓ Insufficient freshwater flow rates in spawning areas,
- ✓ Contaminants (e.g., pesticides),
- ✓ Bycatch of green sturgeon in fisheries,
- ✓ Potential poaching (e.g., for caviar),
- ✓ Entrainment by water projects,
- ✓ Influence of exotic species,
- ✓ Small population size,
- ✓ Impassable barriers, and
- ✓ Elevated water temperatures.

DO is not specifically identified as a limiting factor. But, elevated temperatures and decreased flows have the potential to affect DO concentrations. Green sturgeon have an advantage over salmonids with respect to DO and spawning in their choice of deep, fast water as spawning habitat. The DO conditions of this habitat niche are likely superior to that of more shallow, slow moving water. Staff concludes that DO requirements designed to protect salmonids will reasonably protect sturgeon, as well, even though their spawning and incubation period extends past that of salmonids.

3.5 Smelt

The eulachon (*Thaleichthys pacificus*) and longfin smelt (*Spirinchus thaleichthys*) are both in the smelt family *Osmeridae* and are anadromous fish. Within the North Coast Region, the eulachon has been found historically in the Klamath River, as well as in the Mad River, Redwood Creek, and the Smith River while the longfin smelt has been found in Humboldt Bay, the Eel River estuary, the Klamath River estuary, and the Russian River estuary (Moyle 2002). They (eulachon) have been proposed by the National Marine Fisheries Service (NMFS) to be listed as threatened under the Federal ESA and are considered a species of concern.

The eulachon is the largest species of the smelt family (Moyle 2002). It is a very oily fish, also sometimes called the candlefish because of its historic use when dried to be burned as a candle. It is an anadromous fish, spending most of its life at sea and then spawning in the lower reaches of coastal rivers (Moyle 2002). Eulachon return to freshwater between December and May in their third year and their migration appears to be timed with river temperatures between 4-8 °C (Moyle 2002). Migrating fish seldom travel farther than 7.5 miles (12 km) up river, the fish keeping to the river bottom and shallow river edges (Moyle 2002). Spawning occurs where temperatures are between 4-10 °C, velocities are moderate, and substrate consists of pea-sized gravel or gravel mixed with sand, wood or other debris (Moyle 2002). Fertilization is external with females producing an average of 25,000 eggs (Moyle 2002). Eggs have two membranes, the outer one of which ruptures when the egg hits the channel bottom. This allows the sticky edges to adhere to the substrate where the larvae will hatch in 2-3 weeks. The larvae are quickly washed out to sea (Moyle 2002).

Moyle (2002) states "given the extended ocean life phase of eulachon and the apparently sporadic nature of their abundance in recent years, it is likely that oceanic conditions may

be important determinants of the size of spawning runs." He continues "eulachon are sensitive to a number of environmental factors and their recent decline in California streams may be the result of changes in water quality or spawning habitat in the lower reaches of rivers" (Moyle 2002).

Longfin smelt have a wide salinity and temperature range, reflecting their ability to occupy various estuarine niches depending on the time of year and life cycle stage (Moyle 2002). They spawn in freshwater over sandy or gravel substrates, rocks and aquatic plants as early as November and up through the month of June (Moyle 2002). Embryos hatch in 40 days at temperatures of 7 °C, the newly hatched larvae drift quickly down to the estuary (Moyle 2002). Larvae metamorphose into juveniles after 30-60 days from hatching, depending on the temperature (Moyle 2002). Most adult longfin smelt die after spawning (Moyle 2002).

Pientka and Parrish (2002) found that in a comparison of habitat use by Atlantic salmon and rainbow smelt, the two occupied similar thermal habitat. But, Atlantic salmon generally chose habitat with higher DO concentrations. Staff concludes that DO objectives designed to protect salmonids will be protective of smelt, as well.

3.6 Summary

In summary, there are a number of native fish species of the Klamath Province that are at risk of extinction, including species of: salmonids, lamprey, sucker, sturgeon, and smelt. These fishes occupy a variety of freshwater and estuarine habitats, some of them overlapping with other native species. The life cycles vary considerably with some species spending a majority of their lives in freshwater and others in the ocean. Yet, the information staff has been able to gather on the DO and/or other water quality requirements of each of the species of interest suggests that DO objectives designed to protect salmonids likely will protect the other native species, as well, even for those species with extended larval stages such as the lamprey. This brief assessment is intended only to confirm that the general bias towards salmonids in the establishing of water quality objectives is, at least for DO, warranted.

A summary of various DO recommendations for salmonids is given in Table 3-4 above. From these recommendations, it is determined that Klamath River fishes, including those at risk of extinction, would ideally enjoy the following DO conditions, including:

Early Life Stages: **9.0-11.5 mg/L** as a 7- or 30-day mean or 30- to 90-day average of daily minima to protect eggs and alevin from growth effects, assuming a 1-3 mg/L decrease in DO from the water column to the intergravel environment.
6.0 mg/L IGDO as a 1-day minimum to protect eggs and alevin from acute lethality and growth effects.

Other Life Stages: **8.0 mg/L** as a 7- or 30-day mean to protect against acute lethality and growth effects.

6.0 mg/L as a 1-day minimum to protect against growth effects, avoidance behavior, acute lethality, and synergistic effects. According to research conducted by Washington (2002), this criterion does not appear to protect optimum swimming performance or macroinvertebrate health (except in low elevation streams). USEPA (1986) concludes that optimum swimming performance is only required in short bursts. Moderate swimming performance is protected by criterion that protects growth and is adequate for the protection of the species. USEPA (1986) also acknowledges that some macroinvertebrates are more DO sensitive than fish; but suggests that 6 mg/L as a 1-day minimum is adequate to protect a reasonably diverse macroinvertebrate assemblage, particularly since DO sensitive species seek high flow environments so as to optimize their DO exposure.

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CHAPTER 4.
GENERAL DISCUSSION OF DISSOLVED OXYGEN

The purpose of this chapter is to provide a general discussion of dissolved oxygen (DO), including a discussion of what it is, why it is important, and what factors influence its concentration

Dissolved Oxygen (DO) provides an excellent measure of general aquatic health. It is one of the primary water quality factors that define the habitability of a given aquatic system. Yet, it varies considerably both temporally and spatially in the natural environment. Thus, to interpret DO data, one must know something about the factors influencing its concentration and the expected pattern and range of its variation to be able to discern any deviation from background conditions and/or any critical impact. A general discussion of these issues follows.

4.1 What is Dissolved Oxygen?

Dissolved oxygen, most often measured in mg/L, is the amount of oxygen gas present in a volume of water. Water has a limited capacity to hold oxygen gas in solution. This capacity is defined by a mathematical relationship among the temperature, atmospheric pressure, and salinity at a given site. When water has reached its capacity to hold oxygen gas in solution it is said to be *saturated.* When it exceeds its capacity, it is said to be *supersaturated.* And, when it does not reach its capacity, it is said to be *sub-saturated.*

4.2 Why is Dissolved Oxygen important?

Oxygen is necessary for the respiration of aerobic organisms. Because water has a limited capacity to hold oxygen gas in solution, aquatic organisms have evolved specialized structures or methods of extracting from water the limited amount of oxygen gas that is present in it. These structures or methods generally rely on the partial pressure differential between oxygen in the water column and oxygen in the blood (or the equivalent oxygen receptor). Gills, as an example, are designed to allow the passive diffusion of oxygen from water across the gill membrane to the arterial system.

A healthy riverine system is generally one in which the DO concentration is at or approaches full saturation and is maintained by diffusion (Allan 1995). Under these conditions, aerobic organisms can extract from the water column the oxygen necessary to ensure basic metabolic success (e.g., growth, general health, and reproduction) leading to a greater likelihood of population success. Further, a riverine system approaching DO saturation is better able to support a wide and diverse array of life forms than one which does not.

As the concentration of DO in water is reduced to levels significantly less than saturation, the oxygen partial pressure gradient between the water column and blood (or equivalent oxygen receptor) is reduced and the ability of the gill structure (or equivalent oxygen receptor) to acquire the necessary oxygen for respiration is impaired. This can lead to chronic effects, such as reduced growth, increased susceptibility to disease, reduced reproductive success, or loss of habitat through avoidance. It can also lead to acute effects, such as asphyxiation and death. The term *hypoxia* (meaning “low oxygen”)

refers to the water quality condition in which the dissolved oxygen present in water is insufficient to provide the oxygen requirements of aerobic organisms. Water devoid of oxygen is known as *anoxic*.

4.3 What are the factors influencing the concentration of Dissolved Oxygen?
The concentration of DO in an aquatic environment is controlled by many interrelated variables, including stream temperature, salinity, atmospheric pressure, turbulence, respiration, photosynthesis, and biological and chemical oxygen demanding reactions. To simplify, these factors can be divided two categories: 1) those that define the capacity of the water to hold DO (DO saturation) and 2) those that affect the percent of that capacity which is actually utilized (% DO saturation).

4.3.1 DO saturation
DO saturation is defined by the mathematical relationship among three variables: atmospheric pressure, temperature, and salinity. Variation in DO saturation is proportional with variation in atmospheric pressure and is inversely proportional with variation in temperature and salinity. Thus, as atmospheric pressure increases so does the concentration of DO at saturation. Because atmospheric pressure decreases as elevation increases, DO at saturation is inversely proportional with elevation. At any one elevation, DO at saturation also will vary based on the presence of low or high pressure storm systems.

As water temperature and/or salinity increase, the concentration of DO at saturation decreases. Water temperature varies depending on numerous factors including: latitude, climate, season, presence of springs, shade, and volume of warm water inputs, as examples. Salinity primarily varies based on the degree of oceanic influence.

One of the primary routes by which oxygen dissolves in water is through the diffusion of oxygen across the air-water interface. Atmospheric oxygen exerts a pressure at the air-water interface allowing for the diffusion of oxygen across the boundary until the partial pressure of atmospheric oxygen equals the partial pressure of oxygen in water. The pressure exerted on the air-water interface by oxygen dissolved in water is defined not only by the concentration of oxygen in water, but by the temperature of the water, as well. For example, O_2 molecules become excited and exert a greater partial pressure on the air-water interface when warm then they do when cool. Thus, the warming of a waterbody serves to slow or even reverse the diffusion of oxygen from the air to the water column.

With respect to salinity, one can visualize water as including H_2O molecules and the spaces between them. The spaces between the H_2O molecules allow for various other molecules to be dissolved in water. If the spaces between the H_2O molecules are filled with molecules such as salts, then the number of spaces available for oxygen is reduced. Salinity is a measure of salts and is generally used to define the gradient between freshwater, brackish water, and saltwater systems. An aquatic system with a high salinity (e.g., the ocean) will naturally have a lower DO concentration at saturation than will a freshwater system with little or no salinity.

Staff has calculated and graphed DO at 100% saturation for individual elevations based on a standard pressure of 760 mm Hg (Figure 4-1). These are theoretical DO concentration values based solely on salinity (i.e., freshwater), atmospheric pressure and temperature and represent the physics associated with holding oxygen in a dissolved state in an aqueous solution. Figure 4-1 does not represent DO concentrations as altered by water quality conditions such as turbulence, aerobic decomposition, photosynthesis, etc. For a given elevation and temperature, Figure 4-1 illustrates the maximum DO concentrations physically possible under conditions of equilibrium.

Figure 4-1: Theoretical DO at 100% Saturation (produced by Rich Fadness of the Regional Water Board)

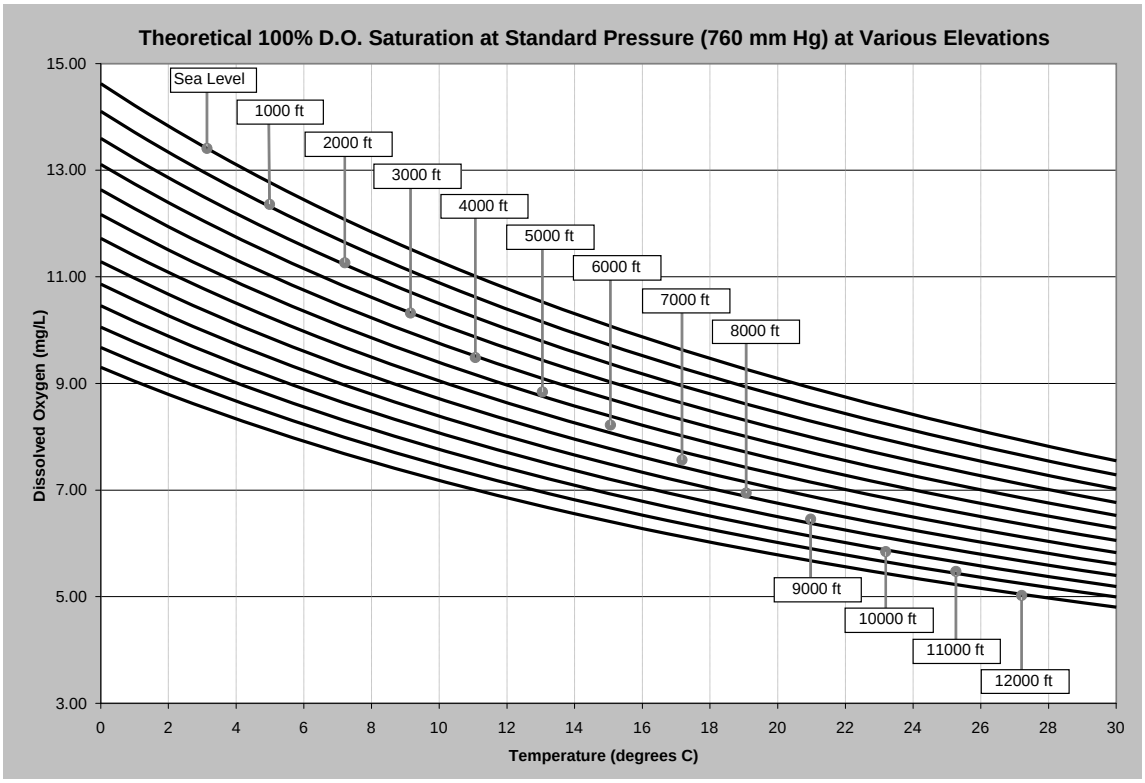


Figure 4-1 illustrates the decline in the ability of water to hold oxygen in solution that occurs as a result of increasing temperatures. For example, at 1,000 feet elevation, DO concentrations range from approximately 14.0 to 7.2 mg/L as temperatures increase from 0 to 30°C. Figure 4-1 also illustrates at a given temperature, an increase in the ability of water to hold oxygen in solution that occurs as water moves from a higher elevation to a lower elevation. For example, at 16°C, DO concentrations range from approximately 6.2 to 10.0 mg/L as water flows from 12,000 feet elevation to sea level. For a given elevation and temperature, Figure 4-1 provides an estimate of the ability of water to hold oxygen in solution (i.e., DO concentration) when in a state of equilibrium. For example, at 3,000 feet elevation, when water temperatures reach 22°C, DO is approximately 7.9 mg/L at 100% saturation.

4.3.2 Percent Saturation

In the natural environment, there are several other factors at play besides the effects of atmospheric pressure, temperature, and salinity. For example, photosynthesis, turbulence, respiration, organic decomposition, and oxygen demanding biological and chemical reactions also effect the concentration of DO in an aquatic system. These factors do not control the capacity of an aquatic system to hold oxygen in solution (DO saturation). Instead, they affect the percentage of the capacity that is actually utilized (percent saturation).

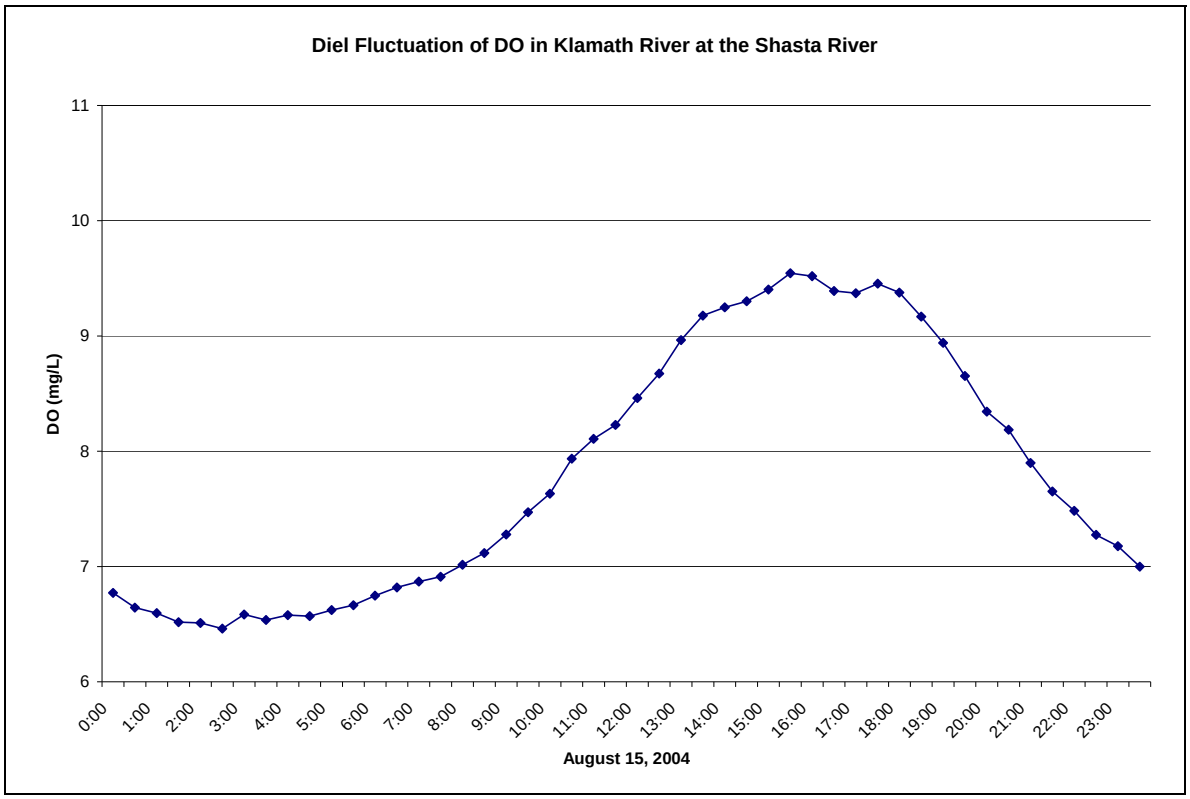
The *photosynthesis* of aquatic plants, algae, and cyanobacteria has a profound effect on the oxygen content of water. Photosynthetic organisms use carbon dioxide to convert the energy contained in sunlight into carbohydrates and oxygen. Aquatic photosynthetic organisms release their oxygen (a waste product) to the water column, temporarily increasing the DO concentration of the water. Areas in which the substrate, light, nutrients and temperature favor the growth of aquatic photosynthetic organisms may see large increases in DO during the late afternoon when the effects of photosynthesis have accumulated through the day. Such areas may be naturally present in an aquatic system (e.g., wetlands; lakes; and slow moving, shallow river reaches) or promoted by anthropogenic activities (e.g., nutrient enrichment, shade removal, reduction in flow, or reduction in water depth through sediment deposition).

The contribution of oxygen to the water column as a result of photosynthesis occurs only during the daylight hours when photosynthesis is active. This source of oxygen is not present during the night when in the absence of sunlight photosynthesis does not occur. The result is a notable cyclical DO pattern where DO is low in the pre-dawn hours, increases slowly during the morning, reaches a peak prior to sunset, and then declines through the night. This is called a *diel* cycle. A typical DO diel cycle results in daily minimum DO concentrations in the pre-dawn hours.

Figure 4-2 depicts the DO diel curve that results from 24-hour DO data collected on August 15, 2004 in the Klamath River at its confluence with the Shasta River. On that day, DO dropped below 7 mg/L sometime prior to 1am and didn't exceed 8 mg/L until 12 noon. The DO concentration peaked at approximately 9.5 mg/L by 3:30pm. These data do not represent natural conditions. But, they do represent the typical shape of a diel DO curve, specifically showing lower DO concentrations at night followed by higher DO concentrations during the day as photosynthesis is active.

The term *turbulence* refers to a physical process in which the air-water interface is disturbed. Turbulence serves to increase the transfer of oxygen across the air-water interface by increasing the surface area of the interface either at the surface of the water or in the form of bubbles of air entrained within the water column (e.g., as occurs at waterfalls or through mechanical mixing). Turbulence can serve to either decrease or increase the transfer of oxygen to the water column depending on whether the water is supersaturated or sub-saturated and whether or not air is entrained in the water column.

Figure 4-2: 24-hour DO data in mid-summer (2004), collected by US Fish and Wildlife Service



The *respiration* of aquatic organisms requires oxygen for the process of converting carbohydrates into energy for growth and reproduction. It also results in the release of carbon dioxide as a waste product. The oxygen fueling the respiration of aquatic organisms comes from the water column and as described above is extracted using specialized structures or methods (e.g., gills

The *decomposition* of organic matter in the aquatic environment is a complex process involving numerous organisms and chemical reactions. Biological oxygen demand is a measure of the pressure exerted on dissolved oxygen supplies by the biological decomposition of organic molecules. Numerous species of micro-organisms are involved in the process of biological decomposition.

Chemical oxygen demand is a measure of the pressure exerted on dissolved oxygen supplies by the chemical oxidation of organic molecules. Some of the reactions are initiated by biological activity. The chemical reactions typically at play in an aquatic environment include: carbonaceous deoxygenation, nitrogenous deoxygenation, nitrification, and methantrophy.

The percentage of the capacity of water to hold oxygen in solution is reported as *percent saturation*. In any given system, it is the unique and fluctuating combination of oxygen sources (e.g., photosynthesis and turbulence) and oxygen sinks (e.g., respiration, biological oxygen demand, and chemical oxygen demand) that define the percent saturation. For example, the infusion of dissolved oxygen into the water column via photosynthesis or turbulence can result in the temporary supersaturation of water (i.e.,

DO concentrations in excess of that described by 100% saturation). These conditions subside either during the night when photosynthesis is no longer active or downstream as water moves out of the influence of waterfalls or rapids.

In the reverse, respiration and decomposition can remove oxygen from the water column resulting in the temporary sub-saturation of water (i.e., DO concentrations less than those described by 100% saturation). These conditions also subside on the spatial and temporal scale. But, the subsidence might occur seasonally, rather than daily. In highly eutrophic systems, the decomposition of organic matter can result in the temporary removal of oxygen from the water column. The loss of oxygen from an aquatic system can result in the temporary loss of all aerobic organisms, such as observed in fish kills.

Figure 4-3: Theoretical DO at 85% (produced by Rich Fadness of the Regional Water Board)

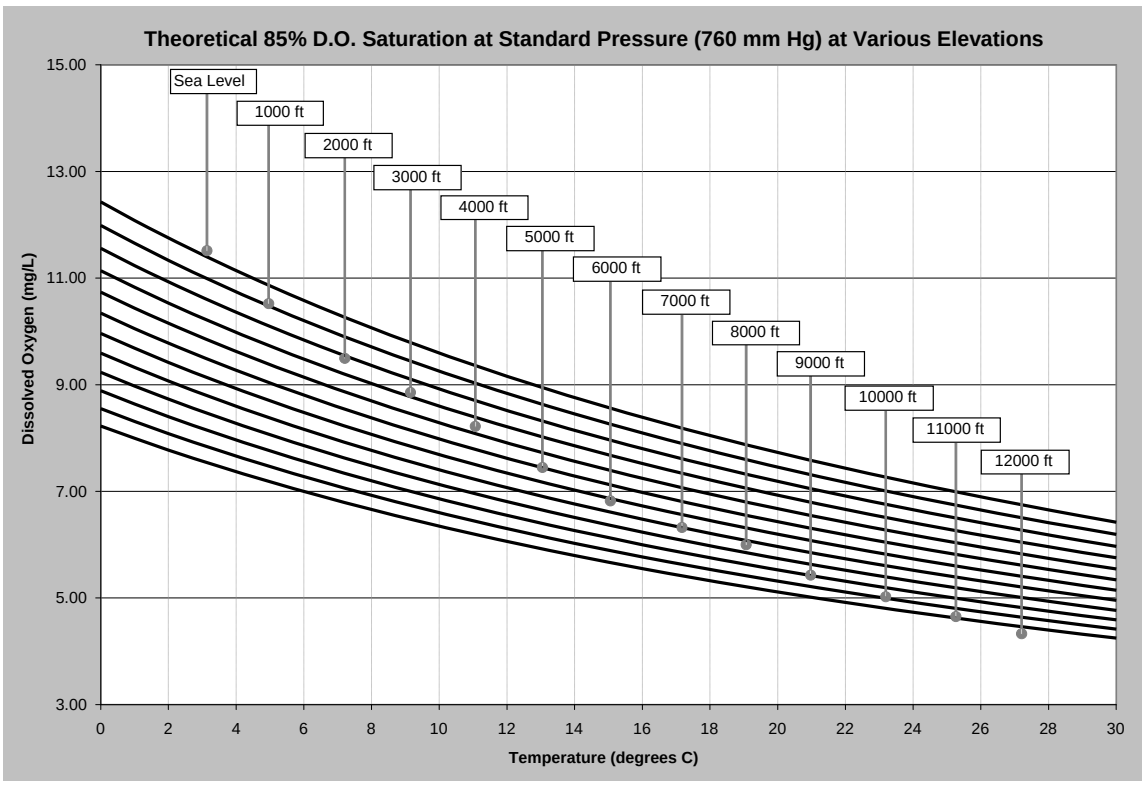


Figure 4-3 represents the theoretical concentration of DO at 85% saturation at various elevations and temperatures. As described in Chapter 7.0 of this Staff Report, staff estimates that 85% saturation is the minimum percent saturation occurring in a healthy, free-flowing stream with moderate nutrient and organic loading.

By comparing Figures 4-1 and 4-3, one can estimate at any given temperature and elevation, the difference in DO concentration at equilibrium versus that influenced by moderate decomposition and respiration, generally estimated to occur at DO saturations no less than 85%. For example, at 3000 feet elevation and 20°C, a DO concentration under equilibrium (100% saturation) decreases from 8.1 mg/L to 6.9 mg/L due to only

moderate decomposition and respiration (85%). In a river with a daily minimum DO requirement of 7.0 mg/L, the only way to achieve compliance at 3000 feet or higher is to ensure that temperatures never reach 20°C or natural organic matter and nutrient loading is curtailed.

4.4 Summary

In summary, DO is the amount of oxygen gas present in a volume of water. DO is the source of oxygen used by aquatic aerobic organisms and is thus a critical indicator of aquatic ecosystem health**.** The concentration of DO in a given aquatic system is defined by the capacity of that system to hold oxygen in solution and the percent of that capacity that is utilized. An aquatic system that is saturated with DO is at equilibrium as defined by the effects of barometric pressure, temperature, and salinity. Variation in saturation occurs as a result of the influences of oxygen sources (e.g., photosynthesis and turbulences) and oxygen sinks (e.g. respiration, decomposition, and biological and chemical oxygen demanding processes). A healthy, free-flowing aquatic system maintains DO concentrations close to full saturation (100%), generally no less than 85%.

CHAPTER 5.
EXISTING WATER QUALITY OBJECTIVES FOR DISSOLVED OXYGEN IN THE KLAMATH RIVER

In this chapter, staff describes the existing Site Specific Objectives (SSO) for Dissolved Oxygen (DO) in the Klamath River mainstem and presents its assessment of their continued appropriateness.

The Regional Water Board adopted the *Water Quality Control Plan for the North Coast Region* (Basin Plan) in which it established the region's water quality standards, including the standards that apply to the 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.

5.1 Beneficial Uses

Chapter 2 of the Basin Plan identifies 28 beneficial uses of water within the North Coast region. The following beneficial uses have been designated as existing uses of the Klamath River mainstem (Basin Plan, Table 2-1):

- 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

The beneficial uses of most importance to the discussion of DO in the Klamath River mainstem are those related to human consumption/contact and aquatic life, including: municipal and domestic supply; water contact recreation; commercial and sport fishing; warm freshwater habitat; cold freshwater habitat; wildlife habitat; rare, threatened and endangered species; marine habitat; migration of aquatic organisms; spawning,

reproduction, and/or early development; shellfish harvesting; estuarine habitat; aquaculture; and Native American culture.

The rare, threatened and endangered cold water aquatic species (RARE, SPWN beneficial uses) of the Klamath River mainstem are identified as the most sensitive of the beneficial uses, thereby requiring the greatest dissolved oxygen to ensure their protection. The spawning, incubation and emergence life stage of these species is identified as the most sensitive life stage

5.2 Water Quality Objectives

The water quality objectives for DO are given in the Basin Plan in two parts. The first part is given as *life cycle DO requirements*, designed to protect individual beneficial uses, including: WARM, MAR, SAL[1], COLD and SPWN. The *life cycle DO requirements* were first adopted in 1975 and are given as daily minima. They do not include weekly or monthly average limits by which to prevent chronic effects of DO stress. These objectives apply to all waterbodies in the North Coast Region *except* those listed in Table 3-1 of the Basin Plan.

The second part of the water quality objectives for DO is given in Table 3-1 of the Basin Plan. These are Site Specific Objectives (SSO) designed to protect the background conditions of individual waterbodies based on the statistical analysis of monthly grab sample data collected in the 1950s and 1960s. From these analyses, daily minima and annual means were established for individually named waterbodies, including fifty-eight (58) separate entries. The Klamath River mainstem is included in Table 3-1 of the Basin Plan with two SSOs for DO: a) 7.0 mg/L as an instantaneous minimum for that portion of the mainstem from the Oregon-California state line to Iron Gate Dam and b) 8.0 mg/L as an instantaneous minimum from Iron Gate Dam to the estuary. Fifty percent of the monthly means must be greater than or equal to 10.0 mg/L DO throughout the length of the Klamath mainstem under California's jurisdiction. The *life cycle DO requirements,* as described above, do not apply in the Klamath River basin.

The framework of the Basin Plan is based on the logic that protection of water quality in the North Coast region is best provided by prohibiting the point source discharge of waste. Some exceptions to this framework are included in the Basin Plan for the Lost River at all times and for the Mad, Eel, and Russian Rivers from October 1 through May 14. In all other streams and all other times of the year, the point source discharge of waste is prohibited, except as stipulated in the Thermal Plan, the Ocean Plan, and the action plans and policies contained in the Point Source Measures section of the Basin Plan. In the Klamath River, a single exception has been granted, under the Hatcheries Policy, to the Iron Gate Fish Hatchery, owned by PacifiCorp and operated by the Department of Fish and Game.

[1] SAL is not a beneficial use identified in the Klamath River.

5.3 Background Conditions

In concept, the DO objectives included in Table 3-1 of the Basin Plan compliment the general framework of the Basin Plan by requiring that background water quality conditions for DO be maintained for all the waterbodies named in Table 3-1, including the Klamath River mainstem. The question that has arisen in recent years is whether or not the SSOs for DO in Table 3-1 truly represent background conditions. Staff has sought to answer this question by assessing two lines of inquiry:

1. Were the landuse activities in the Klamath River basin prior to the 1950s significant with respect to DO?
2. Do the existing SSOs for DO in the Klamath River mainstem represent the true DO minima under background conditions?

5.3.1 Relationship of landuse activities to background DO conditions

Commercial scale mining and logging operations began in areas throughout California, including the North Coast Region in the mid-to-late 1800s spurred by the gold rush of that era. This was followed by dam building and agricultural enterprises, as well as urban development. By the 1950s and 1960s, areas of the North Coast Region were undergoing their second wave of timber cutting, this time with the use of tractors and other heavy ground-based equipment which left a significant foot print on the landscape and downstream watercourses. Though the point source discharge of waste from urban development has been very localized in the North Coast Region, other direct effects on water quality from stream channel modification, road building, dam building, and gravel mining, as examples, have been felt in the North Coast Region for over a century. Further, the indirect effects of nonpoint source pollution emanating from agricultural runoff, wetland reclamation, sedimentation, water diversions, and the like have also been felt in the North Coast for over a century.

The National Research Council, in its assessment of the causes of decline in salmonid populations in the Klamath River watershed, describes the history of land use as the primary factor affecting the decline in the fisheries (NRC 2004). In summary they conclude that

> "The watershed has been drastically altered by human activities. The anadromous fishes have been in decline since the 19th century, when dams, mining, and logging severely altered many important streams and shut off access to the upper basin. The declines continued through the 20th century with the development of intensive agriculture and its accompanying dams, diversion, and warm water." (NRC 2004)

The *Long Range Plan for the Klamath River Basin Conservation Area Fishery Restoration Program* (KRBFTF 1991) provides an excellent description of the history of the land management activities in the Klamath River basin and the reader is referred to it for a good overview. The Natural Research Council's *Endangered and Threatened Fishes in the Klamath River Basin: Causes of Decline and Strategies for Recovery* also includes a description of the basin's history.

5.3.1.1 Fur Trapping

NRC (2004) describes the era of fur trapping in the Klamath Basin during the 1820s as relatively peaceful. Yet, "in an attempt to discourage Americans from laying claim to the region, Hudson Bay Company's written policy was to trap fur-bearing animals from streams south of the Columbia River to extinction (NRC 2004)." Ultimately, the loss of beaver resulted in the degradation of their dams and the draining of the wetlands that had built up behind them. As these wetlands filled in, they became fertile meadows upon

which ranching latter thrived (Elmore and Beschta 1987 as cited by NRC 2004). Staff does not hypothesize any direct link between fur trapping and DO conditions. But, staff believes that the failure of beaver dams, conversion of wetlands to meadows, and use of meadows for grazing has had an effect on DO conditions, as described below.

5.3.1.2 Mining

Mining activities historically prominent in the Klamath River basin include hydraulic mining and suction dredging for gold; lode mining for gold, copper, and chromite; and, gravel mining. Water quality concerns related to mining include water diversions, increased sediment loading, channel alteration, habitat alteration and destruction, acid mine drainage, and turbidity. The water quality impacts associated with mining operations can be enormous, depending on the size of the operation and the sensitivity of the associated stream. NRC (2004) reports that "mining in the 19th century was particularly destructive of fish habitat along the lower Klamath basin."

KRBFTF (1991) reports the beginning of exploratory mining by John Scott and his party at Scott Bar in 1850. The towns of Happy Camp, Orleans, Somes Bar, Sawyers Bar, Hamburg, Callahan, Yreka, and Scott Bar owe their origins to the gold mining boom of the 1800s (Wells 1881 as cited by KRBFTF 1991). "While hydraulic mining was outlawed by the state in the late 1880s for the rivers near Sacramento, the Klamath River was not regulated. Gold production reached a peak in 1894 (KRBFTF 1991)."

Gold mining in the Klamath River basin boomed again in the 1930s, particularly in the Salmon and Scott Rivers, this time using large dredges to rework old tailing dumps and other auriferous gravels (KRBFTF 1991). Stream surveys conducted during this era determined that pools and spawning gravels were filled in with silt and macroinvertebrate production down stream of mining operations was severely impacted (KRBFTF 1991).

> "Many other problems were also noted: increased poaching in the small, clear streams where spawners were forced to congregate; reduced streamflows due to mining diversions into ditches; loss of juvenile salmonids in unscreened mining ditches; and habitat blockage by permanent and temporary diversion dams (Taft and Shapovalov 1935 as cited by KRBFTF 1991)."

Mining in the Klamath, like elsewhere in California, brought with it other subsidiary effects, including population growth, building, timber harvesting, food production, water withdrawl, and fishing, to name a few. Many of these activities also have effects on water quality, including DO conditions as described below.

The information in KRBFTF (1991) regarding the history of gravel mining is fairly vague, particularly with respect to activities prior to 1972. But, KRBFTF (1991) does make the point that "commercial operations are primarily scattered in accessible tributaries near towns." It may be that larger scale gravel activities did not come into operation until the development of Interstate 5 to the east and Highway 101 through Redwood National Park to the west later in the 1970s and 1980s, respectively.

Staff believes it likely that mining activities of the late 19th and early 20th centuries altered DO conditions in select locations as follows:

- Decreased water column DO by decreasing channel depths through increased sediment delivery from increased streambank and hillslope instability and instream modifications.
- Decreased intergravel DO by increasing fines intrusion through increased streambank and hillslope instability and instream modifications.
- Decreased water column and intergravel DO by increasing sediment organic loading and decomposition.

5.3.1.3 Timber Harvest

Timber harvest activities include felling, limbing, and yarding trees, as well as transporting the logs to facilities for milling into lumber. With respect to water quality, the primary issues of concern include:

1. Timber harvest and road building activities in the stream channel which can result in an alteration of stream channel form, loss of hydrologic function, loss of aquatic habitat, increase in sediment loading, increase in organic loading, and the development of migration barriers.
2. Timber harvest and road building activities in the riparian zone which can result in a loss of shade, loss of sources of large woody debris, destabilization of the stream bank, an increase in sediment loading, an increase in organic loading, and an increase in the intensity of stormwater runoff events.
3. Timber harvest and road building activities on the hillslope which can decrease hillslope stability, increase sediment delivery, increase organic loading, decrease rates of transpiration, and increase the intensity of stormwater runoff events.
4. Road building activities which can result in an increase in hillslope instability, increase in stream network density, decrease in soil absorptive capacity, increase in stormwater runoff events, and the development of barriers to surface flow and access to upstream habitat.

NRC (2004) reports that commercial timber operations began in the Klamath basin in 1863 when the U.S. Army constructed a sawmill. In 1881, the Klamath Commercial Company was established to harvest both timber and fish at the mouth of the Klamath River (KRBFTF 1991). "The arrival of the railroad in 1887 near Yreka helped develop the markets for timber in the upper Klamath area (KRBFTF 1991)." Hard wood was shipped to Crescent City for reshipment to San Francisco; and, other mills were built on Hunter Creek near the estuary and Klamathon near what is now Iron Gate Dam (KRBFTF 1991)." Until the development of roads later in the 20th century, logs were "dropped into the Klamath River and floated to the mouth to be made into ocean-going rafts (KRBFTF 1991)."

"Peak lumber production occurred in 1941, when 22 lumber mills processed a total of 808.6 million board feet within the upper basin (NRC 2004)." In the lower Klamath, "timber harvesting began in the 1850s…commensurate with the growth in mining…(and) reached a peak in the 1950s (Sommerstram et al. 1990 as cited by NRC 2004). By 1955,

sports fisherman complained that log rafting in the lower Klamath River was destroying the fishery and required regulation (KRBFTF 1991). The California State Assembly's Interim Committee on Fish and Game held a field trip in August of 1955 and observed "small creeks and streams tributary to the Klamath completely obliterated by earth moved into the stream bed from a 'cat' roadway and in other cases by being choked with logging debris (California Assembly 1957 as cited by KRBFTF 1991)."

KRBFTF (1991) reports in 1953 that due to its rugged terrain, the southwest half of the Klamath River Basin had not yet been substantially logged. By the mid-1960s, road building allowed greater access to the Scott and Salmon river regions (KRBFTF 1991). "The Hog Fire of 1977 burned 56,000 acres in that subbasin (Salmon River) with an estimated 450 million board feet being salvage logged over the ensuing five years (J. West, USFS, personal communication as cited by KRBFTF 1991)." NRC (2004) reports that as logging and fire suppression have generally altered the forest composition of the basin, "the risk of intense fires has increased substantially. Such fires can contribute damaging amounts of sediments and nutrients to streams and rivers."

Staff believes it likely that the timber harvest activities of the early 20th century altered DO conditions in select locations as follows:

- Decreased water column DO by increasing solar radiation through the removal of riparian shade trees;
- Decreased water column DO by decreasing channel depths through increased sediment delivery from increased streambank and hillslope instability.
- Decreased water column DO by increasing organic debris loading and oxygen consumption through decomposition.
- Decreased intergravel DO by increasing fines intrusion through increased streambank and hillslope instability.

5.3.1.4 Agriculture

Agricultural activities in the Klamath River basin include both irrigated agricultural and grazing activities. The Natural Resources Conservation Service (NRCS) has mapped the land use and land cover within the Klamath River basin (NRCS 2004). In California, agricultural activity is shown primarily in the Lost River basin, the Butte River basin, the Shasta River basin, and the Scott River Valley. Considerable additional agricultural activity occurs in Oregon in the Lost River basin, around Upper Klamath Lake, in the Sprague River Valley, and in the Williamson River basin.

Forage crops are the primary agricultural crops served by the Klamath Project, an irrigation project of the US Bureau of Reclamation. But, cereals, field crops, fruits, nuts, and vegetables are also grown in the Upper Klamath Basin (Stene 1994). Irrigated agriculture began in the Upper Klamath Basin in 1882 with the construction of an irrigation ditch connecting the Link River to present day Klamath Falls (Stene 1994). A discussion of water and power projects follows (Section 5.3.1.4). By 1953, approximately 26% of Modoc and Siskiyou counties in California and Klamath County in

Oregon was in agricultural production (USBR 1953). Of this, more than half the crop land was irrigated, nearly tripling that which was irrigated 50 years prior (USBR 1953).

KRBFTF (1991) reports that the droughts of the 1860s and heavy grazing pressure reduced the range of native perennial grasses in Siskiyou County, replacing them with annual grasses and forbs. The new grasses and forbs produced less duff than the native grasses, thereby allowing more rapid runoff and surface erosion, as well as greater peak flows in streams (KRBFTF 1991). Grazing caused greater soil compaction which further exacerbated the problem (KRBFTF 1991). NRC (2004) reports that "cattle increased in abundance during the 1870s and 1880s until by the late 1880s overgrazing became a political and ecological issue. "Government inspectors…recommended that the only solution was to provide more grass by draining wetlands and planting them with hay so that there would be less competition for a dwindling resources (Griffiths 1902 as cited by NRC 2004). NRC (2004) concludes that the effects of grazing in the watershed "were probably profound but are impossible to quantify."

Agricultural issues of concern to DO include: application and runoff of nutrients, alterations in stream flow and flow timing from water impoundment and/or withdrawl, alteration of riparian vegetation and streambank stability, conversion of wetlands and reduction in nutrient sequestration, increased sedimentation due to channel destabilization and reduction in flows.

5.3.1.5 Water and Power Projects

There exist in the Klamath River basin numerous dams and diversions associated with power generation and irrigation. The histories of many of these are well documented and the effects on water yield quantified. The effects of withdrawals and 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). Among the mining dams, some were left in place after cessation of mining, creating additional barriers (KRBFTF 1991).

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 facilities built on the mainstem of the Klamath River (KRBFTF 1991).

Prohibitions 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). 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 began operations 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 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-Trinity 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 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 5.1, 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 5.1 illustrate the magnitude and pattern of flows that would be expected with natural flows in the Scott and Shasta Rivers and without diversions upstream of Keno, Oregon. This unimpaired 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 by the USGS (2006) as monthly means. Although the two types of data sets use different metrics, the data are useful for general comparison purposes.

Altering the shape of the hydrograph through anthropogenic manipulation simultaneously alters the seasonal pattern of DO availability. For example, lower flows from April to

September likely result in lower DO concentrations by increasing the rate at which the river heats during the summer months, thereby reducing the concentration of DO at saturation. Further, the warm and slow moving conditions behind the dams promote the excess growth of algae which simultaneously promotes wider fluctuations in DO, including much lower night concentrations than occur naturally.

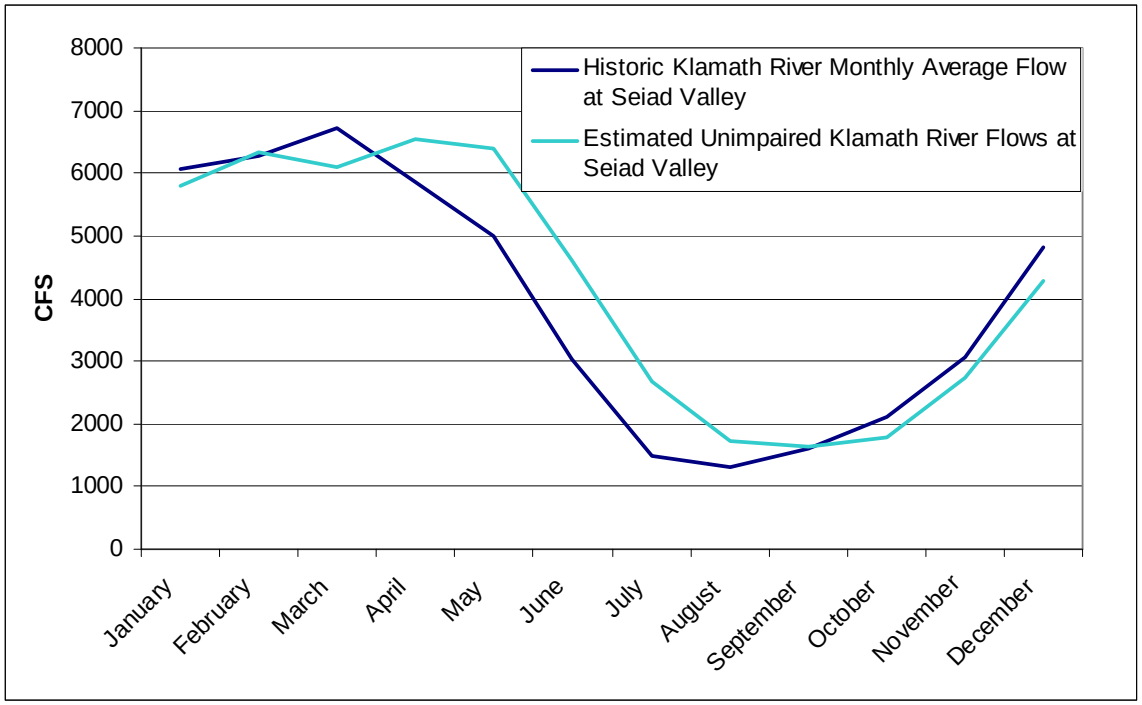


Figure 5.1: Estimated Unimpaired Klamath River Flows at Seiad Valley, California, and Historic Monthly Average Klamath River Flow at Seiad Valley, California; Water Years 1952-2004
Source: United States Bureau of Reclamation [USBR] 2005; USGS 2006

5.3.1.6 Conceptual Model for DOThe USEPA's CADDIS (Causal Analysis/Diagnostic Decision Information System) has produced a conceptual model for dissolved oxygen depicting the potential linkages between and among various environmental and anthropogenic factors.

As depicted in Figure 5-2, the causal pathways potentially resulting in DO impairment include: 1) channel alteration; 2) land cover alteration; 3) water impoundment; and, 4) chemical, organic matter, and nutrient loading. Increased stream temperatures, increased ionic strength, and/or increased sediment loading are interacting stressors that can further exacerbate DO impairment. The biotic responses of concern include changes in behavior, increased mortality, impairment of invertebrate assemblages, impairment of fish assemblages, and other biological impairments. Increased susceptibility to disease, decreased growth, and decreased fecundity are also biotic responses of concern, though not specifically indicated in this model.

The following is USEPA's written explanation of the conceptual model:

> "Certain human activities, such as agricultural, residential, and industrial practices, can contribute to DO depletion (or, less frequently, DO supersaturation), and subsequent biological impairment. These practices may directly introduce chemical contaminants, organic loading, and nutrients to streams, via point and non-point sources such as wastewater treatment plant effluents, fertilizers, animal wastes, landfills, and septic systems. Increases in these substances can increase chemical and biochemical oxygen demand, most notably due to increased respiration of plants and especially microbes.
>
> Physical alteration of the stream channel, through impoundments or channel alterations, can contribute to low DO concentrations in several ways. For example, an impoundment downstream of a location will slow water velocities and increase water depths, which will tend to reduce turbulence and lower incorporation of oxygen into the water column via aeration, as well as reduce diffusion of oxygen from the atmosphere. Channel incision also reduces oxygen diffusion due to decreases in surface-to-volume ratio with increasing stream depth. An impoundment upstream of a location (upper far right of figure 4-4) may reduce DO levels if downstream water releases come from deeper, oxygen-depleted waters of the reservoir (i.e., if they are hypolimnetic), but may increase DO levels if discharges are highly turbulent; whether DO levels increase or decrease will depend on impoundment size and type of release.
>
> Land cover alterations also may reduce stream DO levels by altering in-stream physical characteristics. For example, decreases in riparian vegetation often associated with these activities can reduce large woody debris inputs to the channel, reducing turbulence and aeration; homogenization of stream substrates can have similar effects. In addition these alterations may increase delivery of chemical contaminants, organic material, and nutrients to streams with surface runoff.

> In addition to these processes discussed above, DO concentrations are closely linked to several other stressors…Nutrient enrichment stimulates oxygen-generating (photosynthesis) and oxygen-depleting (respiration) processes. DO levels also are affected by water temperature, ionic strength, and dissolved solids; oxygen solubility decreases as these parameters increase, reducing the amount of available DO in the water. Increased bedded sediment can decrease interstitial flow, reducing oxygen availability for sediment-dwelling organisms, and decreases in water velocity can lower oxygen delivery rates.
>
> DO concentrations directly impact abiotic and biotic stream environments. Low DO…affects the oxidation and reduction (redox) reactions which determine the bioavailability of many inorganic compounds, as well as biologically important materials such as nitrogen and sulfur. For example, lower redox potential (↓ Eh) may decrease the release of precipitated metals, which actually may benefit organisms by reducing bioavailability; however, it also may increase the release of precipitated phosphates, encouraging the proliferation of nitrogen-fixing cyanobacteria and potentially altering food resources for fish and invertebrate assemblages.
>
> The most direct effect of low DO is respiratory distress in biota, which may be exacerbated by relatively rapid fluctuations in available DO. During periods of low DO, some species may increase movement to enhance ventilation across gill structures, attempt to gulp air from the surface, or gather around photosynthesizing plants. Respiratory stress can cause low DO-sensitive taxa [e.g., EPT taxa, or Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddis flies), and salmonid fishes] to decrease; often these taxa are considered indicators of good water quality. Decreases in low DO-sensitive life stages also are potential indicators. Conversely, more tolerant organisms (e.g., cyprinids, amphipods, and chironomids with hemoglobin) and life stages may increase. Increased populations of plant-breathers (e.g., insects that can obtain air from plants, such as certain beetle larvae) and air-breathers (e.g., insects that can carry air bubbles with them underwater) also may be observed. If DO depletion is significant enough, widespread fish kills may occur.
>
> Although biological impairments related to DO usually result from insufficient DO levels, too much DO, or supersaturation, also may pose a problem in certain situations. This supersaturation may result from extremely high levels of oxygen-generating photosynthesis, or from extremely high turbulence and aeration downstream of impoundments. Ultimately, these rapid or large increases in DO may affect organisms by contributing to stressful fluctuations in DO levels, altering redox potentials and bioavailability of potentially toxic substances (e.g., metals), or leading to gas bubble disease (a condition indicated by gas bubbles forming under skin and around eyes) (CADDIS 2007)."

With respect to the kind of activities generally found in the North Coast Region, the conceptual model highlights the importance of evaluating and controlling anthropogenic

inputs of chemicals, nutrients, and organic rich wastes. But, it also highlights the importance of evaluating and managing such disturbances as:

- ✓ Anthropogenic alteration to the natural pattern and range of flows, including stormwater management, groundwater protection, and control of water impoundment and withdrawal;
- ✓ Anthropogenic sources of erosion and sediment delivery;
- ✓ Anthropogenic loss of channel forming materials (e.g., large woody debris);
- ✓ Alteration of the stream channel, such as through gravel mining;
- ✓ Disturbance to wetlands, the flood plain and riparian zone;
- ✓ Anthropogenic sources of nutrients, organic matter, warm water and their delivery to a waterbody, including the discharge of agricultural return flows; and,
- ✓ Threat of loss or alteration (e.g., reduction in flow or increase in temperature) of cold water springs.

Many of these listed disturbances have been impacting the DO conditions of the Klamath River for many decades.

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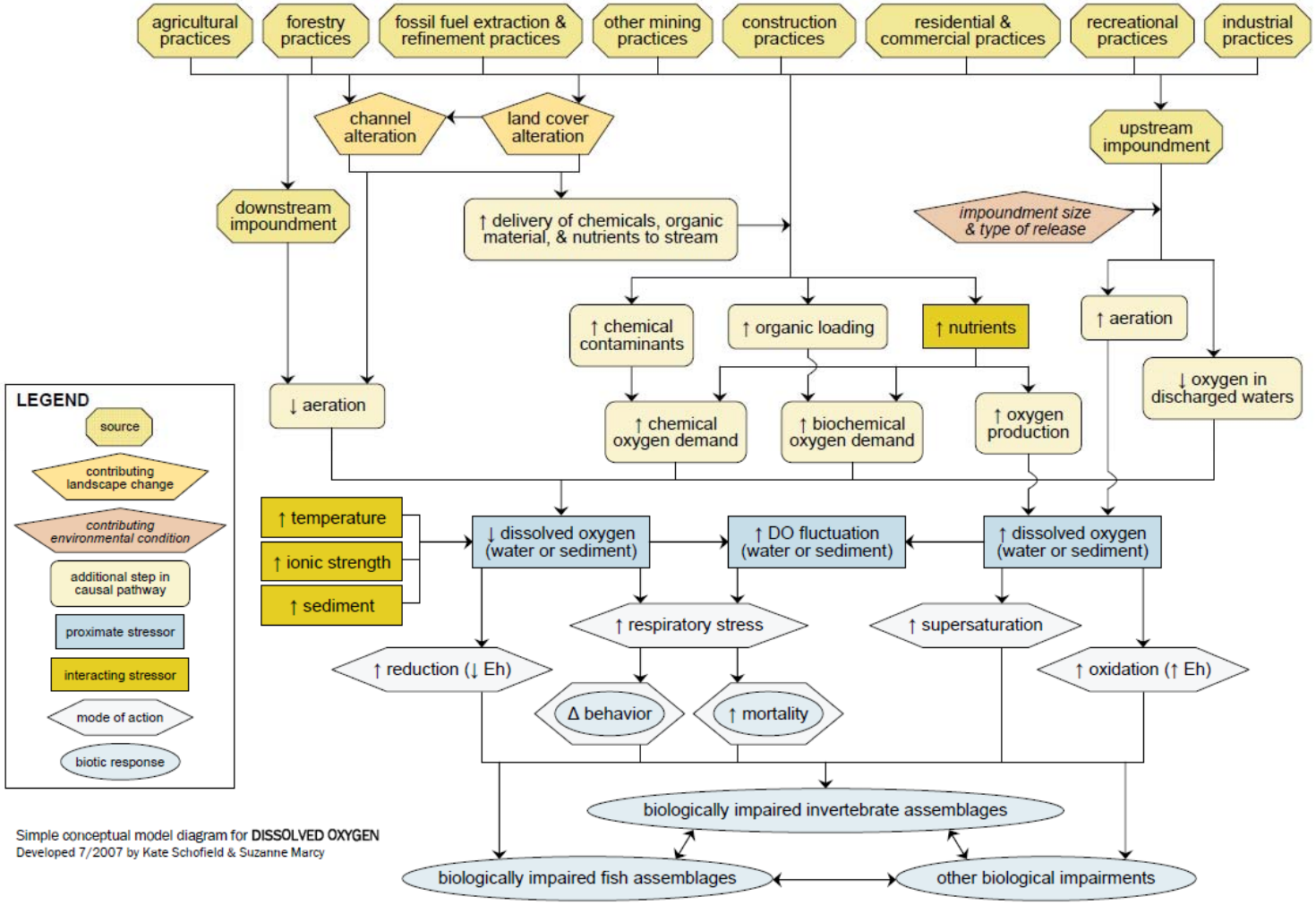
Figure 5-2 CADDIS Conceptual Model for DO



5.3.1.7 Summary

USEPA's CADDIS generic conceptual model depicts the effects on DO expected from activities such as agriculture, forestry, and mining. Effects include channel alteration, watershed land cover alteration, riparian land cover alteration, and impoundments, flow alteration, and discharges of sediment and nutrients. These can lead to a decrease in water velocity, decrease in turbulence, increase in substrate homogenization, increase in organic loading, and increase in nutrients. Secondary results can include an increase in DO fluctuation, decreases in water column and intergravel DO, and decreases in interstitial flow.

A review of the landuse history of the Klamath River basin indicates that numerous, large scale alterations to the landscape from the 1850s through the 1950s have dramatically changed the aquatic ecology. Such landscape alterations are at least partially responsible for the loss and threatened loss of aquatic species in the basin, as described by NRC (2004). Landuse activities such as mining, timber harvest, agriculture, and the development of water and power have had profound effects on water quality, including:

1. Loss of wetland habitat, including nutrient sequestration and flow moderation;
2. Reduction in summer flows and altering of the pattern of flows;
3. Acceleration of surface erosion and increase in peak flows;
4. Elevation of summer water temperatures;
5. Reduction in channel integrity
6. Increase in algae production

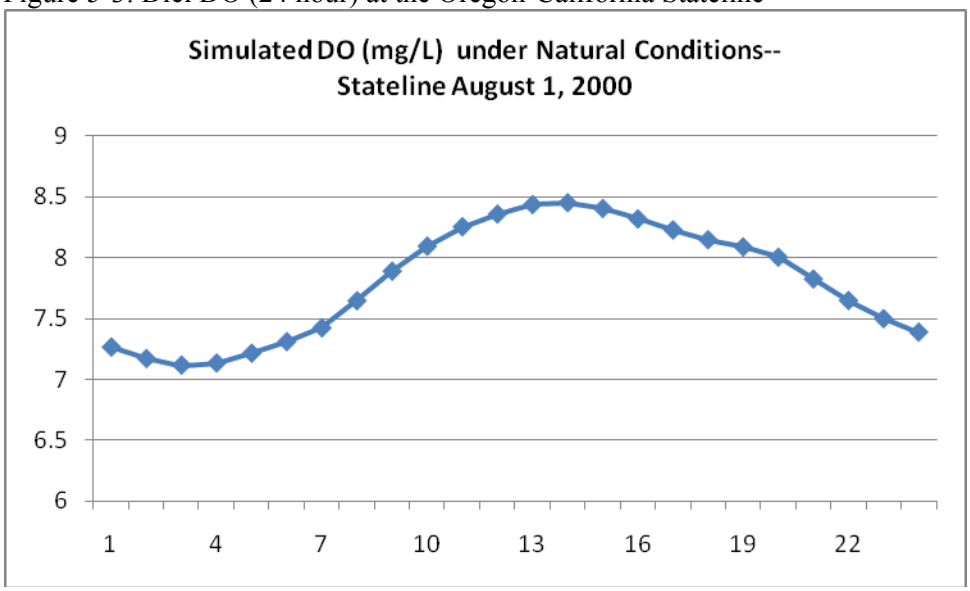
Staff concludes that the landuse history of the Klamath River basin is such that DO conditions in the basin have undoubtedly been altered as a result of them. DO data collected during the 1950s and 1960s most certainly reflect the alteration in water quality resulting from 100 years of landscape manipulation.

5.3.2 Existing SSOs for DO and diel DO fluctuation

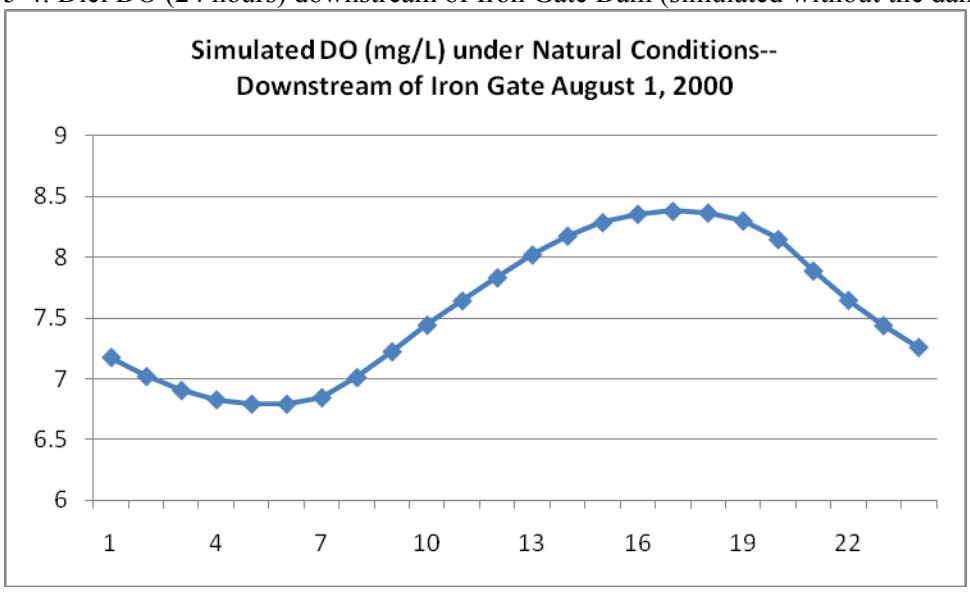
The existing SSOs for DO are contained in Table 3-1 of the Basin Plan and are designed to reflect background conditions as measured in the 1950s and 1960s. The data used to establish these background conditions were collected by a range of partners including federal, state, and local agencies. The Department of Water Resources published the data in annual bulletins beginning with data from 1951. Generally, the data are monthly grab samples that were collected during day light hours and analyzed in the field using the Winkler titration method. The sampling of this period represented an enormous effort, providing results with great statistical power. But, in addition to being collected during a period in which land uses affected water quality, the data were also limited by the fact that they only represented day time conditions.

As discussed in Chapter 4.0 of this Staff Report, the photosynthesis of aquatic plants, algae, and cyanobacteria has a profound effect on the pattern and range of diel DO fluctuation. Photosynthesis has the effect of increasing DO concentrations over the course of the day as plants actively respire oxygen. After reaching a peak in the late afternoon, DO concentrations then decrease through the night until hitting a low in the hours of the early morning. This pattern is apparent in Klamath River as shown in Figures 5-3 and 5-4. These figures depict a simulation of diel DO concentrations

Figure 5-3: Diel DO (24 hour) at the Oregon-California Stateline



5-4: Diel DO (24 hours) downstream of Iron Gate Dam (simulated without the dams)



under natural conditions at the Oregon-California stateline and downstream of Iron Gate Dam (though simulated without the dam) during the summer. The phosphorus-rich volcanic geology and organic matter and nutrients produced and stored in the wetlands of the upper basin naturally

feed episodic algae blooms downstream in the Klamath River mainstem leading to diel fluctuations in DO, particularly during the summer months. These natural conditions originate in the reaches downstream of Upper Klamath Lake in Oregon. Under natural conditions, they dissipate slowly as the river heads downslope. Under existing conditions, though, the fluctuation of DO is exacerbated and perpetuated further downstream by impoundments, agricultural return flows, water diversions, reduction in stream bank stability, reduction in stream side shade, and increase in sediment delivery—conditions which were present when the SSOs for DO were first established.

The SSOs for DO contained in Table 3-1 of the Basin Plan are given as absolute minima (7.0 mg/L upstream of Iron Gate Dam and 8.0 mg/L downstream of Iron Gate Dam) and an annual mean of the monthly means (10 mg/L). Because the absolute minima are developed from grab sample data collected during normal working hours in the 1950s and 1960s, they capture only a moment in time and only from a portion of the diel curve. In particular, the actual minimum concentration, typically observed in the early morning hours, is not represented in the dataset from which the existing SSOs for DO were developed. Further, the dataset from which the existing SSOs for DO were developed includes measurements representing supersatured DO conditions which periodically occur during the late afternoon as a result of elevated photosynthetic activity.

With the development of the existing SSOs for DO in 1975, compliance with the SSOs has been measured by collecting grab samples during normal working hours and performing a Winkler titration in the field. As such, compliance monitoring compared reasonably well to the existing daily minimum SSOs. At issue; however, is how to use the existing SSOs when compliance data is collected using a Hydrolab DataSonde data logger (DataSonde).

A DataSonde measures the current resulting from the electrochemical reduction of oxygen diffusing through a selective membrane (HACH 2008a). It is capable of collecting and storing data at intervals (every 15 minutes, for example) over several days. Thus, one is able to record the entire diel DO curve at a given location, identifying, among other things, the actual daily minimum. The existing SSOs for DO do not lend themselves for comparison to 24 hour DO datasets of this kind. Summers and Engle (1993), as cited by SCCWRP (2003), found that single, daytime instantaneous measures of DO detected hypoxia[2] only 20% of the time that it was known to occur based on 31 days of continuous sampling in the Gulf of Mexico. While this statistic is unlikely to apply to freshwater streams in the North Coast, it nonetheless illustrates the point that minimum objectives based on data collected during the day can not reasonably represent true daily minimums which are more typically experienced at night.

DataSondes are now widely used in the Klamath Basin for monitoring. The DataSondes sometimes suffer from calibration drift and biofouling of the membrane when the device is deployed for multiple days. Quality assurance procedures are critical to ensuring accurate data collection. The availability of Luminescent Dissolved Oxygen technology may reduce the issues of biofouling; however, the use of this new technology is not yet widespread. But, it is expected

[2] Hypoxia means "low oxygen." In estuaries, lakes, and coastal waters low oxygen usually means a concentration of less than 2 parts per million. In many cases hypoxic waters do not have enough oxygen to support fish and other aquatic animals.

to replace the earlier membrane-based probes in the coming year (Fadness 2008). Luminescent Dissolved Oxygen technology has a thicker membrane than its predecessor and is thus less susceptible to biofouling. It is also reported to have the ability to hold a calibration without drift (HACH 2008b). Data can be collected with this device at intervals over a 7-day period (or longer), thus allowing for assessment not only of the daily minimum, but daily and weekly averages, as well. In all other regards, the data collected by Luminescent Dissolved Oxygen technology is comparable to that collected by datasondes (Fadness 2009).

5.4 *Rationale for Revising the SSOs for DO in the Klamath River Mainstem*

Staff has reviewed the existing SSOs for DO in the Klamath River mainstem. The following is a summary of our findings:

1. The SSOs for DO in the Klamath River mainstem are based on a statistical analysis of data collected during the 1950s and 1960s. The background conditions of the Klamath River mainstem codified by Table 3-1 of the Basin Plan are not natural conditions, but conditions modified by decades of mining, timber harvesting, agricultural irrigation and return flows, wetland conversion and other landscape alterations, hydroelectric power operations, dams, and other water withdrawls, as examples.
2. The SSOs for DO in the Klamath River mainstem are based on day time grab samples and thereby do not include the daily minima DO conditions typically expected in the pre-dawn hours of the night.
3. Continuous monitoring data collected by DataSondes are predominantly being used in the Klamath River mainstem to collect DO data and include both day time and night time DO data; this data can not be reasonably compared to the existing SSOs for DO.

Staff concludes that the SSOs for DO in the Klamath River mainstem must be updated to: a) accurately depict daily minima conditions and b) deliberately define background conditions. As they are currently set, the SSOs for DO in the Klamath River mainstem are outdated with respect to the monitoring tools currently available. And, they erroneously establish as background, conditions which very likely reflect significant anthropogenic influence. More accurate and protective SSOs for DO would reflect the actual daily minima expected during the early morning hours and would be based on natural background conditions.

CHAPTER 6.

New Site Specific Information

The Klamath River watershed has been the subject of ecological study for many years, including water quality evaluations. Most recently, the Regional Water Board has been engaged in a project to define the total maximum daily load (TMDL) of pollutants that can be discharged into the Klamath River mainstem and still meet water quality objectives. The Regional Water Board has listed the portions of the Klamath River from the Oregon-California state line to the Pacific Ocean for impairments due to elevated water temperatures, elevated nutrients, and organic enrichment/low dissolved oxygen. Further, the portion of the Klamath River watershed downstream of the Trinity River 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 (2006) section 303(d) List.

Work on the Klamath River TMDLs has resulted in the development of new information regarding water quality conditions in the Klamath River mainstem. Two assessments of interest to the evaluation of the existing SSOs for DO are:

1. Assessment of the range of DO concentrations possible under 100% and 85% saturation. As described in Chapter 4.0, this assessment looks at the physical characteristics of the basin with respect to the ability of the water to hold DO in solution.
2. Assessment of DO under natural water quality conditions as simulated by a series of computer models developed to calculate the TMDLs for the Klamath River mainstem.

The discussion in Chapter 5.0 seeks to demonstrate that the existing SSOs for DO do not achieve the intended goal of establishing as the water quality objective, background conditions in the mainstem. The discussion here in Chapter 6.0 seeks to demonstrate that the existing DO objectives as contained in Table 3-1 of the Basin Plan are unachievable even under natural water quality conditions and therefore require recalculation. The computer simulation of natural water quality conditions provides model output suitable for the recalculation. The model and its output are described below. Alternative methods of recalculating the SSOs for DO are presented in Chapter 7.0.

6.1 *Assessment of 85% and 100% Saturation in the Klamath River Mainstem*

The Klamath River mainstem flows approximately 209 miles from the Oregon-California state line to the Pacific Ocean at Requa, CA. It has a maximum river elevation of 2,885 feet and summer water temperatures that exceed 23 ºC under natural conditions.

Figure 6-1: Range of DO Concentrations at 100% Saturation in the Klamath River Mainstem

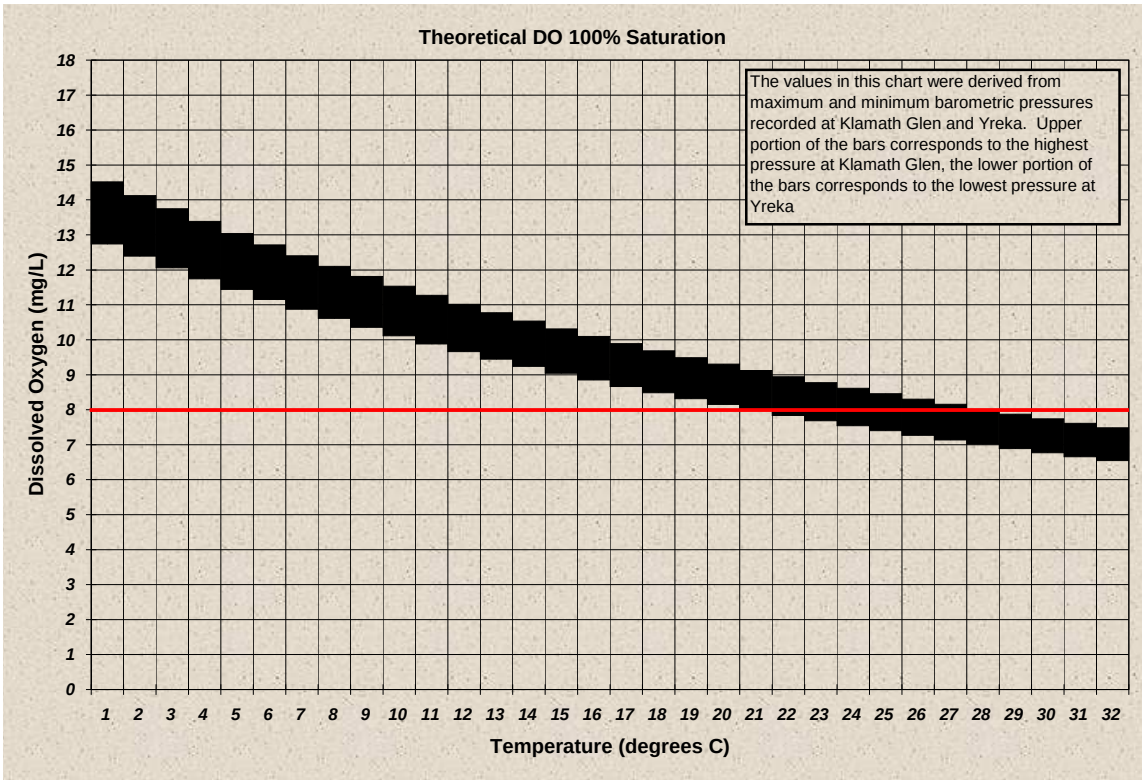
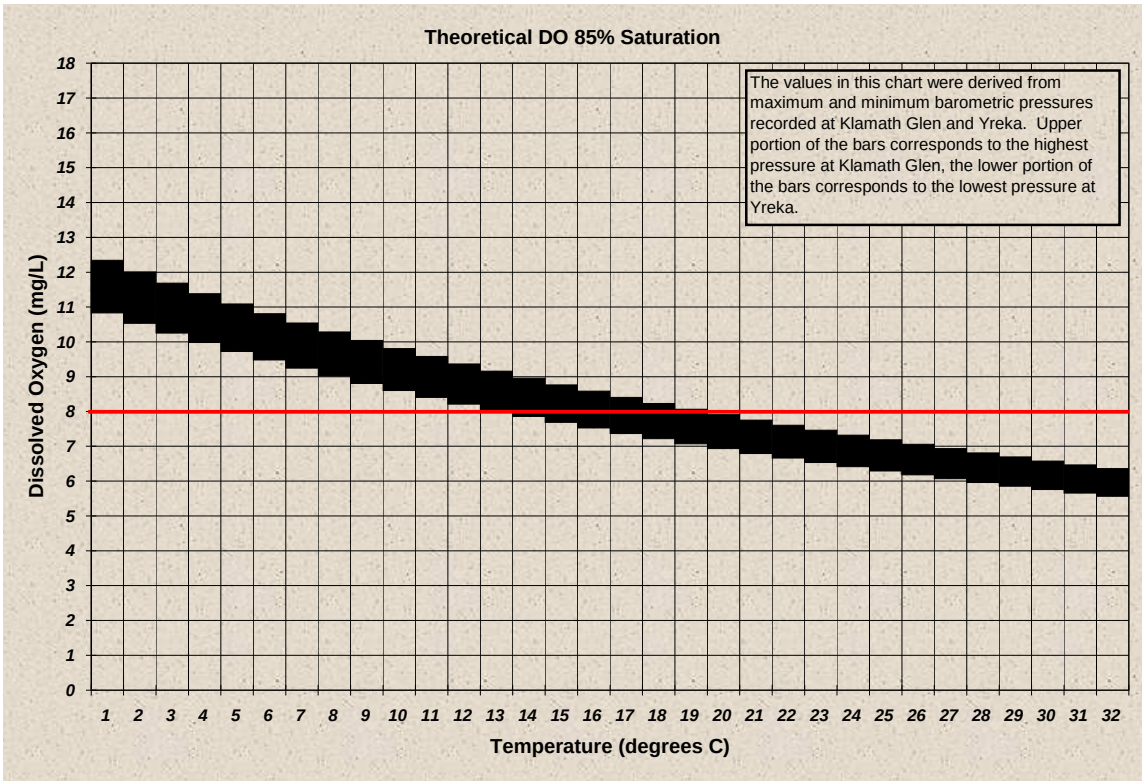


Figure 6-1 depicts the range of DO concentrations at 100% saturation estimated in the Klamath River mainstem at various temperatures. The range is defined by the elevations at two weather stations in the watershed: Yreka, CA (2,648 feet) and Klamath Glen, CA (56 feet). Both stations are within that portion of the Klamath River watershed downstream of Iron Gate Dam in which the existing SSO for DO is 8 mg/L. Figure 6.1 shows the DO concentrations that are theoretically possible when conditions of temperature, barometric pressure and salinity are in equilibrium. The figure demonstrates that during the hottest summer days, when temperatures exceed 21°C, DO concentrations can not physically meet the existing SSO for DO of 8 mg/L at all locations. This is in the absence of other moderating influences such as photosynthesis, turbulence, respiration, decomposition, and chemical oxygen demand.

Figure 6-2 presents the range of DO concentrations at various temperatures when DO saturation is at 85%. The 85% saturation figure is chosen because it represents a reasonable range of variation from equilibrium that occurs in healthy, free-flowing streams, considering the effects of photosynthesis, turbulence, respiration, decomposition, and chemical oxygen demand. In addition, the computer models used to simulate natural water quality conditions (described in detail in Section 6.2.1 and the TMDL Staff Report) also indicate that in the Klamath River mainstem, natural DO conditions maintain a minimum of 85% saturation. At 85% saturation, then, Figure 6.2 illustrates that during even modestly warm days, when temperatures exceed 14 °C, the

water column can not physically hold oxygen in solution at concentrations sufficient to meet the existing SSOs for DO of 8 mg/L at all locations.

Figure 6-2: Range of DO Concentrations at 85% Saturation in the Klamath River Mainstem



This assessment provides a basic framework for understanding the range of DO conditions that can physically occur in the Klamath River mainstem. Figures 6-1 and 6-2 do not provide a basis for recalculating SSOs for DO in the Klamath River mainstem. But, they provide further evidence that the existing SSOs for DO are unattainable at all locations at all times, even under the best possible natural conditions (i.e., 100% DO saturation) and certainly when considering the natural variation that occurs due to photosynthesis, turbulence, respiration, decomposition, and chemical oxygen demand (i.e., 85% DO saturation).

6.2 Assessment of Simulated Natural DO Conditions in the Klamath River Mainstem

Tetra Tech, Inc., under contract to USEPA and with assistance from Regional Water Board staff, and staffs at the Oregon Department of Environmental Quality (ODEQ), and USEPA Regions 9 and 10, has developed a tool for estimating the natural water quality conditions in the Klamath River mainstem. It is with this tool that Regional Water Board staff has unequivocally determined that the existing SSOs for DO are unattainable even under natural conditions and thereby must be recalculated. It is also with this tool that Regional Board staff has recalculated the SSOs for DO. The alternatives by which the

SSOs for DO can be recalculated are presented in Chapter 7.0. In this chapter, staff describes the tool and its results.

6.2.1 Description of the Model

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 (PacifiCorp 2005) when this project commenced. The version of the model available in 2004 is hereafter referred to as the *PacifiCorp Model*. The Regional Water Board, ODEQ, and USEPA determined that this existing *PacifiCorp Model* would provide the optimal basis, after making some enhancements, for TMDL model development. The *PacifiCorp Model* used hydrodynamic and water quality models with a proven track record in the environmental arena and had already been reviewed by stakeholders in the Klamath River watershed. Additionally, it allowed direct comparison 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 to riverine segments including Link River, Keno Dam to J.C. Boyle Reservoir, Bypass/Full Flow Reach, and Iron Gate Dam to Turwar (See Figures 6-3 and 6-4). RMA-2 simulates hydrodynamics while RMA-11 represents water quality processes. The CE-QUAL-W2 model was applied to reservoir segments including Lake Ewauna-Keno Dam, J.C. Boyle Reservoir, Copco Reservoir, and Iron Gate Reservoir (see Figure 6-3). CE-QUAL-W2 is a two-dimensional, longitudinal/vertical (laterally averaged), hydrodynamic and water quality model (Cole et al. 2003). For the purposes of TMDL development, enhancements to the RMA/CE-QUAL-W2 portions of the *PacifiCorp model* were made in the following areas: BOD/organic matter (OM) unification, algae representation in Lake Ewauna, Monod-type continuous Sediment Oxygen Demand (SOD) and OM decay, pH simulation in RMA, OM-dependent light extinction simulation in RMA, re-aeration formulations, and dynamic OM partitioning. The Klamath TMDL staff report and appendices provide more detail on this subject.

Since the estuarine portion of the Klamath River (Turwar to the Pacific Ocean) was not included in the original *PacifiCorp Model*, it was updated to include an estuarine model. USEPA's Environmental Fluid Dynamics Code (EFDC), which is a 3-D hydrodynamic and water quality model, was selected to model the complex estuarine environment. The hydrodynamics and water quality within the estuary are spatially and temporally variable 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 show significant lateral variability, as does DO to a lesser extent.

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. It is an USEPA-endorsed and supported model and available freely in the public domain.

Table 6-1: 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

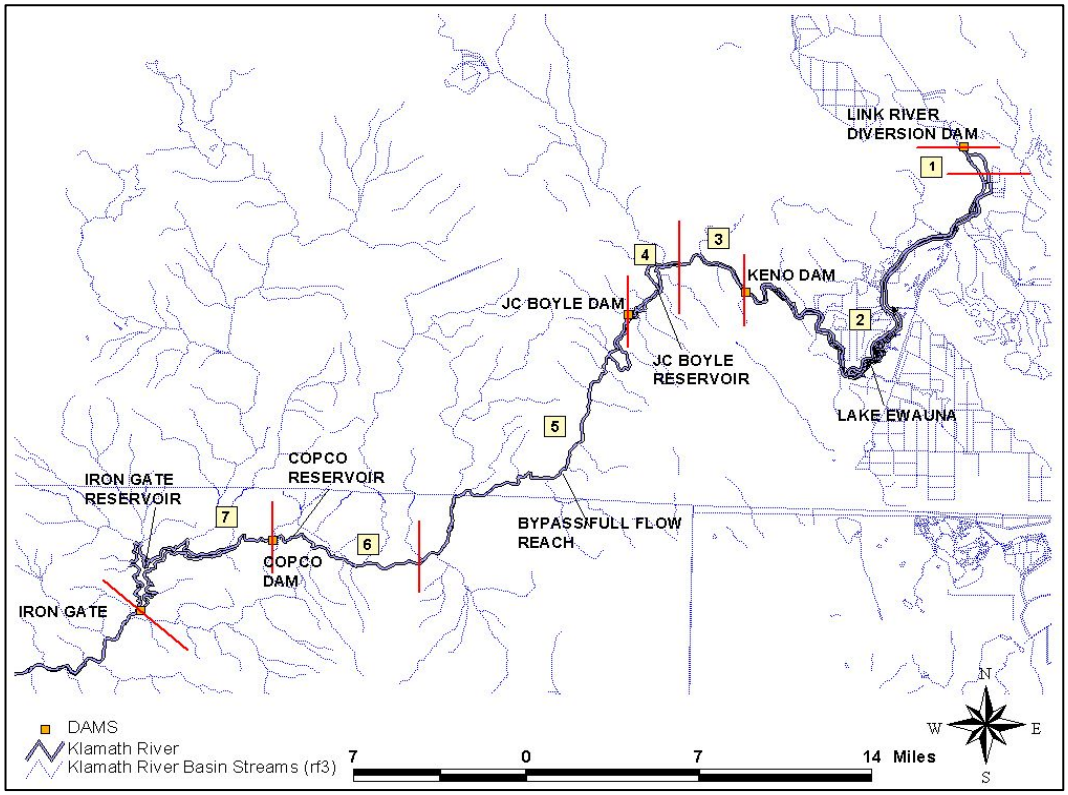
The combination of the *PacifiCorp Model* (RMA and CE-QUAL-W2), with enhancements, and the EFDC model for the estuary resulted in the *Klamath TMDL Model* used for TMDL development. Table 6-1 identifies the modeling elements applied to each river segment. Within each reservoir segment, the model further divides the segment into layers 0.61 to 1.0 meter in depth and 37 to 714 meters in length. Within each river segment, the model further divides the segment into nodes of 75 to 300 meters in length (assumed to be homogeneous in the vertical direction). These nine segments are depicted graphically in Figures 6-3 and 6-4. Linkages between the different modeling segments are 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).

To run the *Klamath TMDL model*, external forcing factors known as boundary conditions must be specified for 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; and include: upstream inflow boundary conditions, tributary inflow boundary conditions, withdrawal boundary conditions, downstream boundary conditions, and surface boundary conditions.

As summarized above, the upstream boundary condition is replicated from the downstream boundary condition produced by the model in the segment above. The surface boundary conditions are determine by meteorological or atmospheric conditions and include air temperature, dew point temperature, wind speed, wind direction, and cloud cover. Data obtained from the U.S. Bureau of Reclamation's (USBR) AgriMet Station (KFLO) near Klamath Falls were used to represent the boundary conditions from J.C. Boyle Dam to Seiad Valley. Data from Brazie Ranch meteorological station represent the surface boundary conditions from Seiad Valley to Turwar. The weather

data from Hoopa and Somes Bay were used to represent the meteorological boundary conditions for those areas. Data from the Arcata Eureka Airport were applied to the estuarine portion of the Klamath River (Turwar to the Pacific Ocean). In addition, tributary and withdrawal boundary conditions are also modeled, including: major springs, tributary streams, stormwater outfall, point source discharges, irrigation withdrawals, agricultural return flows, etc.

Figure 6-3: Model segments in Oregon and Northern California

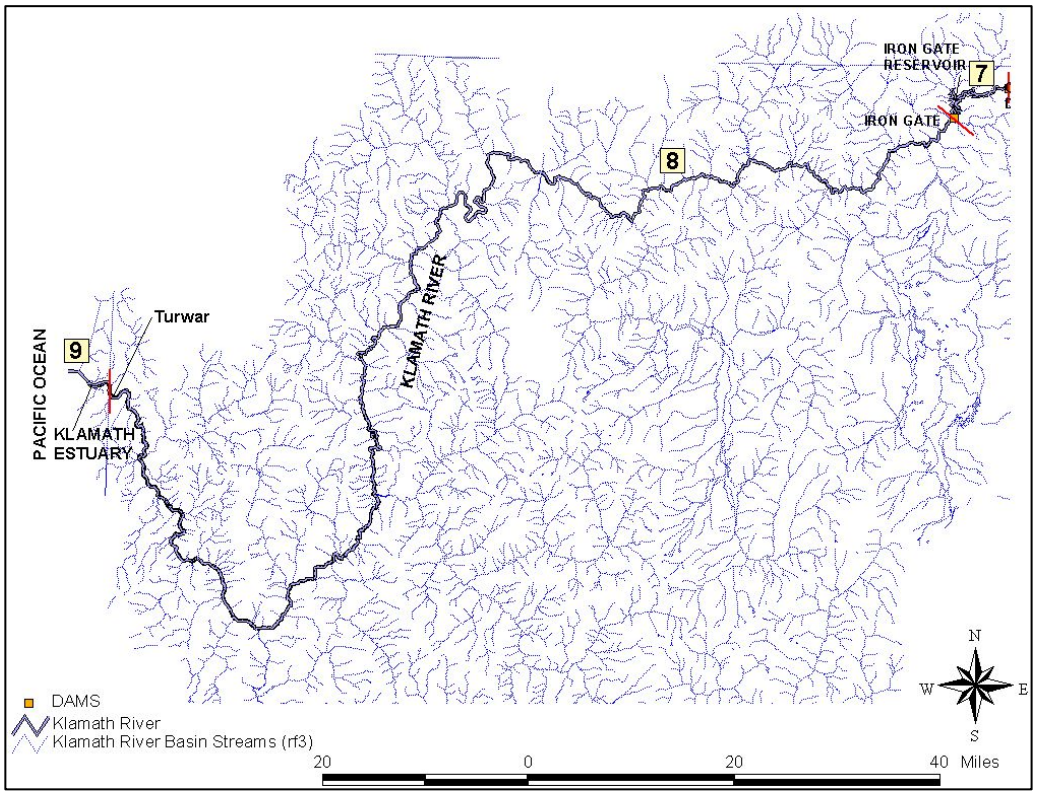


The model was calibrated and validated to known water quality conditions in the Klamath River mainstem. It was then run to simulate natural water quality conditions (referred to as the Natural Conditions *Klamath TMDL model run* and identified in model documentation as T1BSR) and calculate appropriate TMDLs for the listed parameters. These became the basis for the draft TMDL Staff Report and draft DO Staff Report submitted for public review with the comment period ending in September 2009.

Prior to the Regional Water Board's release of the Public Review Draft TMDL Staff Report, the development team initiated various peer reviews related to the *Klamath TMDL model*. In 2005, peer reviews of the *Klamath TMDL model* were completed by Dr. Scott Wells (developer of CE-QUAL-W2 model), Portland State University; Brown & Caldwell (under contract to the City of Klamath Falls, Oregon); and the U.S. Bureau of Reclamation (Technical Services Center – Environmental Applications and Research

Group, Denver). Peer review materials were also sent to Dr. Michael Deas of Watercourse Engineering, Inc. as developer of the *PacifiCorp Model* and technical consultant to PacifiCorp; but, neither Dr. Deas nor PacifiCorp submitted comments at that time. Between 2005 and 2007 the TMDL development team and Tetra Tech, Inc. had informal consultation with Dr. Deas, on behalf of PacifiCorp, regarding the *Klamath TMDL model*. Then, in accordance with Section 57004 of the California Heath and Safety Code, in 2009 the Regional Water Board's draft Staff Report was reviewed by four external scientific peer reviewers. The model has been developed and refined through a process of expert consultation, calibration, validation, and peer review. Finally, the TMDL Staff Report, including details regarding model development were released for public review during two comment periods beginning in June 2009 and

Figure 6-4: Model segments in California



December 2009. These rounds of peer and public review have resulted in additional refinements to the model. The results discussed below reflect the most recent model refinements (November 5, 2009), including refinements to barometric pressure made as a result of consultation with representatives of the Hoopa Valley Tribe (and others). Those refinements are represented for the reach of the Klamath River from Iron Gate Dam to Turwar and are based on a run of the model (T1BSR) for that reach conducted February 2, 2010.

6.2.2 Description of Mainstem Reaches in California

The Klamath River mainstem is divided into three reaches for the purposes of evaluation and modeling. Reach 1 includes that portion of the mainstem from the Stateline to Iron Gate Dam. Iron Gate Dam represents the upper limit of anadromy in the mainstem. Reach 2 includes that portion of the mainstem from Iron Gate Dam to Turwar, downstream of the Klamath's confluence with the Trinity River. And, the third reach encompasses the whole estuary from Turwar to the Pacific Ocean.

6.2.2.1 Stateline to Iron Gate Dam (Reach 1)

The region from the Oregon-California border to Iron Gate Dam currently includes both Copco and Iron Gate dams; though prior to 1917 it was free flowing. The *Klamath TMDL model* evaluates this reach of the river in three model segments: 1) Segment 5 (Bypass/Full Flow Reach), Segment 6 (Copco Reservoir), and Segment 7 (Iron Gate Reservoir); though, Segment 5 originates in Oregon before crossing into California.

The T1BSR run of the *Klamath TMDL model* configures the Klamath River mainstem as a free flowing river from it's headwaters at Upper Klamath Lake (UKL) to the Pacific Ocean. As such, in the Stateline to Iron Gate Dam reach, both Segments 6 and 7 are modified to eliminate the dams. The water quality boundary conditions are defined by the UKL TMDLs at the headwaters and at the Lost River and Klamath Straits Drain, elimination of all point sources, and natural or TMDL conditions for all other tributaries. There are 3 springs in Segment 5 which are estimated to flow at 75 cubic feet per second (cfs).

6.2.2.2 Iron Gate Dam to Turwar (Reach 2)

The mainstem Klamath River from Iron Gate Dam to Turwar is a free flowing river. It is represented in the *Klamath TMDL model* by a single segment (Segment 8) and includes twenty-three tributaries. Five of the tributaries are actively gauged: Shasta River, Scott River, Salmon River, Indian Creek and Trinity River. The remaining minor tributaries are represented in the *Klamath TMDL model* as daily accretion/depletions. Water quality constituent concentrations in the tributaries for all parameters except DO are based on U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, and USEPA data. Temperature data is based on USGS-estimated temperatures for 2002. According to Tetra Tech (2009), the USGS study showed that there is no significant inter-year variation in the predicted in-stream temperature.

DO in the tributaries is estimated based on percent saturation and natural temperatures as follows: 1) 100% saturation in minor tributaries and the Trinity River and 2) 95% saturation in the Shasta, Scott and Salmon rivers.

6.2.2.3 Klamath River Estuary

The Klamath River Estuary is the lower most reach of the river and flows from Turwar to the Pacific Ocean. This reach is established as Segment 9 in the *Klamath TMDL model*. For Segment 9, the EFDC model was used (Tetra Tech 2009), allowing for three dimensional water quality predictions. The model was calibrated using data collected in 2004 and including chlorophyll *a*, DO, PO_4, NH_4, and NO_2/NO_3. The model reproduces

the observed diel fluctuation of DO in both the surface and bottom water. Since the model and observed data both show very low algae concentrations in the estuary, significant diel fluctuations of DO do not occur as a result of phytoplankton. Periphyton biomass, however, is predicted at high levels in the shallow regions of the estuary. This is likely a key contributor to diel DO fluctuation. The T1BSR run of the *Klamath TMDL model* generates simulated data for the Upper, Middle and Lower Estuary. With respect to DO, the Upper and Middle Estuary act like freshwater reaches. The Lower Estuary, however, does not.

6.2.3 Natural Watershed Characteristics

The Klamath River TMDL models were applied to characterize natural baseline water quality conditions of the Klamath River. To estimate natural conditions, several characteristics of the Klamath River watershed had to be considered, including the natural nutrient loading, limited buffering capacity, and elevated summer temperatures.

6.2.3.1 Nutrient Loading

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.

6.2.3.2 Buffering Capacity

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.

6.2.3.3 Summer Temperatures

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.

6.2.3.4 Summary

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 nutrient, heat, and organic matter loads to the Klamath River underscore the very limited capacity of the river to assimilate anthropogenic pollutant sources.

6.2.4 Natural Baseline Conditions (T1BSR) Model Configuration

The natural baseline conditions scenario (T1BSR) of the *Klamath TMDL model* run simulates the Klamath River from Upper Klamath Lake to the Pacific Ocean in the absence of all dams and uses a different configuration than for the current conditions scenario. For example, the entire length of the river from Upper Klamath Lake to just upstream of the estuary is simulated using the riverine RMA model. No CE-QUAL-W2 modeling segments are included since the natural configuration includes no impoundments.

The Upper Klamath Lake (UKL) boundary is the starting point for the *Klamath TMDL model*. The UKL boundary condition for the model is derived from the Upper Klamath Lake TMDL (ODEQ 2002) which has been adopted by the State of Oregon and approved by USEPA. The median concentrations for water quality constituents and existing temperature are applied at the outlet and based on 1995 Upper Klamath Lake model output. Flow from Upper Klamath Lake is set at existing conditions, in order to maintain consistency with the existing conditions modeling scenario. Without this consistency, the TMDL team would not have been able to compare the existing conditions scenario to the natural background conditions scenario, impeding their ability to establish appropriate TMDLs for the pollutants of concern.

The flow balance for the current conditions model (when dams are present) and the reservoir operations limit the ability of the model to represent natural flows. It should be noted however, that results for two model runs: one that uses current conditions flows from Upper Klamath Lake and one that uses estimated flows from a natural regime (USBR 2005), were compared and not found to be substantially different.

Permitted point sources are 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) are represented using current conditions flow however, their water quality and temperature are set to be the same as the Upper Klamath Lake (TMDL compliant water quality conditions). Current flow is again used to maintain consistency with the current conditions scenario in order to calculate pollutant load reductions, and associated TMDL load allocations, necessary to meet water quality standards. For major springs and tributaries to the Klamath River in California, natural and TMDL conditions are represented, depending on the tributary.

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

- Representation of the river with no dams;
- 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 major springs and tributaries flow and water quality conditions set at estimated natural and existing TMDL compliant conditions.

The model simulation was run for the year 2000.

6.2.4.1 Barometric Pressure

As described in Chapter 4.0, barometric pressure plays an important role in determining the concentration of DO that a body of water is capable of holding in solution. The model was originally configured using barometric pressure data at three locations. Data from KFLO near Klamath Falls was used to define the barometric pressure from J.C. Boyle Dam to Seiad Valley. Data from Brazie Ranch was used to define the barometric pressure from Seiad Valley to Turwar and, data from the Arcata Eureka Airport was used to define the barometric pressure in the estuary. These data provide an accurate depiction of barometric pressure for those locations on the river closest to the stations from which the data were collected. However, the accuracy is reduced at locations as one moves farther from the station of origin. In addition, there is a large jump in estimated barometric pressure between locations where a switch is made from one dataset to the next. This results in inaccuracies in the associated estimates of DO at the downstream location.

To resolve this problem, Tetra Tech, Inc. with guidance from Regional Water Board staff and as a result of consultation with representatives of the Hoopa Valley Tribe (and others), corrected the barometric pressure data as collected at the given meteorological stations. The barometric pressure data was refined to reflect elevations at the locations downstream of Iron Gate Dam to Turwar, correcting for elevation at each modeling node. A single barometric pressure was applied to all locations above Iron Gate Dam. A single barometric pressure was also applied to all locations in the estuary, downstream of Turwar..

There still is to be expected a minor artifact relating to the barometric pressure jumps, particularly at the first location represented by an elevation correction. But, the node dependent barometric pressure assignment in Reach 2 serves to smooth out any jumps considerably. As a result of the correction to barometric pressure, new data simulating DO under natural conditions was made available February 2, 2010 and is reflected in this updated Staff Report.

6.2.4.2 Percent Saturation

Percent DO saturation is one of the surface boundary conditions requiring assignment for individual tributaries throughout the watershed. Regional Water Board staff evaluated

historic data and applied best professional judgment to make the following percent saturation assignments:

1. For minor tributaries, 100% saturation
2. For the Shasta, Scott and Salmon Rivers, 95% saturation
3. For the Trinity River, 100% saturation

These are the percent saturation assignments made in the most recent (December 2009) run of the *Klamath TMDL model*. They vary only slightly from previous runs of the model.

6.2.5 Discussion of Modeled DO Results

The results of T1BSR, the natural conditions baseline model run of the *Klamath TMDL model*, simulate DO concentrations and saturation values at selected nodes for every hour of the modeled year. Staff presents the modeling results in a number of different ways. First, staff presents the daily minimum and monthly average DO concentrations resulting from the T1BSR natural conditions model run. Second, staff compares these model outputs to the existing SSOs for DO. Third, staff compares the T1BSR model output to the life stage requirements of salmonids as presented in Chapter 3.0. Finally, staff evaluates percent saturation model output.

6.2.5.1 <u>DO Output for the T1BSR Natural Conditions Model Run</u>

Monthly data output for several stations down the length of the Klamath River mainstem from Stateline to the lower estuary have been developed.

These data indicate that in the Klamath River mainstem, when considering *24-hour* data, the *natural background* baseline DO concentrations are as follows:

Upstream of Iron Gate Dam	6.9 mg/L as a daily minimum
	9.4 mg/L as an annual median of the monthly means
Downstream of Iron Gate Dam	6.9 mg/L as a daily minimum
	9.4 mg/L as an annual median of the monthly means
Bottom of the Lower Estuary	7.0 as a daily minimum
	8.8 mg/L as an annual median of the monthly means

6.2.5.2 <u>Comparison of Natural Conditions to Existing SSOs for DO</u>

As described in Chapter 5.0, the existing SSOs for DO were developed with the intention of establishing background conditions as the water quality objective, keeping in mind the prohibition against point source discharge in the basin. By comparing the simulated natural conditions with the existing SSOs for DO, staff is able to determine how well the existing SSOs for DO represent background conditions, as intended. With respect to this comparison, Table 6-2 illustrates a number of important points.

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Table 6.2: Minimum DO Concentrations in the Klamath River Mainstem based on T1BSR run of the *Klamath TMDL model*

Location	Jan mg/L	Feb mg/L	Mar mg/L	Apr mg/L	May mg/L	Jun mg/L	Jul mg/L	Aug mg/L	Sep mg/L	Oct mg/L	Nov mg/L	Dec mg/L	Min mg/L	Median mg/L	Max mg/L
Stateline	10.9	10.1	9.2	8.7	8.1	7.3	7.3	7.2	7.8	8.4	10.3	11.3	7.2	8.5	11.3
DS Copco Dam	11.1	10.2	9.2	8.7	8.0	7.3	7.1	7.1	7.9	8.5	10.4	11.3	7.1	8.6	11.3
US Iron Gate Dam	11.2	10.3	9.2	8.6	7.9	7.2	7.0	6.9	7.8	8.4	10.5	11.3	6.9	8.5	11.3
Upstream of Iron Gate Dam Reach	**10.9**	**10.1**	**9.2**	**8.6**	**7.9**	**7.2**	**7.0**	**6.9**	**7.8**	**8.4**	**10.3**	**11.3**	**6.9**	**8.5**	**11.3**
DS Iron Gate Dam	11.2	10.3	9.2	8.6	7.9	7.2	7.0	6.9	7.8	8.4	10.5	11.6	6.9	8.5	11.6
US Shasta	11.3	10.4	9.2	8.6	7.9	7.2	7.2	7.2	8.0	8.6	10.5	11.7	7.2	8.6	11.7
DS Shasta	11.4	10.5	9.3	8.7	8.1	7.4	7.3	7.3	8.2	8.7	10.5	11.6	7.3	8.7	11.6
US Scott	11.6	10.7	9.6	9.0	8.2	7.6	7.3	7.3	8.2	8.7	10.6	11.7	7.3	8.9	11.7
DS Scott	11.5	10.7	9.8	9.2	8.5	7.8	7.4	7.3	8.2	8.7	10.6	11.6	7.3	9.0	11.6
Seiad	11.7	10.9	10.0	9.4	8.6	7.8	7.3	7.3	8.1	8.6	10.7	11.7	7.3	9.0	11.7
US Indian Creek	12.1	11.2	10.3	9.7	8.7	7.8	7.4	7.3	8.2	8.7	10.9	11.9	7.3	9.2	12.1
DS Indian Creek	12.0	11.2	10.3	9.8	8.8	7.9	7.5	7.4	8.2	8.8	10.9	11.9	7.4	9.3	12.0
US Salmon	12.1	11.6	10.8	10.3	9.2	8.2	7.7	7.7	8.3	8.9	11.1	12.1	7.7	9.8	12.1
DS Salmon	12.1	11.5	10.8	10.2	9.2	8.2	7.8	7.7	8.3	8.9	11.0	12.0	7.7	9.7	12.1
Hoopa	12.0	11.5	10.8	10.2	9.2	8.3	7.7	7.6	8.3	9.0	11.0	11.9	7.6	9.7	12.0
US Trinity	12.0	11.5	10.8	10.2	9.2	8.2	7.7	7.6	8.3	8.9	11.0	11.9	7.6	9.7	12.0
DS Trinity	12.0	11.6	10.9	10.4	9.5	8.5	8.0	7.8	8.4	9.1	10.9	11.8	7.8	10.0	12.0
Youngsbar	11.9	11.6	10.9	10.4	9.5	8.5	8.0	7.8	8.4	9.1	10.9	11.8	7.8	10.0	11.9
Turwar	11.8	11.5	10.7	10.3	9.3	8.0	7.7	7.5	8.3	9.0	10.8	11.6	7.5	9.8	11.8
Downstream of Iron Gate Dam Reach	**11.2**	**10.3**	**9.2**	**8.6**	**7.9**	**7.2**	**7.0**	**6.9**	**7.8**	**8.4**	**10.5**	**11.6**	**6.9**	**8.5**	**11.6**
Upper Estuary	11.7	11.3	10.6	10.1	9.2	7.9	7.6	7.5	7.9	8.7	10.7	11.5	7.5	9.7	11.7
Middle Estuary - Top	11.7	11.3	10.7	10.2	9.3	8.0	7.7	7.6	8.0	8.7	10.6	11.4	7.6	9.7	11.7
Middle Estuary - Bottom	11.7	11.3	10.7	10.2	9.3	8.0	7.7	7.6	8.0	8.7	10.6	11.4	7.6	9.7	11.7
Upper and Middle Estuary Reach	**11.7**	**11.3**	**10.6**	**10.1**	**9.2**	**7.9**	**7.6**	**7.5**	**7.9**	**8.7**	**10.6**	**11.4**	**7.5**	**9.7**	**11.7**
Lower Estuary - Top	8.1	11.1	10.5	9.9	9.0	7.8	7.6	7.8	7.9	8.3	9.7	10.1	7.6	8.7	11.1
Lower Estuary - Bottom	8.0	8.5	8.7	8.4	8.1	7.6	7.5	7.3	7.0	7.2	7.9	8.0	7.0	7.9	8.7
Lower Estuary Reach	**8.0**	**8.5**	**8.7**	**8.4**	**8.1**	**7.6**	**7.5**	**7.3**	**7.0**	**7.2**	**7.9**	**8.0**	**7.0**	**7.9**	**8.7**

Table 6.3: Monthly Mean DO Concentrations in the Klamath River Mainstem based on the T1BSR run of the *Klamath TMDL model*

Location	Jan mg/L	Feb mg/L	Mar mg/L	Apr mg/L	May mg/L	Jun mg/L	Jul mg/L	Aug mg/L	Sep mg/L	Oct mg/L	Nov mg/L	Dec mg/L	Min mg/L	Max mg/L	Median mg/L
Stateline	11.5	10.5	9.7	9.1	8.8	8.2	8.0	8.0	8.7	9.6	11.4	11.9	8.0	11.9	9.4
DS Copco Dam	11.7	10.7	9.8	9.3	8.8	8.2	8.1	8.1	8.8	9.7	11.6	12.0	8.1	12.0	9.5
US Iron Gate Dam	11.7	10.7	9.9	9.3	8.8	8.2	8.1	8.1	8.8	9.7	11.6	12.0	8.1	12.0	9.5
Upstream of Iron Gate Dam Reach	**11.5**	**10.5**	**9.7**	**9.1**	**8.8**	**8.2**	**8.0**	**8.0**	**8.7**	**9.6**	**11.4**	**11.9**	**8.0**	**11.9**	**9.4**
DS Iron Gate Dam	11.7	10.7	9.8	9.3	8.8	8.2	8.1	8.1	8.8	9.7	11.7	12.0	8.1	12.0	9.5
US Shasta	11.8	10.8	9.9	9.4	8.8	8.3	8.0	8.1	8.8	9.8	11.8	12.2	8.0	12.2	9.6
DS Shasta	11.8	10.8	10.0	9.5	8.9	8.4	8.1	8.1	8.9	9.9	11.7	12.1	8.1	12.1	9.7
US Scott	12.0	11.1	10.2	9.8	9.0	8.5	8.0	8.1	8.8	9.9	11.9	12.3	8.0	12.3	9.9
DS Scott	11.9	11.0	10.3	9.9	9.1	8.6	8.1	8.1	8.9	9.9	11.9	12.2	8.1	12.2	9.9
Seiad	12.1	11.3	10.6	10.1	9.3	8.7	8.2	8.2	8.9	10.1	12.1	12.5	8.2	12.5	10.1
US Indian Creek	12.4	11.7	11.0	10.4	9.5	8.8	8.4	8.3	8.9	10.1	12.2	12.6	8.3	12.6	10.2
DS Indian Creek	12.4	11.7	11.0	10.5	9.6	8.9	8.4	8.3	9.0	10.1	12.2	12.6	8.3	12.6	10.3
US Salmon	12.7	12.0	11.5	10.8	10.0	9.1	8.6	8.5	9.1	10.3	12.3	12.7	8.5	12.7	10.6
DS Salmon	12.5	11.9	11.4	10.8	10.0	9.1	8.6	8.5	9.1	10.3	12.2	12.6	8.5	12.6	10.5
Hoopa	12.4	11.9	11.5	10.8	10.0	9.2	8.6	8.5	9.1	10.3	12.0	12.4	8.5	12.4	10.5
US Trinity	12.4	11.9	11.5	10.8	10.0	9.2	8.6	8.5	9.1	10.3	12.0	12.4	8.5	12.4	10.5
DS Trinity	12.3	11.9	11.5	10.8	10.2	9.3	8.8	8.6	9.2	10.3	11.9	12.3	8.6	12.3	10.6
Youngsbar	12.3	11.8	11.5	10.8	10.1	9.3	8.7	8.6	9.1	10.2	11.8	12.2	8.6	12.2	10.5
Turwar	12.2	11.7	11.4	10.7	10.0	9.1	8.7	8.5	9.0	10.1	11.7	12.1	8.5	12.1	10.4
Downstream of Iron Gate Dam Reach	**11.7**	**10.7**	**9.9**	**9.3**	**8.8**	**8.2**	**8.0**	**8.0**	**8.8**	**9.7**	**11.6**	**12.0**	**8.0**	**12.0**	**9.5**
Upper Estuary	12.0	11.6	11.3	10.6	9.9	9.1	8.8	8.8	9.4	10.3	11.7	12.0	8.8	12.0	10.4
Middle Estuary - Top	12.0	11.6	11.3	10.6	9.9	9.1	8.8	8.8	9.4	10.2	11.6	12.0	8.8	12.0	10.4
Middle Estuary - Bottom	12.0	11.6	11.3	10.6	9.9	9.1	8.8	8.8	9.4	10.2	11.6	12.0	8.8	12.0	10.4
Upper and Middle Estuary Reach	**12.0**	**11.6**	**11.3**	**10.6**	**9.9**	**9.1**	**8.8**	**8.8**	**9.4**	**10.2**	**11.6**	**12.0**	**8.8**	**12.0**	**10.4**
Lower Estuary - Top	11.8	11.5	11.2	10.4	9.8	9.1	9.0	9.2	9.5	9.7	10.5	11.1	9.0	11.8	10.1
Lower Estuary - Bottom	10.8	10.9	10.9	9.7	9.1	8.7	8.8	8.8	8.6	8.3	8.4	8.7	8.3	10.9	8.8
Lower Estuary Reach	**10.8**	**10.9**	**10.9**	**9.7**	**9.1**	**8.7**	**8.8**	**8.8**	**8.6**	**8.3**	**8.4**	**8.7**	**8.3**	**10.9**	**8.8**

As shown in Tables 6-2 and 6.3, neither the existing daily minimum nor the monthly mean requirements as contained in Table 3-1 of the Basin Plan reasonably represent that which is achievable under natural conditions as simulated by the T1BSR run of the *Klamath TMDL model*. There are a number of locations where the simulated DO concentrations meet neither the daily minimum requirement (7.0 mg/L above Iron Gate Dam and 8.0 mg/L below Iron Gate Dam) nor the monthly mean requirement (10.0 mg/L) and the months of violation range from May to September for the daily minima and March to October for the monthly mean. Violations of the daily minima occur from Iron Gate Dam to the Pacific Ocean. Violations of the monthly mean requirement occurs from the Stateline to Seiad and in the lower estuary.

The lower estuary does not meet the daily minimum requirement for 4 months of the year at the surface and 6 months of the year at depth. The monthly mean criteria is met at the surface 50% of the year as required. But , it is only met 25% of the year at depth. As shown even more dramatically in Section 6.2.5.4, the lower estuary, with its tidal influence, presents a special case with respect to DO and deserves separate consideration and treatment. Chapter 7.0 (Alternatives) offers some suggestions to address the unique DO conditions present in the lower estuary.

Table 6-4: T1BSR Model Results as compared to Existing SSOs for DO

Location	**Existing SSO for DO –min. (mg/L)**	**Existing SSO for DO-- 50% monthly means (mg/L)**	**Simulated min. (mg/L)**	**No. of Months. Exceeding min.**	**% of simulated monthly means greater than 10 mg/L**
Stateline	≥7.0	≥10.0	7.2	0	33
DS Copco Dam	≥7.0	≥10.0	7.1	0	33
US Iron Gate Dam	≥7.0	≥10.0	6.9	1	33
DS Iron Gate Dam	≥8.0	≥10.0	6.9	5	33
US Shasta	≥8.0	≥10.0	7.2	4	33
DS Shasta	≥8.0	≥10.0	7.3	3	42
US Scott	≥8.0	≥10.0	7.3	3	42
DS Scott	≥8.0	≥10.0	7.3	3	42
Seiad	≥8.0	≥10.0	7.3	3	58
US Indian	≥8.0	≥10.0	7.3	3	58
DS Indian	≥8.0	≥10.0	7.4	3	58
US Salmon	≥8.0	≥10.0	7.7	2	58
DS Salmon	≥8.0	≥10.0	7.7	2	58
Hoopa	≥8.0	≥10.0	7.6	2	50
US Trinity	≥8.0	≥10.0	7.6	2	50
DS Trinity	≥8.0	≥10.0	7.8	1	67
Youngsbar	≥8.0	≥10.0	7.8	2	67
Turwar	≥8.0	≥10.0	7.5	2	67
Upper Estuary	≥8.0	≥10.0	7.5	4	58
Top Middle Estuary	≥8.0	≥10.0	7.6	2	58
Bottom Middle Estuary	≥8.0	≥10.0	7.6	2	58
Top Lower Estuary	≥8.0	≥10.0	7.6	4	50

Location	Existing SSO for DO –min. (mg/L)	Existing SSO for DO-- 50% monthly means (mg/L)	Simulated min. (mg/L)	No. of Months. Exceeding min.	% of simulated monthly means greater than 10 mg/L
Bottom Lower Estuary	≥8.0	≥10.0	7.0	6	25

Shading indicates those locations which under natural water quality conditions are in noncompliance with the existing SSOs for DO.

6.2.5.3 Comparison of Natural Conditions to Salmonid Life Stage Requirements

A fundamental element of recalculating appropriate SSOs for DO in the mainstem Klamath is determining the degree to which beneficial uses are protected given the natural biochemical processes of the Klamath River (under natural conditions). As described in Chapter 3.0, salmonid cold water habitat, including spawning habitat, is identified as the most sensitive beneficial uses of the Klamath River with respect to DO and stands as a surrogate for the other beneficial uses for which DO is important. Chapter 3.0 identifies the DO concentrations demonstrated by laboratory studies as necessary to ensure little to no population impairment. Staff have compared the DO output from the T1BSR (natural conditions) run of the *Klamath TMDL model* to these life cycle requirements as well as National DO Criteria.

Of the range of DO conditions identified in Chapter 3.0 appropriate for the protection of salmonids, staff has chosen for comparison purposes daily minima and monthly averages that reflect USEPA (1986) guidance on DO criteria development to ensure "no production impairment" or "slight production impairment". Specifically, staff has taken heed of USEPA's (1986) recommendation that

> "if slight production impairment or a small but indefinable risk of moderate production impairment is unacceptable, then continuous exposure conditions should use the no production impairment values as means and the slight production impairment values as minima."

This approach results in DO criteria for the protection of salmonid life stages as follows:

- 6.0 mg/L as a daily minimum to protect other life stages,
- 8.0 mg/L as a 30-day average to protect other life stages,
- 9.0 mg/L as a daily minimum to protect early life stages, assuming a 3 mg/L difference between the intergravel DO and water column DO, and
- 11.0 mg/L as a 30-day average to protect early life stages, assuming a 3 mg/L difference between the intergravel DO and water column DO.

In addition, staff began its assessment by presuming that the period in which salmonids spawn in the Klamath River, including early development and fry emergence, is the same as the period identified for the Trinity River: September 15 through June 4.

A comparison of these criteria to Tables 6.2 and 6.3 illustrate several important phenomena. With respect to the daily variation in DO, the T1BSR natural conditions modeled results show that DO at all locations in the mainstem, including the estuary, are consistently above 6.0 mg/L. This suggests that under natural conditions, the mainstem provides adequate daily DO conditions to protect other (non-embryo, non-larval) life stages against growth effects, avoidance behavior, acute lethality, and synergistic effects. This is critical because the mainstem Klamath provides the corridor through which adult fish migrate upstream to high quality spawning habitat and juveniles migrate downstream to the estuary and ocean. In addition, the mainstem Klamath provides rearing habitat for numerous species of salmonids and other fishes.

The T1BSR natural condition modeled results also show that daily DO conditions in the mainstem do not consistently meet a 9.0 mg/L daily minimum requirement designed to protect early (embryo and larval) life stages during the spawning season (presumed to be September 15 through June 4). A 9.0 mg/L DO requirement is only met from November 1 through March 31. National criteria, as described in USEPA (1986), however, require a daily minimum of 8.0 mg/L as protection of early life stages. The *Klamath TMDL model* (Table 6.2) indicates consistent compliance with 8.0 mg/L as a daily minimum from October 1 through April 30 and compliance at most locations from September 1 through May 31.

With respect to the 30-day average requirements, The T1BSR natural conditions run of the *Klamath TMDL model* (Table 6.3) indicates consistent compliance with an 8.0 mg/L as a 30-day average throughout the mainstem Klamath and throughout the year. As above, this suggests that under natural conditions, the mainstem provides adequate monthly average DO conditions to protect other (non-embryo, non-larval) life stages against growth effects, avoidance behavior, acute lethality, and synergistic effects. This is critical because the mainstem Klamath provides the corridor through which adult fish migrate upstream to high quality spawning habitat and juveniles migrate downstream to the estuary and ocean. In addition, the mainstem Klamath provides rearing habitat for numerous species of salmonids and other fishes.

DO under natural conditions as estimated by the *Klamath TMDL model* and depicted in Table 6.3 does not meet an 11 mg/L monthly average during the spawning and incubation period, except from about November through January. The National criterion for the protection of early life stages is a 7-day mean of 9.5 mg/L. If raised to 10.0 mg/L and applied as a 30-day mean, then the *Klamath TMDL model* (Table 6.3) indicates consistent compliance with early life stage criteria from November through February and from October through April with a some exceptions above the Scott River.

It is possible that the weekly average SPWN-related metric as derived by using USEPA (1986) for no production impairment may overstate the DO requirements of salmonids in the Klamath River. For example, it may be that less than 3 mg/L DO is lost between the water column and intergravel environment in the mainstem Klamath, such that no production impairment in the intergravel environment is assured by water column DO concentrations less than 11.0 mg/L as a monthly average. Future monitoring efforts

should investigate the relationship between water column DO concentrations and intergravel DO concentrations in the mainstem Klamath and important spawning tributaries.

Further, Chapter 3.0 highlights the spawning and incubation periodicity of salmonids in the Klamath River, to the degree they are known. Shaw et al. (1997) reports that coho spawning occurs from November through January with emergence occurring from late February through April. They also report that spring-run Chinook migrate up the Klamath River beginning in June and hold over until the fall to spawn, primarily in the tributaries (Shaw et al. 1997). For fall-run Chinook "spawning in the mainstem Klamath begins during the second week of October, peaks during the last week of October and declines by the end of November (Shaw et al. 1997)." Juveniles emerge from early February through the end of April (Shaw et al. 1997). Chum salmon are said to be at the southern end of their historic range and are rare in the Klamath River, historically present primarily in the estuary (Hamilton et al. 2005). No Klamath-specific spawning and incubation periodicity information was identified for cutthroat trout. However, their preference for smaller tributaries was noted.

Though not definitive, these observations coupled with the results of T1BSR natural conditions model run suggest that the spawning and incubation period for salmonids in the mainstem Klamath is primarily from October through April.

Staff believe that under natural conditions, when the upper watershed was open to migration and tributaries were free of excess sediment and other migration barriers, the mainstem may have provided only secondary spawning habitat, the primary spawning and incubation occurring in conjunction with cold springs and in high quality tributary streams. In support of this, NRC (2004) reports that coho salmon, spring-run Chinook salmon and summer steelhead in particular depended heavily on tributaries to complete their life cycles and sustain their populations. The *Klamath TMDL model* indicates that under natural conditions, daily minimum and monthly mean DO concentrations ensure no production impairment and no more than slight production impairment, respectively, of other (non-embryo and non-larval) life stages of salmonid. It also indicates that under natural conditions, daily minimum and monthly mean DO concentrations essentially meet National criteria for the protection of all early (embryo and larval) life stages if the primary spawning and incubation season in the mainstem Klamath River is understood to occur from about October 1 through April 30.

6.2.5.4 Percent Saturation under Natural Conditions

The *Klamath TMDL model* was used to produce an estimate of percent saturation at each location in the Klamath River mainstem as a corollary to the concentration estimates. Tetra Tech, Inc. has compiled the monthly percent saturation values for each of the stations and they are included in Table 6-5.

As described in Section 6.2.4.1, the *Klamath TMDL model* has been adjusted to account for differences in elevation at specific locations as compared to the meteorological stations from which barometric pressure data was collected. The elevations used to

calculate percent saturation at each of the locations are given in Figure 6.5. For those locations from the Stateline to Iron Gate Dam and from Turwar to the Pacific Ocean, barometric pressure is not corrected for elevation (e.g. 909.83 millibars from Stateline to Iron Gate Dam and 1012.60 millibars from Turwar through the estuary). As a result, there may be a small artifact of the modeling process represented in the DO data associated with the locations within each of these reaches where the elevation is different from that of the associated weather station. But, from Iron Gate Dam to Turwar, the barometric pressure has been adjusted for elevation at every modeling node. This has resulted in a far smoother depiction of DO conditions throughout this reach. By adjusting barometric pressure at more locations throughout the mainstem than was the case in previous model runs, jumps in barometric pressure have been significantly minimized.

Figure 6.5:Barometric Pressure as assigned at individual nodes within the Klamath River mainstem from Iron Gate Dam to Turwar in the January 2010 T1BSR run (new pressure assignment) of the *Klamath TMDL Model*

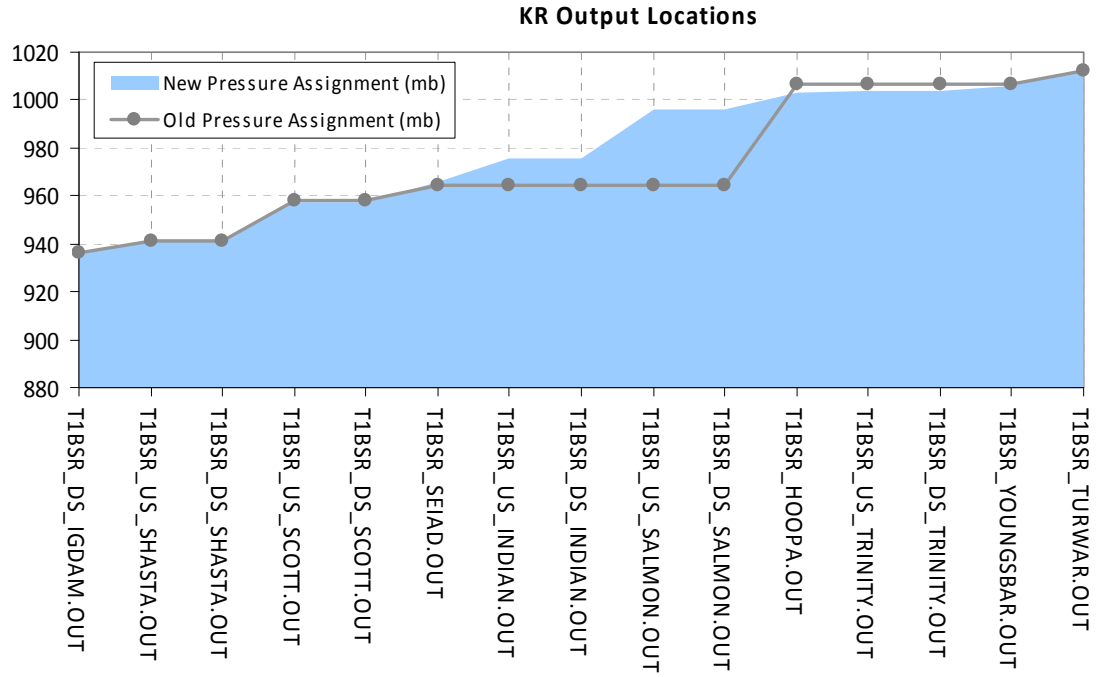


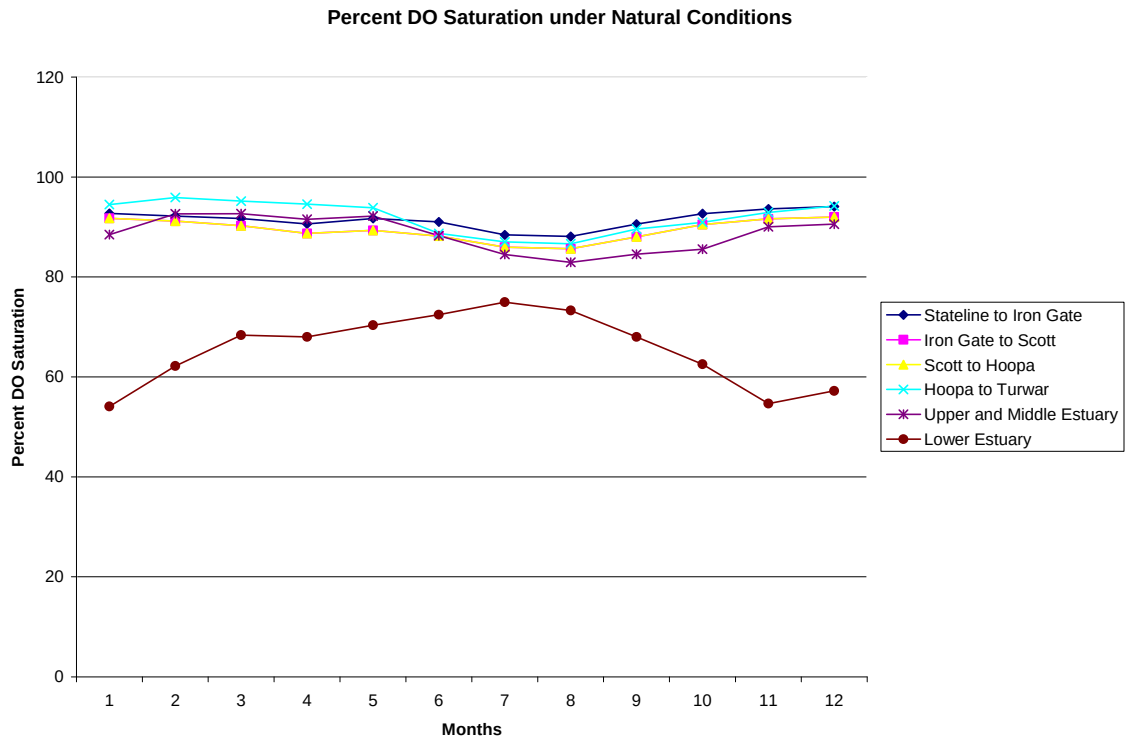
Table 6.5 presents the monthly minimum percent saturation values estimated by the T1BSR run of the *Klamath TMDL model* to occur at specific locations. It also presents the annual minimum percent DO saturation, as well as the minimum to occur in the Klamath River mainstem, overall. (The mainstem minima exclude the data associated with the Klamath River estuary.) The T1BSR model run estimates that under natural conditions, the minimum percent DO saturation in the mainstem Klamath River is 86%. It estimates that the minima range from 86% to 98% depending on the location; and, that the lowest percent DO saturation occurs during the months of July and August.

Figure 6.6 depicts the monthly minimum percent DO saturation within the mainstem over the course of the year. With the exception of the lower estuary, the graph shows a relatively smooth pattern of change in saturation in which saturation is at its lowest during the summer months, rises in the fall and winter and then decreases again in the spring. The T1BSR data output for percent DO saturation demonstrates even more clearly than the DO concentration data output, the need to consider the lower estuary separately from the freshwater-dominated portion of the river.

Table 6.5: Minimum Percent DO Saturation at Locations throughout the Klamath River Mainstem under Natural Conditions (T1BSR Model Run)

Min. % saturation under natural conditions (T1BSR) at each location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Stateline	93	92	92	91	92	91	90	90	91	93	94	94	**90**
DS Copco Dam	94	93	92	91	92	91	91	90	91	93	94	95	**90**
US Iron Gate Dam	94	94	93	91	92	91	88	88	91	93	94	95	**88**
DS Iron Gate Dam	92	91	90	89	89	88	86	86	88	90	92	92	**86**
US Shasta	92	91	90	89	89	88	88	89	90	91	93	93	**88**
DS Shasta	92	92	91	90	90	89	89	90	91	92	93	94	**89**
US Scott	93	92	92	92	92	90	90	90	92	93	94	93	**90**
DS Scott	93	93	93	93	93	92	91	91	92	93	94	94	**91**
Seiad	95	95	94	94	95	92	90	90	93	94	95	95	**90**
US Indian Creek	96	96	96	96	96	92	90	90	93	94	96	96	**90**
DS Indian Creek	97	97	96	96	96	93	90	91	93	94	96	97	**90**
US Salmon	97	98	97	97	97	94	92	92	93	95	96	97	**92**
DS Salmon	97	97	97	97	96	94	92	92	94	95	96	97	**92**
Hoopa	96	97	96	96	95	92	89	89	91	93	95	96	**89**
US Trinity	96	97	96	96	95	92	89	88	91	92	95	96	**88**
DS Trinity	97	98	98	97	97	95	92	91	92	94	96	97	**91**
Youngsbar	97	98	97	97	96	94	91	90	91	93	95	96	**90**
Turwar	94	96	95	95	94	89	87	87	90	91	93	94	**87**
STATELINE TO TURWAR	**92**	**91**	**90**	**89**	**89**	**88**	**86**	**86**	**88**	**90**	**92**	**93**	**86**
Upper Estuary	93	93	93	92	92	88	85	84	85	88	92	92	**84**
Middle Estuary Surface	93	93	93	92	93	89	86	83	85	86	90	91	**83**
Middle Estuary Subsurface	93	93	93	92	93	89	86	83	85	86	90	91	**83**
Lower Estuary Surface	82	90	91	89	90	86	83	78	75	72	71	73	**71**
Lower Estuary Subsurface	54	62	68	68	70	72	75	73	68	63	55	57	**54**

Figure 6.6: Fluctuation in percent DO saturation under natural conditions (T1BSR simulation) in individual reaches from the Stateline to the estuary.



6.3 Summary of Findings

Water has a limited ability to hold oxygen in solution that is defined by barometric pressure, temperature, and salinity. An assessment of the theoretical DO concentrations at 100% and 85% saturation indicate that water in the Klamath River is unable as a result of these simple physical properties to consistently meet the existing SSOs for DO. The *Klamath TMDL model* simulates, among other things, water quality conditions in the Klamath River mainstem under natural conditions, including DO concentration and percent DO saturation. It indicates that the daily minimum DO values above Iron Gate Dam and below Iron Gate Dam are less than the existing SSO for DO. Similarly, the annual median of monthly means is less than the existing SSO for DO, as well. . In short, the *Klamath TMDL model* demonstrates that even under natural conditions, water quality in the mainstem Klamath River is of insufficient quality to consistently attain the existing SSOs for DO.

A closer assessment of the DO output from the natural conditions run of the *Klamath TMDL model* indicates the following:

- The lower estuary experiences DO fluctuations that are dissimilar from the fluctuation that occurs elsewhere in the mainstem.
- The period in which DO concentrations meet the "no production impairment" or "slight production impairment" requirements of salmonid

embryos and alevin (as defined by USEPA 1986) is from October through April.

- Under natural conditions, the transfer of DO from the water column to the intergravel environment is likely to be more efficient than estimated by USEPA (1986). If this is the case than water column DO concentrations less than 11.0 mg/L as a monthly average may sufficiently ensure intergravel DO concentrations of 8.0 mg/L DO as a monthly average to ensure "no production impairment" of salmonid embryos and alevin.
- The protection of salmonid refugia may be an important companion to the recalculation of the SSOs for DO in the Klamath River mainstem.
- Under natural conditions, the daily minimum DO upstream of the Lower Estuary is 6.9 mg/L. The annual median of monthly means is 9.4 mg/L. In the lower estuary, the daily minimum is 7.0 mg/L and the annual median of the monthly means in 8.8 mg/L.
- Under natural conditions, the Klamath River (excluding the estuary) maintains a minimum DO saturation greater than or equal to 86% at all times.

CHAPTER 7.
ALTERNATIVES ANALYSIS AND PROPOSED RECALCULATION OF THE SSOs FOR DO IN THE KLAMATH RIVER MAINSTEM

In this chapter, staff analyzes the new information presented in Chapter 6.0 and discusses the alternatives for recalculating the SSOs for DO in the Klamath River mainstem. As a result of the assessment of the existing SSOs for DO, staff has determined that the four main goals of the recalculation are to:

1. Represent an improved understanding of *natural background* conditions,
2. Accommodate updated monitoring techniques that allow for 24-hour DO sampling,
3. Be protective of identified beneficial uses, and
4. Represent physically achievable DO conditions.

The alternatives presented are 1) no change, 2) recalculated SSOs based on simulated DO concentrations under natural conditions, or 3) recalculated SSOs based on simulated percent DO saturation under natural conditions. Staff has not developed an alternative based on salmonid life cycle DO requirements. This is because, as shown in Chapter 6.0, the *Klamath TMDL model* indicates that DO under natural conditions does not consistently meet criteria designed to ensure no production impairment. Recovery of threatened and endangered species requires protection against further production impairment.

Staff uses the simulations resulting from the T1BSR run of the *Klamath TMDL model* because it offers the best estimate, to date, of DO under natural conditions. A description of the model and the natural conditions run are given in Chapter 6.0. T1BSR simulates DO in the mainstem considering conditions of barometric pressure, salinity, natural temperatures, and diel fluctuation. Staff believes that the T1BSR run of the *Klamath TMDL model* represents a more accurate and protective basis for establishing background DO objectives than the day time data collected in the 1950s and 1960s which was used to establish the existing SSOs for DO. This is because the T1BSR model run simulates conditions in the absence of anthropogenic influence (e.g., without dams), incorporates 24-hour data, and is directly comparable to data collected by datasondes, as well as grab samples.

Of importance is the observation in Chapter 6.0 that DO conditions in the lower Klamath estuary are different enough from conditions in the mainstem to warrant separate treatment. The existing SSOs for DO are given as two separate criteria: those that apply above Iron Gate Dam and those that apply below Iron Gate Dam. As a consequence, the criteria established for locations below Iron Gate Dam are applied to the estuary without consideration of the unique hydrological, ecological, and water quality (e.g., salinity concentrations) conditions present in the estuary.

USEPA (1986) guidance says:

> "Where natural conditions alone create dissolved oxygen concentrations less than 110 percent of the applicable criteria means or minima or both, the minimum acceptable concentration is 90 percent of the natural concentration."

Based on this guidance, staff has assessed various means by which DO objectives based on natural concentrations could be developed. The proposed recalculation of the SSOs for DO in the mainstem Klamath River are designed to protect salmonids and other aquatic resources by ensuring that DO in the mainstem Klamath River is consistent with natural background conditions.

7.1 Alternative 1- No Change of the Criteria

Alternative 1 proposes to make no changes to the existing SSOs for DO in the Klamath River mainstem, except to add a footnote making clear that the objectives represent background conditions during daylight hours and can not reasonably be compared to data collected during the night. In this way, the potential for inaccuracies resulting from comparison of 24-hour data collected by DataSondes to the SSOs for DO is reduced. It leaves unaddressed however, the fact that the SSOs for DO represent background conditions as measured during the 1950s and 1960s after over 100 years of widespread anthropogenic influence on water quality. It also leaves unaddressed the fact that during the summer months, the SSOs for DO downstream of Iron Gate Dam are frequently unachievable due to conditions of barometric pressure and natural temperatures. Further, it does not address the unique conditions found in the lower estuary.

7.2 Alternative 2- DO Concentration Limits

Alternative 2 is to replace the SSOs for DO now existing in Table 3-1 of the Basin Plan with new concentration limits that are more precisely based on natural background DO conditions and can be compared to 24-hour data as have been more commonly collected in the last few years. The Alternative 2 DO concentration limits are intended to be the 24-hour equivalent replacement of the existing SSOs which were designed to be compared to day time samples, only. This means that the data set used to recalculate the SSOs includes the nighttime DO low, thereby resulting in true daily minima. This alternative is divided into Alternative 2a and 2b to allow for two differing ways of configuring the reaches within the mainstem.

Tables 6.2 and 6.3 presents the simulated minimum and monthly mean DO data resulting from the T1BSR run of the *Klamath TMDL model*. These simulated data are the basis for the Alternative 2 proposal.

USEPA's (1986) recommendation to derive water quality objectives as 90% of natural background accommodates naturally occurring inter-annual variation. For example, the T1BSR run of the *Klamath TMDL model* provides hourly estimates of natural DO concentration for every day of a given year. It provides a data record which is orders of magnitude greater than the one used to establish the original SSOs for DO in the Klamath mainstem. Yet, it is based on the climatic conditions of a single test year. Inter-annual variability in DO concentration due to variation in climatic conditions is predicted. As

such, establishing water quality objectives as 90% of natural conditions is appropriate. With this correction, the potential for confusing natural variation for anthropogenic influence is reduced. Thus, in accordance with USEPA (1986), staff proposes for Alternative 2 criteria that are 90% of the natural concentrations estimated in the Klamath River mainstem.

7.2.1 Alternative 2a - DO Concentration with Existing Reach Configuration

Alternative 2a is to replicate the format of the existing SSOs for DO (adding new criteria for the estuary), but replace the numeric criteria with the simulated data resulting from the T1BSR run of the *Klamath TMDL model*, corrected with a 90% factor as recommended by USEPA (1986). Table 6.3 depicts the minimum monthly DO concentrations from the Stateline through the Lower Estuary.

7.2.1.1 Stateline to Iron Gate Dam

The minimum DO concentration from Stateline to Iron Gate Dam is 6.9 mg/L with an annual median of the monthly means of 9.4 mg/L. Staff recommends adding a monthly mean to better monitor for chronic DO impairment. The minimum monthly mean for this reach is 8.0 mg/L.

The DO concentrations under natural conditions are multiplied by 90% (0.90) to derive the following proposed concentration-based SSOs for DO in the Klamath River mainstem from the Stateline to Iron Gate Dam.

- 6.2 mg/L minimum
- 7.2 mg/L monthly mean
- 8.5 mg/L annual median of monthly means

7.2.1.2 Iron Gate Dam to Turwar

The minimum DO concentration from Iron Gate Dam to Turwar is 6.9 mg/L with an annual median of the monthly means of 9.5 mg/L. Staff recommends adding a monthly mean to better monitor for chronic DO impairment. The minimum monthly mean for this reach is 8.0 mg/L.

The DO concentrations under natural conditions are multiplied by 90% (0.90) to derive the following proposed concentration-based SSOs for DO in the Klamath River mainstem from Iron Gate Dam to Turwar, excluding the reach under the jurisdiction of the Hoopa Valley Indian Tribe.

- 6.2 mg/L minimum
- 7.2 mg/L monthly mean
- 8.6 mg/L annual median of monthly means

7.2.1.3 Upper and Middle Estuary

For the Upper and Middle Estuary, the DO is fairly uniform from the top of the water column to the bottom. The minimum DO concentration in this reach is 7.5 mg/L while the annual median of monthly means is 10.4 mg/L. As above, staff recommends adding a monthly mean to better monitor for chronic DO impairment. The minimum monthly

mean for this reach is 8.8 mg/L.

The concentrations under natural conditions are multiplied by 90% (0.90) to derive the following proposed concentration based SSOs for DO in the upper and middle Klamath River estuary.

- 6.8 mg/L minimum
- 7.9 mg/L monthly mean
- 9.4 mg/L annual median of monthly means

7.2.1.4 Lower Estuary

The Basin Plan lists over 30 rivers and creeks as providing estuarine habitat (EST) in the North Coast Region, including the Klamath River. At present however, the Basin Plan does not include water quality objectives specifically designed to protect the EST beneficial use. In part this is because estuarine water quality data is fairly sparse and extensive estuarine studies rare.

The estuarine portion of the Klamath River is relatively short in relation to the watershed, though the length of the estuary varies seasonally with salt water intrusion achieving its greatest length during low flow when brackish water extends a couple of miles upriver (NRC 2004). NRC (2004) reports that the tidal amplitudes in the estuary vary up to 2 m.

The T1BSR run of the *Klamath TMDL model* provides some insight into the DO conditions in the Lower Klamath Estuary. Tables 6.2 and 6.3 provide simulated minimum and mean DO concentrations at the top and bottom of the water column. Of note is the fact that DO remains fairly constant at the bottom of the water column, fluctuating under natural conditions by only 1 mg/L from 7.0 to 8.0 mg/L. This is likely a function of the relatively constant water quality characteristics of salt water which, heavier than fresh water, forms a wedge at the bottom of the estuary. At the surface, on the other hand, DO fluctuates more widely (7.6 to 11.1 mg/L). This is likely a function of freshwater which forms a wedge at the surface of the estuary and varies in temperature, nutrients, and other water quality characteristics.

Estuarine DO conditions vary daily, seasonally, and annually. The degree and pattern of variation in the Lower Klamath Estuary is not yet very well understood. Without further study, staff does not believe the simulated estuarine data is sufficient to establish SSOs for this reach.

As an alternative, staff proposes the development of a narrative objective that identifies the water quality protection goals for this reach. Staff further proposes that as part of its Triennial Review of the Basin Plan, the Regional Water Board consider the development of numeric water quality standards for North Coast estuaries, including the Lower Klamath Estuary.

Under this alternative, staff proposes the following narrative objective:

"For the protection of estuarine habitat (EST), the dissolved oxygen content of the lower Klamath estuary shall not be depressed to levels adversely affecting beneficial uses as a result of controllable water quality factors."

7.2.1.5 Summary of Alternative 2a

Table 7.1- Alternative 2a

	Minimum (mg/L)	**Monthly Mean (mg/L)**	**Annual Median of Monthly Means (mg/L)**
Stateline to Iron Gate Dam	6.2	7.2	8.5
Iron Gate Dam to Turwar	6.2	7.2	8.6
Upper and Middle Estuary	6.8	7.9	9.4
Lower Estuary (Reach 4)	For the protection of estuarine habitat (EST), the dissolved oxygen content of lower Klamath estuary shall not be depressed to levels adversely affecting beneficial uses as a result of controllable water quality factors.		

7.2.2 Alternative 2b - DO Concentration with Reconfiguration of Reaches

The simulated DO concentration data resulting from the T1BSR run of the *Klamath TMDL model* suggests a configuration of reaches that differs from that used with the existing SSOs for DO. For example, Table 6.2 shows minimum DO concentrations under natural conditions from the Stateline to the Shasta River ranging from 6.9 to 7.2. From the Shasta to the Trinity River, the natural DO concentrations range from 7.2 to 7.4 mg/L. From the Trinity River to the Lower Estuary, the natural DO concentrations range from 7.5 to 7.7 mg/L. If the river is divided in this way, the ranges of minimum values are reduced in each reach ensuring that the daily minimum objective more closely mimics the natural conditions throughout the reach.

7.2.2.1 Stateline to Shasta River

The daily minimum for this reach is given in Table 6.2 as 6.9 mg/L. The monthly mean is given in Table 6.3 as 8.0 mg/L and the annual median of monthly means is given as 9.4 mg/L. Applying a 90% correction factor, the resulting criteria are as follows:

- 6.2 mg/L minimum
- 7.2 mg/L monthly mean
- 8.5 mg/L annual median of monthly means

7.2.2.2 Shasta River to Trinity River

The daily minimum for this reach is given in Table 6.2 as 7.3mg/L. The monthly mean is given in Table 6.3 as 8.0 mg/L and the annual median of monthly means is given as 9.9 mg/L. Applying a 90% correction factor, the resulting criteria are as follows:

- 6.6 mg/L minimum
- 7.2 mg/L monthly mean
- 8.9 mg/L annual median of monthly means

7.2.2.3 Trinity River to Lower Estuary

The daily minimum for this reach is given in Table 6.2 as 7.5 mg/L. The monthly mean

is given in Table 6.3 as 8.5 mg/L and the annual median of monthly means is given as 10.4 mg/L. Applying a 90% correction factor, the resulting criteria are as follows:

- 6.8 mg/L minimum
- 7.7 mg/L monthly mean
- 9.4 mg/L annual median of monthly means

7.2.2.4 Lower Estuary

As with Alternative 2a, staff recommends a narrative objective describing the water quality protection goals for the lower estuary.

7.2.2.5 Summary of Alternative 2b

Table 7.2: Alternative 2b

	Minimum (mg/L)	**Monthly Mean (mg/L)**	**Annual Median of Monthly Means (mg/L)**
Stateline to Shasta	6.2	7.2	8.5
Shasta to Trinity	6.6	7.2	8.9
Trinity to Lower Estuary	6.8	7.7	9.4
Lower Estuary (Reach 4)	For the protection of estuarine habitat (EST), the dissolved oxygen content of the lower Klamath estuary shall not be depressed to levels adversely affecting beneficial uses as a result of controllable water quality factors.		

7.3 Alternative 3 - Percent DO Saturation

An alternative to recalculating the SSOs as concentration based objectives is to establish the objectives based on percent saturation. DO in healthy streams and rivers approaches saturation, fluctuating slightly due to the natural processes associated with photosynthesis and decomposition (Deas and Orlob 1999). The range of fluctuation in saturation in such a system is generally defined as 80-100% (Hauer and Hill 2007; SFBRWQCB 2007; Moyle 2008).

There are numerous regions, states and countries that utilize percent saturation as a water quality criterion for DO. For example, the San Francisco Bay Regional Water Quality Control Board (Region 2) requires that the median DO concentration for any three consecutive months not be less than 80% of the DO content at saturation (SFBRWQCB 2007). It further states that in areas unaffected by waste discharges, a level of about 85% of oxygen saturation exists (SFBRWQCB 2007). The Central Coast Regional Quality Control Board (Region 3) requires that median values not fall below 85% saturation as a result of controllable water quality conditions (CCRWQCB 1994). The Central Valley Regional Water Quality Control Board (Region 5) requires that for those surface water bodies outside the legal boundaries of the Delta, the monthly median of the mean daily DO concentration shall not fall below 85% of saturation in the main water mass (CVRWQCB 2007). It further requires that for water bodies unable to meet concentration-based DO objectives due to natural conditions, DO must be maintained at or above 95% of saturation (CVWQCB 2007). Finally, the Santa Ana Regional Water Quality Control Board (Region 8) requires that waste discharges shall not cause the median DO concentration to fall below 85% of saturation (SARRWQCB 2008).

The State of Oregon applies a 90% saturation criterion in those COLD waterbodies unable to meet concentration-based limits due to conditions of barometric pressure, altitude and temperature, and 95% saturation in SPWN waterbodies under the same conditions. The Hoopa Valley Tribe has proposed a 90% saturation criterion under natural receiving water temperatures in those COLD and SPWN waterbodies unable to meet concentration-based limits due to natural conditions. The National Rivers Authority of England requires DO in their RE1 waterbodies (very high quality, suitable for all fisheries) to be at or above 80% of saturation (NRA 1994).

One of the appealing aspects of percent saturation as a DO criterion is that it establishes a relationship between DO and temperature so that as temperatures decline in the winter, DO concentrations naturally increase even if percent saturation remains the same. This natural pattern of DO fluctuation—rising through the fall, reaching a peak in the winter, and declining in the spring—follows the same pattern as required of salmonids and other aquatic organisms (see Chapter 3.0). This natural pattern of DO concentration and DO life cycle requirements is better represented by a percent saturation criterion than a static minimum concentration limit.

The T1BSR run of the *Klamath TMDL model* produces simulated percent saturation data as presented in Table 6.5. The model calculates percent saturation based on estimates of natural temperatures, salinity, and barometric pressure as adjusted by elevation at locations throughout the mainstem. With the exception of the Hoopa proposal, the percent saturation criteria as described above are applied based on *actual* temperature. As a result, the DO concentrations associated with the criteria adjust based on changes in temperature, including anthropogenically influenced changes such as loss of riparian canopy or decrease in flow to water diversions.

A Technical Advisory Committee (TAC), chaired by Dr. Gary Chapman the author of USEPA's guidance on water quality criteria development for DO (USEPA 1986), was established to review the State of Oregon's water quality criteria for DO. In its' review (Oregon 1995), the TAC made the following observation.

> "Saturation criteria may result in inadequate protection at high temperatures and greater than necessary criteria at low temperatures, often inversely related to the needs of the resource. Because of the high level of protection warranted for salmonid spawning, concentration and saturation criteria would be similar for this use."

To overcome the problem of under protection at high temperatures, staff recommend that a percent DO saturation criterion be calculated based on estimates of *natural* water temperatures rather than existing water temperatures as is more widely done. By this method, the DO concentrations resulting from a calculation of percent saturation will reflect *natural* background conditions rather than allow for anthropogenic influences on temperature, particularly injurious during otherwise warm summer months. Further, by calculating the DO concentration associated with a given percent DO saturation criteria

as based on natural temperatures, the criteria easily can be adjusted to accommodate improvements in the estimate of natural temperatures, including consideration of the effects of climate change, as necessary.

Table 7.3- Percentage of time in which a Percent Saturation Criterion of 90% DO Saturation is met under Natural Conditions (T1BSR)

90% Saturation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Stateline	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
DS_COPCO DAM	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
DS_IGDAM	0%	0%	0%	9%	1%	8%	23%	27%	7%	0%	0%	0%
US_SHASTA	0%	0%	0%	5%	1%	7%	6%	1%	0%	0%	0%	0%
DS_SHASTA	0%	0%	0%	1%	0%	2%	1%	0%	0%	0%	0%	0%
US_SCOTT	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
DS_SCOTT	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SEIAD	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
US_INDIAN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
DS_INDIAN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
US_SALMON	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
DS_SALMON	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
HOOPA	0%	0%	0%	0%	0%	0%	2%	6%	0%	0%	0%	0%
US_TRINITY	0%	0%	0%	0%	0%	0%	3%	6%	0%	0%	0%	0%
DS_TRINITY	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
YOUNGSBAR	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TURWAR	0%	0%	0%	0%	0%	1%	21%	20%	1%	0%	0%	0%
Upper Estuary	0%	0%	0%	0%	0%	5%	21%	34%	30%	8%	0%	0%
Middle Estuary - Top	0%	0%	0%	0%	0%	3%	15%	34%	34%	18%	0%	0%
Middle Estuary - Bottom	0%	0%	0%	0%	0%	3%	15%	35%	35%	19%	0%	0%
Lower Estuary - Top	21%	0%	0%	0%	1%	17%	29%	51%	57%	90%	100%	91%
Lower Estuary - Bottom	40%	28%	22%	49%	63%	70%	65%	66%	84%	100%	100%	98%

Lightly shaded cells are months and locations at which a 90% saturation criterion is always met under natural conditions. Dark shaded cells are months and locations at which a 90% saturation criterion is violated no more than 1% of the time. Unshaded cells are months and locations at which a 90% saturation criterion is violated under natural conditions.

As described above, USEPA (1986) recommends with respect to concentration based objectives, applying a 10% correction factor when deriving objectives from estimates of natural DO concentrations. Staff has considered whether or not a similar correction factor should be applied when deriving objectives from estimates of natural DO percent saturation. As an example, 90% of an 85% DO saturation criterion is 77% (85*0.9).

DO objectives must protect beneficial uses and, if derived from estimates of natural conditions should be established in such a way as to accommodate natural, inter-annual variation. Staff does not believe a criterion less than 80% would adequately protect the beneficial uses. Indeed, establishing a percent saturation criteria for an entire reach or for the entire year, necessarily allows for some flexibility at some locations during some times of the year. To better identify a protective yet implementable and appropriate program, staff has reviewed compliance statistics for assumed percent DO saturation criteria of 95, 90, and 85%.

None of the locations in the Klamath River mainstem achieve a 95% DO saturation criteria for the whole year while all of the locations achieve an 85% DO saturation criteria, except the Upper and Middle Estuary during the month of August. In question, then, is whether or not there are reaches or seasons in which a 90% DO saturation criteria might be appropriate.

Table 7.3 presents the compliance statistics for an assumed percent DO saturation criterion of 90%. Dark shaded cells indicate noncompliance with a 90% DO saturation criterion less than 1% of the time, under natural conditions. Light shaded cells indicate full compliance with a 90% DO saturation criterion. From Table 7.3 staff makes the following observations.

- From the Stateline to Shasta, a 90% criterion is met under natural conditions from October to March.
- From upstream of the Scott River to Hoopa, a 90% criterion is met under natural conditions for the entire year.
- From Hoopa through the Turwar, a 90% criterion is met under natural conditions from October through May. A 90% criterion is estimated to be violated 1% of the time during the month of September based on a daily minimum of 89.53% DO saturation which occurs during 6 one-hour increments during this period.

Table 7.4: Minimum DO Concentrations Resulting from Alternative 3 Percent DO Saturation Criteria

DO Concentrations (mg/L)	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**
Stateline to Scott River—90% October 1 through March 31 and 85% April 1 through September 30												
Stateline	10.4	9.6	8.5	7.6	7.0	6.3	6.3	6.4	6.9	7.8	9.5	10.6
Downstream Copco Dam	10.4	9.6	8.5	7.6	6.9	6.3	6.3	6.4	6.9	7.8	9.5	10.6
Downstream Iron Gate Dam	10.8	9.9	8.8	7.8	7.1	6.5	6.5	6.5	7.1	8.1	9.7	10.9
Upstream Shasta River	10.8	10.0	8.9	7.9	7.1	6.6	6.4	6.4	7.1	7.9	9.6	10.8
Downstream Shasta River	10.8	10.1	9.0	7.9	7.2	6.7	6.5	6.5	7.2	8.0	9.7	10.9
Upstream Scott River	10.9	10.2	9.1	8.1	7.2	6.7	6.4	6.5	7.1	7.9	9.8	10.9
Scott River to Hoopa—90% all year												
Downstream Scott River	10.8	10.2	9.3	8.7	7.9	7.3	6.9	6.9	7.6	8.0	9.8	10.9
Seiad Valley	10.9	10.2	9.3	8.8	7.8	7.2	6.9	6.9	7.5	7.9	9.9	10.9
Upstream Indian Creek	11.0	10.3	9.4	8.9	8.0	7.3	7.0	7.0	7.5	7.9	9.9	10.8
Downstream Indian Creek	11.0	10.3	9.5	9.0	8.1	7.4	7.0	7.0	7.6	8.0	9.9	10.8
Upstream Salmon River	11.2	10.6	9.8	9.3	8.4	7.5	7.2	7.2	7.7	8.2	10.0	11.0
Downstream Salmon River	11.1	10.6	9.9	9.4	8.5	7.6	7.2	7.2	7.7	8.2	10.0	10.9
Hoopa to Turwar—90% September 1 through May 31 and 85% June 1 through August 31												
Hoopa	11.0	10.6	10.0	9.5	8.5	7.2	7.0	6.9	7.8	8.3	10.1	11.0
Upstream Trinity River	11.0	10.6	10.0	9.5	8.5	7.2	7.0	6.9	7.8	8.3	10.0	11.0
Downstream Trinity River	10.9	10.6	9.9	9.5	8.6	7.4	7.1	7.0	7.9	8.4	10.0	10.9
Youngsbar	10.9	10.6	9.9	9.5	8.7	7.4	7.1	7.0	7.9	8.4	10.0	10.9
Turwar	10.9	10.5	9.9	9.5	8.6	7.2	6.9	6.8	7.6	8.1	9.8	10.8
Upper and Middle Estuary- 90% November 1 through May 31, 85% September 1 through October 31 and June 1 through July 31, 80% August 1 through August 31												

DO Concentrations (mg/L)	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Upper Estuary	10.9	10.6	10.1	9.5	8.6	7.3	7.1	6.7	7.6	8.0	10.0	10.7
Middle Estuary	10.9	10.6	10.1	9.6	8.6	7.3	7.2	6.8	7.8	8.2	10.1	10.8
Lower Estuary—Narrative Objective												

The goal in choosing the appropriate set of percent DO saturation criteria for the mainstem Klamath River is to provide maximum protection of the beneficial uses, particularly the rare, threatened, and endangered aquatic species. Simultaneously, criteria must be implementable and reasonably accommodate natural inter-annual variation and other uncontrollable influences.

To accomplish these goals, then, Alternative 3 is presented in Table 7.5. The proposal is based on the simulation of *natural* background DO data (T1BSR) and accommodates 24-hour DO datasets. It also reflects the improvement in DO conditions that naturally occurs during the spawning season from late fall through early spring. Finally, it is intended as a means of balancing the need to establish maximum resource protection and simultaneously ensure that the objectives reasonably accommodate inter-annual variation.

Table 7.5 Alternative 3 Summary

Location	**Percent DO Saturation based on natural receiving water temperatures**	**Time period**
Stateline to Scott River	90%	October 1 through March 31
	85%	April 1 through September 30
Scott River to Hoopa	90%	Year round
Hoopa to Turwar	90%	September 1 through May 31
	85%	June 1 through August 31
Upper and Middle Estuary	80%	August 1 through August 31
	85%	September 1 through October 31 and June 1 through July 31
	90%	November 1 through May 31
Lower Estuary	For the protection of estuarine habitat (EST), the dissolved oxygen content of the Lower Klamath Estuary shall not be depressed to levels adversely affecting beneficial uses as a result of controllable water quality factors.	

Alternative 3 is implemented by calculating the corresponding DO concentration resulting from a given percent DO saturation using site-specific barometric pressure, site-specific salinity, and an estimate of site-specific natural temperatures as derived from the T1BSR run of the *Klamath TMDL model.* Staff envision the future possibility that new data may be developed or the modeling tool improved in such a way as to improve the estimate of natural receiving water temperatures. In this case, an opportunity for public review should be offered and use of improved or updated estimates of natural receiving water temperatures first reviewed and approved by the Executive Officer.

For the purpose of this assessment, site-specific natural temperatures are estimated by the *Klamath TMDL model*. Table 7.4 presents the minimum monthly DO concentrations resulting from Alternative 3 as calculated by the *Klamath TMDL model.*

7.4 Comparison of Alternatives

To identify the most protective and appropriate alternative, staff has had to develop a means of comparing Alternatives 1, 2a, 2b, and 3. This is made difficult by the fact that

Alternative 1 (No Change) is based on daytime DO samples while Alternatives 2a, 2b, and 3 are based on 24-hour simulated data. Because of the diel pattern of DO fluctuation, with daily minima generally occurring during the night, Alternative 1 is not reasonably compared to the other alternatives.

Further, as described in Chapter 4.0, Alternative 1 is not consistently achievable, particularly during the summer months at higher elevations when temperatures exceed 16 ºC and at lower elevations when temperatures exceed 22 ºC (see Figure 7.1). This is due simply to conditions of barometric pressure and temperature and the effect these parameters have on the ability of water to hold oxygen in solution (see Chapter 4). A review of Table 6.2 further indicates that under natural conditions from June to September, the daily minimum DO concentration is less than 8.0 mg/L at many locations. During the months of July and August the daily minimum DO *throughout* the mainstem ranges from 6.9 to 7.9 m/L, never reaching 8.0 mg/L.

Tetra Tech has calculated the DO concentrations resulting from Alternatives 2a, 2b, and 3 when using simulated data generated for the hours of 9am to 5pm, only—excluding the nighttime simulations. By this means, Alternatives 1, 2a, 2b, and 3 can be directly compared to one another. This comparison is necessary to determine which of the alternatives offers the greatest overall water quality protection, particularly with respect to the life cycle requirements of sensitive salmonid species. One must keep in mind that Table 7.6 is for comparison purposes, only. With respect to Alternatives 2a, 2b, and 3, it does not represent the actual proposed criteria. In addition,with respect to Alternative 1, the 8.0 mg/L DO required downstream of Iron Gate Dam is unachievable at higher elevations during the month of June and throughout the mainstem during the months of July and August.

For ease of presentation, Table 7.6 does not include all listed sampling locations. A subset of locations has been chosen as representative of the conditions found throughout the mainstem. These locations include: Stateline, downstream of Iron Gate Dam, downstream of the Scott River, downstream of the Trinity River, and the Middle Estuary.

In Table 7.6 the Alternative 1 objective of 8.0 mg/L DO downstream of Iron Gate Dam is crossed out for some of the summer months because they have been demonstrated to be unachievable solely due to the effects of barometric pressure and natural temperatures. The resulting comparison of the 4 alternatives strongly recommends Alternative 3 as the most protective alternative, overall. Table 7.6 demonstrates that during the summer, Alternative 1 requires higher DO concentrations than do Alternatives 2a, 2b, and 3 during some months at some locations with DO concentrations ranging from 0.1 to 0.7 mg/L higher and on one occasion, 0.9 mg/L higher. Table 7.6 also demonstrates, however, that the protection offered by Alternative 3 during the salmonid spawning and incubation period is far superior to that offered by any of the other alternatives. For this reason, staff recommends the adoption of Alternative 3 as the recalcualtion of the SSOs for DO in the Klamath River.

Alternative 3 offers one additional benefit over the other alternatives. DO saturation is based on the relationship of barometric pressure, temperature, and salinity. As such, a percent saturation criteria inherently incorporates temperature, a closely related water quality parameter. Alternative 3 uniquely calls for the implementation of the percent DO saturation criteria using estimates of *natural* temperature, rather than existing temperatures as is more common. Using natural temperatures as the basis for calculating the DO concentrations associated with the given percent DO saturation criteria ensures that the resulting concentrations more closely mimic natural DO conditions than would

Table 7.6 Comparison of Alternatives 1, 2a, 2b, and 3, DO Minimum Concentration Values for the Hours of 9am to 5pm																				
	Stateline (mg/L)				**Downstream Iron Gate Dam (mg/L)**				**Downstream Scott River (mg/L)**				**Downstream Trinity River (mg/)**				**Middle Estuary (mg/L)**			
Alt	**1**	**2a**	**2b**	**3**	**1**	**2a**	**2b**	**3**	**1**	**2a**	**2b**	**3**	**1**	**2a**	**2b**	**3**	**1**	**2a**	**2b**	**3**
Jan	7.0	6.2	6.2	10.4	8.0	6.2	6.2	10.8	8.0	6.2	6.6	10.8	8.0	6.2	6.8	10.9	8.0	6.8	6.8	10.9
Feb	7.0	6.2	6.2	9.6	8.0	6.2	6.2	9.9	8.0	6.2	6.6	10.2	8.0	6.2	6.8	10.6	8.0	6.8	6.8	10.6
Mar	7.0	6.2	6.2	8.5	8.0	6.2	6.2	8.8	8.0	6.2	6.6	9.3	8.0	6.2	6.8	9.9	8.0	6.8	6.8	10.1
Apr	7.0	6.2	6.2	7.6	8.0	6.2	6.2	7.3	8.0	6.2	6.6	8.7	8.0	6.2	6.8	9.5	8.0	6.8	6.8	9.6
May	7.0	6.2	6.2	7.0	~~8.0~~	6.2	6.2	7.1	8.0	6.2	6.6	7.9	8.0	6.2	6.8	8.6	8.0	6.8	6.8	8.6
Jun	7.0	6.2	6.2	6.3	~~8.0~~	6.2	6.2	6.5	~~8.0~~	6.2	6.6	7.3	8.0	6.2	6.8	7.4	8.0	6.8	6.8	7.3
Jul	7.0	6.2	6.2	6.3	~~8.0~~	6.2	6.2	6.5	~~8.0~~	6.2	6.6	6.9	8.0	6.2	6.8	7.1	~~8.0~~	6.8	6.8	7.2
Aug	7.0	6.2	6.2	6.4	~~8.0~~	6.2	6.2	6.5	~~8.0~~	6.2	6.6	6.9	~~8.0~~	6.2	6.8	7.0	~~8.0~~	6.8	6.8	6.8
Sep	7.0	6.2	6.2	6.9	~~8.0~~	6.2	6.2	7.1	8.0	6.2	6.6	7.6	8.0	6.2	6.8	7.9	8.0	6.8	6.8	7.8
Oct	7.0	6.2	6.2	7.8	8.0	6.2	6.2	8.1	8.0	6.2	6.6	8.0	8.0	6.2	6.8	8.4	8.0	6.8	6.8	8.2
Nov	7.0	6.2	6.2	9.5	8.0	6.2	6.2	9.7	8.0	6.2	6.6	9.8	8.0	6.2	6.8	10.0	8.0	6.8	6.8	10.1
Dec	7.0	6.2	6.2	10.6	8.0	6.2	6.2	10.9	8.0	6.2	6.6	10.9	8.0	6.2	6.8	10.9	8.0	6.8	6.8	10.8

occur using existing temperatures, in most cases. Further, using an estimate of natural temperatures as the basis for calculating DO concentration allows for consideration of the effects of climate change. If convincing data is developed which confirms a rise in natural temperatures due to the effects of climate change, then consideration can be given to adjusting the estimate of natural temperatures upon which the percent saturation criteria are based. Staff do not intend to pre-judge whether or not a rise in natural temperature due to climate change will be considered natural but, only mean to acknowledge the flexibility of this approach, as compared to others, for dealing with the effects of climate change. For example, if the percent saturation criteria were applied based on existing temperatures, no specific consideration would be given to climate change and all increase in natural temperature would automatically adjust the DO objective without executive or public review.

7.5 Proposed Alternative

Staff proposes the adoption of Site Specific Objectives (SSOs) for the Klamath River mainstem, to replace the existing SSOs for DO in Table 3-1 of the Basin Plan, as given in Table 7.5. Staff further proposes that the *Klamath TMDL model* as described in the Klamath TMDL Staff Report be used to determine natural receiving water temperatures with which to calculate the DO concentrations associated with the given percent saturation criteria. Finally, staff propose that a clause be included in the Basin Plan that allows for the re-evaluation of natural temperatures as new data or modeling improvements become available, but only after public review and if the Executive Officer finds that re-evaluation is warranted. It must be understood that the proposed alternative will be applied to the maximum extent allowed by law. To the extent that the State lacks jurisdiction, the proposed SSO is extended as a recommendation to the applicable regulatory authority. Proposed Basin Plan Amendment language is presented in Appendix A of this Staff Report.

CHAPTER 8.
REGULATORY REQUIREMENTS

The protection of water quality in the State of California is guided by the Porter-Cologne Water Quality Control Act as amended. Section 13000 states that

> "The Legislature finds and declares that the people of the state have a primary interest in the conservation, control and utilization of the water resources of the state, and that the quality of all the waters of the state shall be protected for use and enjoyment by the people of the state."

To this end, nine Regional Water Quality Control Boards were established and each created water quality control plans with which to regulate water quality within their respective regions. The first comprehensive water quality control plans were approved for the North Coast Region in 1975, including a the Klamath Basin Plan for all waters draining to the Pacific Ocean from the mouth of the Klamath River north to the Oregon border and a separate North Coast Basin Plan for those waters draining to the Pacific Ocean south to San Antonio Creek at the Sonoma-Marin County boundary. The Water Quality Control Plan for the North Coast Region (Basin Plan), combining the Klamath and North Coast Basin Plans into one document, was approved in 1988. A triennial review of the Basin Plan is required, resulting in periodic updates and alterations.

As part of the 2007 Triennial Review, the Regional Board directed staff to develop revised water quality objectives (objectives) for dissolved oxygen (DO). To this end, a draft Staff Report has been developed, resulting from CEQA scoping and scientific peer review. Staff intends to bring a final report and proposed Basin Plan Amendment to the Regional Board for their consideration in late 2010. This Staff Report has been developed to support a proposed amendment of the site-specific DO objectives to the Klamath River mainstem, only.

Chapter 5.0 describes the existing Klamath River Site Specific Objectives (SSO) for DO currently contained in Table 3-1 of the Basin Plan. In this chapter, staff concludes that the existing SSOs for DO in the Klamath are established at levels too high to represent actual daily minima. This is because they are based on data collected during day light hours only. In fact, they are higher than is physically possible at all locations and during all times of the year, based on conditions of barometric pressure, temperature, and salinity. Staff also concludes that the human activities in the basin prior to and including the 1950s and 1960s were such that the pattern and range of DO in the basin was very likely altered from natural conditions. In particular, the presence of dams in the upper basin likely perpetuates downstream the effects of natural organic and nutrient loading from Upper Klamath Lake which would otherwise have been assimilated in the reaches above Iron Gate Dam.

Chapter 6.0 describes the new information available as a result of the Klamath TMDLs being developed to assess and control impairments due to elevated nutrients, temperatures, and organic enrichment/low DO. As described in Chapter 6.0 of this Staff

Report, a general assessment of DO saturation, based on the range of barometric pressures and temperatures observed in the basin indicates that at summer temperatures, the existing 8.0 mg/L DO requirement downstream of Iron Gate Dam is physically impossible to achieve. This is the case for an assumed 100% DO saturation and even more pronounced at an assumed 85% DO saturation, as is expected in a healthy, free-flowing river with moderate levels of organic and nutrient loading.

The *Klamath TMDL models* simulate, among other things, hourly DO conditions throughout the length of the mainstem Klamath River. The T1BSR run of the *Klamath TMDL models* unequivocally demonstrate that during the summer months, in various reaches of the mainstem, DO conditions do not meet the existing DO objectives under natural conditions. This is an indication that the existing DO objectives are ill-suited for comparison to data collected using modern tools for sampling and data analysis. In the 1950s and 1960s, day time samples were collected as grab samples and analyzed in the field as were compliance samples. Compliance samples can now be collected with datasonde data probes, however, which allow for 24 hours of sampling. These compliance data can not usefully be compared to the existing day time DO objectives.

Chapter 7.0 describes several alternatives for recalculating the SSOs for DO in the Klamath River mainstem. The alternatives include: 1) No Action, 2) recalculation of existing SSOs using simulated concentration data produced by the T1BSR run of the *Klamath TMDL models*, and 3) recalculation of existing SSOs using simulated percent saturation data produced by the T1BSR run of the *Klamath TMDL models.* Staff recommends the adoption of Alternative 3, creating a new approach to DO compliance by applying a percent DO saturation criteria based on an estimate of natural temperatures. By applying a percent DO saturation requirement based on natural temperatures, the objective reflects natural DO conditions in the basin. Using percent DO saturation (based on natural temperatures) as the metric ensures that it is physically possible to achieve, unlike a static DO concentration requirement that may not be achievable at some elevations and/or at some temperatures. And, not only does a percent DO saturation requirement (based on natural temperatures) ensure a given minimum DO condition, it also ensures a normal pattern of DO fluctuation, including elevated DO in the winter when salmonid eggs are incubating.

Chapter 8.0 provides an assessment of the proposed alternative to confirm that it meets the following requirements:

1. Section 13241 of Porter-Cologne Water Quality Act
2. State and Federal antidegradation requirements
3. Protection of the Hoopa Valley Tribal Waters downstream of California waters.

In addition, Chapter 8.0 provides a discussion of how the proposed alternative is to be applied in the reservoir portions of the Klamath River mainstem. This later part is described in detail in the Klamath TMDL Staff Report.

8.1 Section 13241 of Porter Cologne Water Quality Act

Section 13241 of the Porter Cologne Water Quality Act requires that each regional board establish water quality objectives to ensure the reasonable protection of beneficial uses and the prevention of nuisance, recognizing that it may be possible for the quality of water to be changed to some degree without unreasonably affecting beneficial uses. Section 13241 lists the following factors for consideration:

a. Past, present and probable future beneficial uses of water;
b. Environmental characteristics of the hydrographic unit under consideration, including the quality of water available thereto;
c. Water quality conditions that could reasonably be achieved through the coordinated control of all factors which affect water quality in the area;
d. Economic considerations;
e. The need for developing housing within the region; and,
f. The need to develop and use recycled water.

8.1.1 Past, Present, and Probable Future Beneficial Uses of Water

The past, present and probable future beneficial uses of Klamath River water are listed in Section 2 of the Basin Plan and summarized in Chapter 5.0 of this Staff Report. The mainstem Klamath River is listed as providing benefit for both human uses (e.g. MUN, AGR, IND, PRO, NAV, POW, REC1, REC2, COMM, SHELL, AQUA, and CUL) and environmental uses (e.g., GWR, FRSH, WARM, COLD, WILD, RARE, MAR, MIGR, SPWN, and EST). With respect to DO, the most sensitive beneficial uses are those associated with salmonids threatened with extinction.

Staff considered the needs of past, present and probable future beneficial uses of water in the following ways. First, staff determined the beneficial use most sensitive to DO conditions so as to ensure a conservative approach to the protection of beneficial uses. As above, staff determined that the spawning and incubation of salmonids forms the most sensitive of the mainstem Klamath uses.

Second, staff identified the DO requirements of all fish species at risk in the Klamath River mainstem; focusing on those of salmonids. Chapter 3.0 describes the DO requirements of the fish species evaluated.

Third, staff compared simulated natural DO conditions to the requirements of salmonids and determined that under natural conditions the Klamath River has never consistently provided ideal DO conditions, particularly during hot summer months. The *Klamath TMDL model* is a tool developed over the course of many years by an interdisciplinary and intergovernmental team of representatives of two States and two USEPA regions, including their consultant. The tool has been calibrated, validated, peer reviewed (multiple times), and reviewed by the public. It is this tool that staff has relied on to determine natural DO conditions under a scenario absent anthropogenic influences. Staff is confident that the *Klamath TMDL model* provides simulated data of sufficient quality to reasonably represent natural conditions in the Klamath River. (See Tetra Tech 2009, Appendix 6 of the Klamath TMDL Staff Report for a more detailed discussion of this topic).

Fourth, to ensure the best possible DO regime, for the benefit of threatened and endangered salmonids, staff proposed the adoption of DO objectives based on *natural conditions*. Specifically, staff proposed the adoption of percent DO saturation objectives based on natural temperatures as the method by which to establish natural DO conditions. This approach ensures that not only reasonable minimum DO conditions are maintained, but the natural seasonal pattern of DO fluctuation is also maintained. This is important to the protection of salmonids because spawning and incubation requires DO concentrations higher than other life cycle stages. And, these uses occur during the late fall, winter, and early spring when DO naturally increases with decreasing temperatures. The proposed SSO for DO incorporates the spawning and incubation DO needs of salmonids by applying a metric that more accurately depicts the natural seasonal pattern and ensures its preservation.

Fifth, in Chapter 6.0 staff determined that ideal salmonid DO conditions (i.e., "no production impairment" as defined by USEPA 1986) have never been consistently met, even under natural conditions. To determine how salmonids once thrived in the Klamath River basin, despite periodically moderate DO, staff further evaluated the spawning habits of salmonids. Staff determined that salmonids do indeed spawn in the mainstem; but, by far the largest majority of salmonids make more use of tributaries for spawning, particularly the large tributaries such as the Trinity, Salmon, Scott and Shasta rivers. Further, salmonids historically made considerable use of the tributaries of the upper basin which are now blocked from use by a series of dams, Iron Gate Dam being the first encountered.

These facts have led staff to develop two hypotheses. One hypothesis is built upon the fact that incubating salmonid embryos and alevin require a greater concentration of DO in the water column than do other life stages. This is because they reside in the gravels which, depending on the degree of sedimentation, sediment oxygen demand, and other factors, may receive only a percentage of the DO contained in the water column. Thus, to meet their DO needs for growth and development in the intergravel environment, DO in the water column must be higher. USEPA (1986) argues that DO in the water column must be 3 mg/L higher than that required in the intergravel environment to protect incubating salmonids. Others argue that the factor more accurately ranges from 1-6 mg/L. Still others argue that the factor difference between the water column and intergravel environment is best determined on a site-by-site basis.

Using USEPA (1986) guidance, staff compared the DO needs of incubating salmonids to simulated DO conditions during the spawning and incubating season and determined that a daily minimum of 9.0 mg/L was reasonably met under natural conditions; but, a weekly average of 11.0 mg/L was not. Staff hypothesizes that under natural conditions, sedimentation, especially during the late fall through early spring, may not historically have posed a significant problem in the mainstem Klamath. As such, the transfer of oxygen from the water column to the intergravel environment may have been relatively efficient. Unfortunately, neither historic nor current intergravel DO data exists for the Klamath River mainstem with which to assess the validity of this hypothesis. For the

protection of the beneficial uses of intergravel waters, however, the Basin Plan includes several narrative objectives associated with the settling of suspended material, including sediment. For example, the Basin Plan requires that "Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses." The Basin Plan also requires that "Water shall not contain substances in concentrations that result in deposition of material that causes nuisance or adversely affect beneficial uses." In addition, it reads "The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses." Thus, whatever the validity of staff's hypothesis regarding historic mainstem sedimentation, the Basin Plan provides adequate current protection.

With respect to staff's second hypothesis, there appears to be general agreement that the tributaries to the Klamath River have played a critical role in the historic success of salmonids in the Klamath River basin (NRC 2004). Staff hypothesize that the loss of access to tributaries upstream of Iron Gate Dam, as well as the degradation of water quality and habitat in tributaries downstream of Iron Gate Dam have severely impacted the ability of salmonid populations to rebound from other assaults such as overfishing, disease, drought, water withdrawals, water impoundment, and loss of mainstem habitat, to name a few. The tributaries have offered refuge.

In addition to the TMDLs for the Klamath River, of which this Staff Report is a part, the Regional Board and/or USEPA has also adopted TMDLs for several of the main tributaries to the Klamath River, including: the Lower Lost River, Shasta River, Scott River, Salmon River, Trinity River, and South Fork Trinity River. The implementation of these TMDLs will result in the improvement of tributary water quality conditions so as to better support the salmonid populations that make use of them. In the mean time, however, staff believes that known, existing salmonid refugia should be afforded special protection as a way of more immediately providing for the needs of these threatened and endangered species. To that end, Chapter 6.0 of the Klamath TMDL Staff Report describes the plan to implement the Klamath TMDL and SSOs for DO in the Klamath River. The implementation plan includes the proposed protection measures in and around known thermal refugia. The known refugia are named and mapped.

Finally, staff have conducted an environmental analysis of the likely impacts associated with the potential means by which landowners/dischargers in the Klamath River watershed will achieve compliance with the plan for implementing the Klamath River TMDLs and the recalculated SSOs for DO. This analysis was conducted in compliance with the requirements of CEQA and are included as Chapter 9 of the Klamath TMDL Staff Report of which this staff report is a part. The CEQA analysis is incorporated as a part of the DO Staff Report by reference. The CEQA analysis considers the beneficial uses of the Klamath River in the context of determining whether or not any significant environmental impacts are likely.

In summary, staff has considered the past, present and probable future beneficial uses of the Klamath River mainstem by proposing SSOs for DO designed to protect the most

sensitive of the listed beneficial uses-- salmonids. The proposed SSOs for DO protect salmonids by protecting not the anthropogenically altered DO conditions in the basin, but the natural DO conditions. The proposed SSOs for DO do this by approximating natural DO conditions through the application of percent DO saturation criteria based on natural temperatures. This is a unique approach to the use of percent DO saturation criteria that serves to better associate the protection of DO conditions with the protection of temperature conditions. Further, to ensure immediate protection of salmonids, staff also proposes—as described in the Klamath TMDL Staff Report of which this is a part—the adoption of protective measures in known thermal refugia. This further cements the relationship between DO and temperature.

8.1.2 Environmental characteristics of the hydrographic unit

Section 13241 of the Porter Cologne Act requires when developing water quality objectives that the Regional Board consider the environmental characteristics of the hydrographic unit under consideration, including the quality of water available thereto. This Staff Report describes the site specific assessment that is the basis for the proposed alternative for the recalculation of the SSOs for DO in the mainstem Klamath. Chapter 2.0 describes the physical setting of the Klamath River basin. Chapter 3.0 describes the fishes of the Klamath region. Chapter 4.0 provides a general discussion of DO. Chapter 5.0 describes the existing water quality objectives for DO in the Klamath River. Chapter 6.0 describes new site specific environmental data and information associated with the Klamath River basin. This includes the development and implementation of the *Klamath TMDL model* which assesses on an hourly basis the effects of various input parameters at thousands of points throughout the river from Upper Klamath Lake in Oregon to the Pacific Ocean. Further, this Staff Report is a companion to the Klamath TMDL Staff Report, an even more thorough and detailed analysis of the environmental characteristics of the Klamath River basin and its water quality.

Staff believes the environmental characteristics of the Klamath River hydrographic unit have been thoroughly and completely considered and form the foundation for the proposed action. In addition, staff believes that the analysis of the environmental characteristics of the Klamath River basin as represented by this Staff Report and the Klamath TMDL Staff Report is significantly broader and deeper than that represented by the existing SSOs for DO in the mainstem Klamath River. This is due to an improvement in monitoring and analytical tools which allows to staff to better represent the diel and seasonal cycling of DO and to better simulate alternate conditions, such as natural conditions.

8.1.3 Water quality conditions that could reasonably be achieved through the coordinated control of all factors which affect water quality in the area;

Section 13241 of the Porter Cologne Act requires when developing water quality objectives that the Regional Board consider the water quality conditions that could reasonably be achieved through the coordinated control of all factors which affect water quality in the area. This Staff Report and the associated Klamath TMDL Staff Report describe the relationships among several related parameters and propose a coordinated approach to their control.

This Staff Report considers the relationship between DO and water temperature as well as DO and sedimentation. It also considers the relationship between DO impairment and protection of refugia. The proposed SSO for DO in the mainstem Klamath River relates DO and temperature by establishing a percent DO saturation criteria that is calculated based on an estimate of natural temperatures. This is a unique approach to the application of percent DO saturation as a water quality objective which is otherwise more often calculated based on existing temperatures. But, staff proposes the use of percent saturation based on natural temperatures as a technique for estimating natural DO conditions because the simulation of natural temperatures is viewed as a much easier task than the simulation of DO conditions (Tetra Tech 2009). Further, DO concentration varies inversely to fluctuations in temperature and thus must be viewed together to ensure an accurate understanding of the water quality dynamics and appropriate implementation measures.

In addition, this Staff Report describes the importance of thermal refugia to the success of salmonids in the Klamath River basin. Thermal refugia, particularly in the tributary streams, provides a place for salmonids, otherwise stressed by mainstem water quality conditions, to find respite from environmental stress, including stress due to low DO conditions. As a companion to the proposed recalculation of the SSOs for DO in the mainstem Klamath River, staff has also proposed the adoption of protective measures in thermal refugia, including known mapped refugia. More discussion of this is included in the Klamath TMDL Staff Report, Chapter 6.0.

The Klamath TMDL Staff Report addresses several other related parameters, assesses the degree of water quality impairment, proposes point and nonpoint source load reductions, and a plan for implementing the reductions. The pollutants of concern include: temperature, dissolved oxygen, nutrient and microcystin.

Chapter 6.0 of the Klamath River TMDL Staff Report describes a plan for the implementation of measures necessary to control the discharge of pollutants responsible for temperature, DO, nutrient and microcystin impairment. The implementation plan contained in the Klamath River TMDL Staff Report is incorporated by reference into this Staff Report and includes the actions staff believes are necessary to control DO impairment.

Finally, the Basin Plan already contains several other numeric and narrative objectives which are applied to the protection of water quality in coordination with one another. Most notable with respect to salmonids and the issues associated with water quality in the Klamath River are the objectives designed to protect against harmful suspended material, settleable material, biostimulatory substances, sediment, turbidity, bacteria, temperature, toxicity, and pesticides.

Staff believes a thorough and complete assessment of the related parameters of concern to DO conditions in the mainstem Klamath River has been conducted and described in this Staff Report. More detail is provided in the Klamath River TMDL Staff Report, of which this Staff Report is a part. Staff further believes that the implementation plan contained in Chapter 6.0 of the Klamath River TMDL Staff Report describes all the actions necessary to ensure achievement of the proposed DO objective and control of the other related parameters.

8.1.4 Economic considerations

Section 13421 of the Porter Cologne Act requires when developing water quality objectives that the Regional Board consider economic factors. Chapters 6, 9 and 10 of the Klamath TMDL Staff Report consider two proposed actions: adoption of a Basin Plan Amendment to incorporate the Klamath TMDLs and adoption of a Basin Plan Amendment to update the SSOs for DO for the mainstem Klamath River. As such, Chapters 6, 9 and 10 of the Klamath TMDL Staff Report are incorporated here by reference.

Chapter 6 of the Klamath TMDL Staff Report describes the policies; including a waste discharge prohibition staff believes are necessary to implement the proposed TMDL load allocations and recalculated SSOs for DO. Chapter 9 of the Klamath TMDL Staff Report presents the California Environmental Quality Act (CEQA) analysis, including an analysis of the potential means by which landowners and land managers may comply with the load allocations, recalculated SSOs for DO, and proposed policies and prohibitions. Chapter 10 of the Klamath TMDL Staff Report presents an analysis of the costs associated with the potential means of compliance.

Chapter 10 of the Klamath TMDL Staff Report, incorporated here by reference, highlights the potential costs associated with each of the potential means of compliance but does not present a total cost. A total cost was deemed impossible to calculate because of the unknown condition of much of the landscape within the Klamath River watershed. Many of the potential compliance measures are measures that may be required by other regulatory programs, as well. And, many of the potential compliance measures are measures typically identified in TMDLs for the control of sediment, temperature, nutrients and DO. Many of these measures are earmarked by state and federal grant programs for full or partial government funding.

The identification of the potential compliance measures necessary for PacifiCorp to achieve compliance with the SSOs for DO and TMDLs were identified in work conducted by PacifiCorp, including their own pricing of these measures. In some instances, PacifiCorp has through other negotiations made obligations with respect to the funding of these measures and/or their testing.

As such, staff concludes that the costs associated with the implementation of the SSOs for DO are reasonable when compared with the water quality benefits that will ensue and generally represent the costs associated with good land stewardship.

8.1.4.1 <u>Point Source Discharges</u>

The Basin Plan prohibits the point source discharge of waste to the Klamath River except as stipulated by the Thermal Plan, the Ocean Plan, and the action plans and policies contained in the Point Source Measures section of the Basin Plan. Under the "Policy on the Regulation of Fish Hatcheries, Fish Rearing Facilities, and Aquaculture Operations" (Hatchery Policy), an exception to this prohibition has been granted to the California Department of Fish and Game and PacifiCorp for the operation of the Iron Gate Hatchery. The Hatchery Policy recognizes the potential for beneficial uses to be enhanced by the operation of fish hatcheries.

The Hatchery Policy allows for discharge from a fish hatchery as long as the discharge does not adversely impact beneficial uses, does not include wastes generated from cleaning activities, and does not include detectable levels of disease treatment and control chemicals. A permit can be issued depending on the characteristics of the discharge, and in the case of the Iron Gate Hatchery is issued as NPDES Permit No. CA0006688. The Iron Gate Hatchery is the only permitted point source discharge to the Klamath River within the boundaries of State of California.

NPDES Permit No. CA 0006688 was last issued in 2000 and is overdue for renewal. Issuance of a renewed permit has been delayed to ensure that a new permit is compliant with the Hatcheries Policy and includes the discharge limitations necessary to comply with the Klamath River TMDLs and recalculated SSOs for DO. The Iron Gate Hatchery currently treats water released from the fish production ponds in a set of two settling ponds which discharge directly to the Klamath River below Iron Gate Dam and immediately below Bogus Creek. The current permit is designed to achieve an ambient DO of 7.0 mg/L as a daily minimum. The proposed recalculated SSOs for DO at that location range from 6.3 mg/L during the summer to 10.6 mg/L during the winter. Monitoring data for 2008 indicates upstream and downstream ambient DO conditions as shown in Table 8.1

These data indicate that the Iron Gate Hatchery discharge may be responsible for a reduction in ambient DO during the months of February, May, August, and September as shown by a lower DO downstream of the discharge as compared to that measured upstream of the discharge. On the other hand, the Iron Gate Hatchery discharge may be responsible for an increase in ambient DO during the months of January, March, April, and June as shown by a higher DO downstream of the discharge as compared to that measured upstream of the discharge. Ambient Klamath River water upstream and downstream of Iron Gate Dam, as shown by 2008 monitoring data, does not meet proposed SSOs for DO during the months of October through January. Downstream DO conditions do not meet proposed SSOs for DO during the month of September, as well.

Table 8.1: DO Monitoring Results Upstream and Downstream of the Iron Gate Hatchery Discharge for the Year of 2008.

2008	Proposed SSO for DO Downstream of Iron Gate Dam (mg/L)	Klamath River Upstream of Iron Gate Hatchery (mg/L)	Klamath River Downstream of Iron Gate Hatchery (mg/L)
January	10.8	9.2	9.5
February	9.9	11.4	10.8
March	8.8	12.8	13.0
April	7.8	13.2	15.3
May	7.1	10.55	8.72
June	6.5	10.96	11.14
July	6.5	9.47	9.44
August	6.5	7.36	6.65
September	7.1	7.6	6.34
October	8.1	6.15	6.3
November	9.7	6.0	6.11
December	10.9	6.01	6.23

Light grey shaded cells indicate upstream ambient waters that do not meet proposed SSOs for DO. Dark grey shaded cells indicate downstream ambient waters that do not meet proposed SSOs for DO.

Staff has evaluated the monitoring data of only one year (e.g., 2008). Renewal of the NPDES permit will require a thorough analysis of the monitoring data from additional years. From this one dataset, however, it appears that some additional treatment may be necessary to achieve compliance during the month of September. It also appears that an evaluation of the role of Iron Gate Dam on the ambient DO conditions downstream during the months of October through January is warranted, including consideration of the effects of water withdrawals by the Hatchery from the nutrient-rich waters of the reservoir's hypolimnion.

As described in Chapter 10 of the Klamath TMDL Staff Report, the California Department of Fish and Game and PacifiCorps will have to conduct an engineering study to determine what additional treatment will be necessary to meet new permit limits designed to attain TMDL allocations and recalculated SSOs for DO. Until that time, any estimate of the cost of compliance would be unreasonably speculative. PacifiCorps, however, has signed an agreement by which it will provide funding to the Hatchery, perhaps including some portion of the cost of treatment upgrade.

8.1.4.2 Nonpoint Source Discharges

The nonpoint source discharges of concern to the Klamath TMDLs and proposed SSOs for DO include:

- Modifications to water quality resulting from the Klamath Hydroelectric Project
- Road construction and maintenance activities
- Grazing
- Irrigated agriculture
- Timber harvest activities

The economic analysis (Chapter 10 of the Klamath TMDL staff repot) considers the costs associated with each of these activities. It also considers the costs associated with the proposed prohibition against discharge in the vicinity of thermal refugia. Finally, it highlights several public funding sources, as well as funding associated with other similar programs such as the Recovery Strategy for Coho Salmon. Staff believes Chapter 10 of the Klamath TMDL Staff Report presents information sufficient to satisfy the requirements of Section 13421 of the Porter Cologne Act.

8.1.5 Housing

Section 13421 of the Porter Cologne Act requires when developing water quality objectives that the need for developing housing within the region be considered. The 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 is Klamath Falls in Oregon (19,462 people in 2000) 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. The largest blocks of private ownership are agricultural areas in the upper Klamath watershed and agricultural and timber properties in the Shasta and Scott Valleys and adjacent areas of the mainstem. 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 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 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. The Klamath River basin is primarily a rural river basin.

Population growth and the need for housing are of limited concern in the Klamath River basin. As described in Chapter 9 of the Klamath TMDL Staff Report (CEQA Analysis) none of the actions required by the adoption of the Klamath TMDL or the recalculated SSOs for DO on the mainstem Klamath River will result in displacement of existing housing or the need for additional development.

In any event, the recalculation of the SSOs for DO in the mainstem Klamath does not impact the ability of entities to develop land in the basin for housing, if necessary. With the existing prohibition against the discharge of waste in the Klamath River, any discharge of organic or nutrient waste, such as point source domestic wastewater, must be discharged to land. Staff believes it has thoroughly considered the issue of housing in the development of the recalculated SSOs for DO in the mainstem Klamath River.

8.1.6 Recycled water

Section 13421 of the Porter Cologne Act requires when developing water quality objectives consideration of the need to develop and use recycled water. The existing prohibition against the discharge of waste to the Klamath River ensures as the baseline that any development be predicated on the development first of recycled water as a means of reducing the amount of land necessary for the treatment of discharged waste. With respect to the recalculation of the SSOs for DO specifically, one of the primary producers of organic and nutrient rich discharge to the Klamath River comes from agricultural activities. Chapters 6 and 9 of the Klamath TMDL Staff Report (Implementation Plan and CEQA Analysis, respectively) describe the required and likely actions necessary for the agricultural community to comply with the TMDL and recalculated SSOs for DO. These actions include development and use of recycled water, particularly the reuse of irrigation return flows to reduce water quality impacts.

Staff believes it has thoroughly considered the issue of recycled water in the development of the recalculated SSOs for DO in the mainstem Klamath River.

8.2 State and Federal Antidegradation Requirements

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.

8.2.1 State Antidegradation Resolution 68-16

While requiring the continued maintenance of existing high quality waters, Resolution 68-16 provides conditions under which a change in water quality is allowable. A change must:

- Be consistent with maximum benefit to the people of the state;
- Not unreasonably affect present and anticipated beneficial uses of water; and
- Not result in water quality less than that prescribed in water quality control plans or policies.

Table 7.6 provides a comparison of the daytime values associated with the three alternatives evaluated in the recalculation of the SSOs for DO. Alternative 1 is to leave the existing SSOs for DO as they are, including a footnote indicating their applicability during the daytime, only. Alternative 3—the proposed alternative—is to calculate natural DO concentrations based on given percent DO saturation criteria and estimates of natural temperature. In the comparison of criteria, one sees that the existing SSOs for DO provide a more protective DO concentration value during the summer months. But, for many of these months, the given concentration is unattainable simply due to conditions of barometric pressure, temperature and salinity and are therefore inappropriate. During the fall, winter, and spring, however, Alternative 3 provides significantly greater protection and this during the spawning and incubation period of the basin's most sensitive beneficial use. It is on this basis that Alternative 3 is proposed.

Staff argues the proposed recalculation of the SSOs for DO in the mainstem Klamath River provide greater protection to the beneficial uses than the existing SSOs for DO. Because of the ambiguous nature of the analysis during the summer months, however, staff believes it important to consider the three issues presented by Resolution 68-16 with respect to any change in water quality.

1). Staff believes that protecting the rare and threatened salmonids of the Klamath River is of maximum benefit to the people of the state. This is because of the inherent value of protection species from extinction. It is also because of the value of restoring a fishery which once supported an important cultural and commercial fishing use. As one of the State's largest salmon fisheries, impacts to the Klamath fisheries have State wide impacts.

2) Staff believes this action does not unreasonably affect the present and anticipated beneficial uses of water; in fact, it serves to better protect the beneficial uses of water.

3) Staff believes the water quality resulting from this action is greater than that prescribed in the existing water quality control plan, particularly in the fall, winter and spring when the most sensitive beneficial use requires greater DO conditions.

8.2.2 Federal Antidegradation Policy

The federal antidegradation policy is found at 40 CFR Section 131.12. The federal policy must be addressed whenever it is proposed to relax a standard (beneficial use or water quality objective) for surface water. As described above, staff believes that the recalculation of the existing SSOs for DO does not result in a relaxed standard but, in fact, results in an improved standard providing greater protection of beneficial uses, particularly the spawning and incubation of salmonids—the most sensitive beneficial use. During the summer months when the existing SSOs for DO are represented as higher than those associated with the proposed recalculated SSOs, many of these values are unattainable due simply to conditions of barometric pressure, natural temperature, and salinity. As such, they are inappropriate for use during that period. The proposed SSOs for DO, on the other hand, represent conditions that are achievable year round under natural conditions and represent the highest DO conditions physically possible for the mainstem.

8.3 Hoopa Valley Tribe's Water Quality Objectives for DO

The Hoopa Valley Tribe has a water quality control plan, approved by USEPA and implemented by the Tribe. With respect to DO, the Water Quality Control Plan for the Hoopa Valley Indian Reservation (Hoopa 2008) requires the following in the mainstem Klamath:

> *Water Column Dissolved Oxygen* –Klamath River D.O. criteria based on the designated use COLD (year-round), the 7-day moving average of the daily minimum D.O. in the water column shall not drop below **8.0 mg/L**, whereas SPWN (whenever spawning occurs, has occurred in the past or has potential to occur), the 7-day moving average of daily minimum D.O. in the water column shall not drop below **11.0 mg/L**. If dissolved oxygen standards are not achievable due to natural conditions, then the COLD and SPAWN standard shall instead be dissolved oxygen concentrations equivalent to 90% saturation under natural receiving water temperatures.

> If water quality monitoring indicates that dissolved oxygen levels are below the criteria listed, then an investigation of impact will be conducted.
>
> *Inter-gravel Dissolved Oxygen*-- Klamath River D.O. criteria that are based on the designated use SPWN (whenever spawning occurs, has occurred in the past or has potential to occur), where the 7- day moving average of the daily minimum D.O. in the inter gravel water shall not drop below **8.0 mg/L**. If dissolved oxygen standards are not achievable due to natural conditions, then the COLD and SPAWN standard shall instead be dissolved oxygen concentrations equivalent to 90% saturation under natural receiving water temperatures.

USEPA approved Hoopa (2008) with one exception; it did not approve the use of the 90% saturation criteria until the Hoopa Valley Tribe could develop a method for determining if natural conditions prevent the attainment of the approved concentration based criteria. For the purposes of this report, staff compares the proposed recalculation of the SSOs for DO in the California portion of the Klamath mainstem to both the concentration limits and the percent DO saturation limits. This is because, while the concentration limits are the approved limits associated with the Hoopa (2008), Regional Water Board staff have participated in the development of the *Klamath TMDL models,* a tool with which to assess DO under natural conditions.

Based on conversations with representatives of the Hoopa Valley Tribe (and others), staff directed Tetra Tech to rerun the *Klamath TMDL model* for that portion of the river from Iron Gate Dam to Turwar to improve the way in which barometric pressure was represented. This was undertaken to improve the DO model output in the reach just above and including the Hoopa Valley Tribe Reservation and thereby improve the potential for the Hoopa Valley Tribe to adopt the *Klamath TMDL model* as it's own tool for establishing natural conditions. Further, it allowed staff to propose a SSO for DO in the reach up to the California-Hoopa boundary which is consistent with the Hoopa objective.

8.3.1 Life cycle-based DO objectives

Figure 8-1: T1BSR modeled daily DO concentrations at Hoopa-California boundary

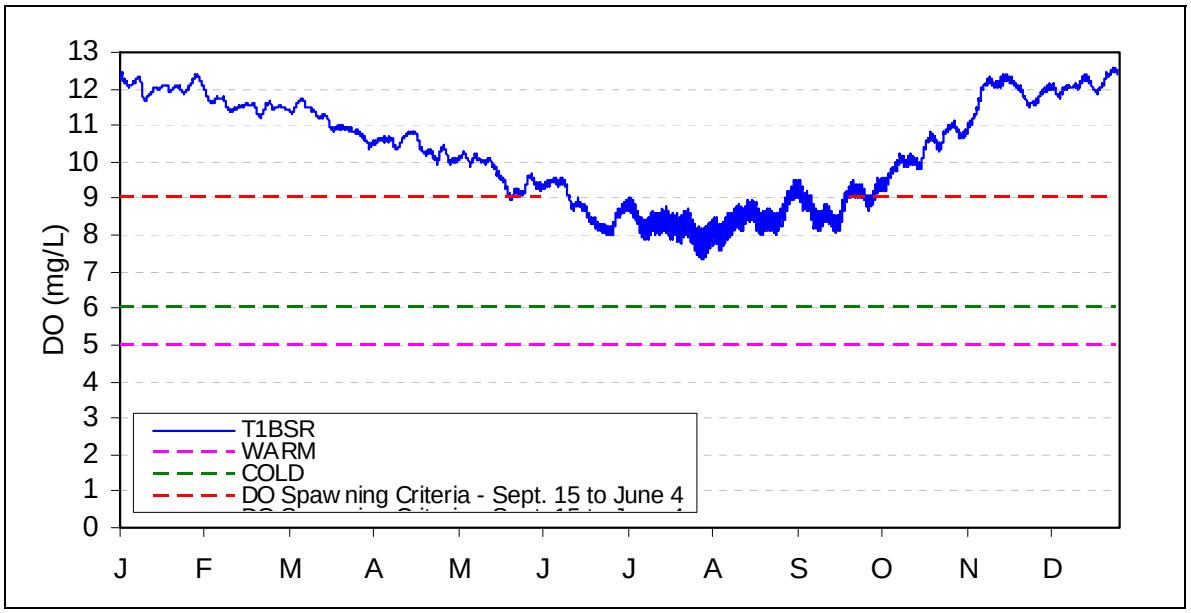


Figure 8-1 depicts simulated daily minimum DO concentrations at the Hoopa-California border. A line drawn at the 8.0 mg/L mark indicates that except from about July through mid-August, the daily minima are otherwise above 8.0 mg/L under natural conditions. As such a moving 7-day average of the daily minima is also above 8.0 mg/L. During the period from July through mid-August, the daily minima drop to a low of about 7.3 mg/L in late July making it possible that under natural conditions a 7-day moving average of the daily minima from late July through mid-August may not meet an 8.0 mg/L objective.

With respect to spawning and incubation requirements, a line drawn at 11.0 mg/L on Figure 8-1 indicates that from early November through mid-March, the daily minima under natural conditions are greater than 11.0 mg/L ensuring that the 7-day average of the daily minima is also above 11.0 mg/L. Under natural conditions from mid-March to June, however, the daily minima drop steadily from 11.0 mg/L to about 9.0 mg/L ensuring that the moving 7-day average of the daily minima fall short of 11.0 mg/L for at least some portion of this period. Similarly, under natural conditions from mid-September through October, the daily minima rise steadily from 9.0 mg/L to 11.0 mg/L ensuring that the moving 7-day average of the daily minima fall short of 11.0 mg/L for some portion of this period, as well.

Hoopa (2008) requires the application of objectives designed to protect SPWN during the period and in those locations in which spawning actually occurs, has occurred in the past, or has the potential to occur. Though not specifically mentioned in the definition of beneficial uses, SPWN is intended to apply not only to spawning but incubation, as well. The period of SPWN, as estimated in the Trinity River is from September 15 through June 4. The T1BSR (natural conditions) run of the *Klamath TMDL model* indicates that DO conditions favor spawning and incubation [as based on Regional Water Board staff's reading of USEPA (1986)] from about October through April. In either case, ambient water quality under natural conditions does not achieve the life cycle objectives for SPWN for several weeks to months of the year.

This analysis demonstrates that ambient water quality conditions are unable to achieve the SPWN objectives as contained in Hoopa (2008) within the California-Hoopa boundary.

8.3.2 Percent saturation

The *Klamath TMDL model* provides an excellent, validated, calibrated, and peer-reviewed tool with which to demonstrate that under natural conditions DO life cycle objectives as defined by Hoopa (2008) are unachievable. It was the lack of such a tool in 2007 that prevented USEPA from approving the 90% saturation element of Hoopa (2008). With the current availability of the *Klamath TMDL model* the Hoopa Valley Tribe can consider applying the 90% DO saturation criteria (under natural receiving water temperatures) as is contained in its water quality control plan.

- For the reach of the Klamath from the Scott River to the California-Hoopa boundary, the recalculated SSOs for DO call for a 90% DO saturation criteria (based on natural temperatures) year round. This is supported by the T1BSR run of the *Klamath TMDL model* and is identical to the percent saturation criteria contained in the Hoopa Basin Plan. At a monitoring location on Hoopa land, the T1BSR (natural conditions) run of the *Klamath TMDL model* indicates a minimum percent DO saturation for every month of the year as listed below. In only two months does the minimum percent DO saturation fall below 90% under natural conditions; and then achieves a minimum 89% DO saturation. The rate of violation of the 90% DO saturation objective is 2% during the month of July (based on 14 one-hour excursions during the month) and 6% during the month of August (based on 44 one-hour excursions during the month). January 96%
- February 97%
- March 96%
- April 96%
- May 95%
- June 92%
- July 89%
- August 89%
- September 91%
- October 93%
- November 95%
- December 96%

Regional Water Board staff concludes that the proposed SSOs for DO in the reach from the Scott River to the Hoopa boundary are consistent with the Hoopa percent DO saturation objective. Staff also conclude that the *Klamath TMDL model,* as improved by consultation with representatives of the Hoopa Valley Tribe (and others), provides a reasonable tool by which to establish natural conditions in that portion of the Klamath River on the Hoopa Valley Tribe Reservation. When applying the *Klamath TMDL model*

as the tool by which to establish natural DO conditions, the State's proposed 90% DO saturation objective (based on natural receiving water temperatures) for that reach from the Scott River to the Hoopa-California boundary achieves the Hoopa's 90% DO saturation objective and is consistent with these downstream requirements.

8.4 Application of Recalculated SSOs for DO in Impounded Reaches

The mainstem Klamath River is impounded behind dams in several places above the Shasta River confluence. Behind the dams, the biochemical interactions associated with nutrient and organic loading differ from those in the free-flowing portions of the river. The proposed recalculated SSOs for DO do not speak to these differences because the Klamath TMDL addresses the issue by requiring that the DO objectives be applied across a depth and width of the reservoirs that is equivalent to the depth and width of the river as it would exist without the impoundments. Further, the DO objective is to be applied in a zone that overlaps with a zone in which the temperature objectives apply, ensuring that a lens of water of sufficient quality to support beneficial uses exists within the reservoirs.

8.5 Summary

Staff conclude that the proposed Site Specific Dissolved Oxygen Objectives for the Klamath River in California meet all the regulatory requirements associated with the adoption of a basin plan amendment, including Section 13241 of Porter Cologne Water Quality Act, federal and state antidegradation requirements, and the downstream water quality requirements of the Hoopa Valley Tribe.

CHAPTER 9.
PUBLIC PARTICIPATION

Chapter 1 describes the history of the effort to revise Dissolved Oxygen objectives in the existing Basin Plan. In the fall of 2008, staff released a CEQA scoping document for public review and presented the concept for DO objective revision at two scoping meetings: one in the southern part of the Region (Santa Rosa) and the other in the northern portion (Weaverville). A peer review draft was produced and submitted for formal peer review in the spring of 2009. The project was modified to focus only on the mainstem Klamath River and a public review draft was released as an appendix to the Klamath TMDL Staff Report in June 2008. This Staff Report (Appendix 1 of the Klamath TMDL Staff Report,) was presented for public review beginning on December 23, 2009. Public comments were received by February 9, 2010 and are incorporated into this March 2010 draft, as appropriate. This March 2010 draft also reflects consultation with representatives of the Hoopa Valley Tribe (and others) regarding the means by which barometric pressure was represented in the *Klamath TMDL model* for that portion of the river from Iron Gate Dam to Turwar. The *Klamath TMDL model* was updated for this portion and rerun on February 2, 2010, the resulting revised DO data incorporated into this Staff Report. A proposed Basin Plan Amendment, based on the findings of this Staff Report, will go before the Regional Water Board in March 2010 in a public hearing regarding its adoption.

Chapter 11 of the Klamath TMDL Staff Report describes in detail the public participation process with respect to the Klamath TMDL. During 2009, public meetings addressing the Klamath TMDL have also addressed the development of the SSOs for DO.

CHAPTER 10.
IMPLEMENTATION PLAN

Chapter 6 of the Klamath TMDL Staff Report includes implementation measures necessary to achieve the proposed recalculated SSOs for DO in the mainstem Klamath River. Chapter 6 of the Klamath TMDL Staff Report is incorporated into this Staff Report by reference.

CHAPTER 11.
ECONOMICS

Chapter 10 of the Klamath TMDL Staff Report assesses the economics associated with implementation of the Klamath TMDL and SSOs for DO. Chapter 10 of the Klamath TMDL Staff Report is incorporated into this staff report by reference.

CHAPTER 12.
CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA)

Chapter 9 of the Klamath TMDL Staff Report assesses the environmental impacts associated with implementation of the Klamath TMDL and SSOs for DO as required under the California Environmental Quality Act (CEQA). Chapter 9 of the Klamath TMDL Staff Report is incorporated into this staff report by reference.

CHAPTER 13.
MONITORING

Chapter 7 of the Klamath TMDL Staff Report describes a monitoring plan for the assessment of ambient water quality conditions and compliance with the Klamath TMDL and SSOs for DO. Chapter 7 of the Klamath TMDL Staff Report is incorporated into this staff report by reference.

[In Table 3-1 of the Basin Plan, strikeout 6 separate dissolved oxygen (DO) objectives and replace with a footnote directing the reader to a new Table 3-1a including Site Specific Objectives for DO for the mainstem Klamath River. The DO objectives to be struck include:

Middle Klamath River HA
Klamath River above Iron Gate Dam including Iron Gate and Copco Reservoirs
7.0 mg/L minimum
10.0 50% lower limit

Klamath River below Iron Gate Dam
8.0 mg/L minimum
10.0 mg/L 50% lower limit

Lower Klamath River HA
Klamath River
8.0 mg/L minimum
10.0 mg/L 50% lower limit]

New Footnote to Table 3-1
"The Site Specific Objectives (SSOs) for dissolved oxygen (DO) have been recalculated for the mainstem Klamath River and are presented separately in Table 3-1a."

Recalculated SSOs for DO in mainstem Klamath River

"Table 3.1a[1]

Location[2]	**Percent DO saturation based on natural receiving water temperatures[3]**	**Time period**
Stateline to the Scott River	90%	October 1 through March 31
	85%	April 1 through September 30
Scott River to Hoopa	90%	Year round
Downstream of Hoopa-California boundary to Turwar	85%	June 1 through August 31
	90%	September 1 through May 31
Upper and Middle Estuary	80%	August 1 through August 31
	85%	September 1 through October 31 and June 1 through July 31
	90%	November 1 through May 31
Lower Estuary	For the protection of estuarine habitat (EST), the dissolved oxygen content of the lower estuary shall not be depressed to levels adversely affecting beneficial uses as a result of controllable water quality factors.	

*[1] States may establish site specific objectives equal to natural background (USEPA, 1986. Ambient Water Quality Criteria for Dissolved Oxygen, EPA 440/5-86-033; USEPA Memo from Tudor T. Davies, Director of Office of

Science and Technology, USEPA Washington, D.C. dated November 5, 1997). For aquatic life uses, where the natural background condition for a specific parameter is documented, by definition that condition is sufficient to support the level of aquatic life expected to occur naturally at the site absent any interference by humans (Davies, 1997). These DO objectives are derived from the T1BSR run of the Klamath TMDL model and described in Tetra Tech, December 23, 2009 *Modeling Scenarios: Klamath River Model for TMDL Development.* They represent natural DO background conditions due only to non-anthropogenic sources and a natural flow regime.

[2] These objectives apply to the maximum extent allowed by law. To the extent that the State lacks jurisdiction, the Site Specific Dissolved Oxygen Objectives for the Mainstem Klamath River are extended as a recommendation to the applicable regulatory authority.

[3] Corresponding DO concentrations are calculated as daily minima, based on site-specific barometric pressure, site-specific salinity, and natural receiving water temperatures as estimated by the T1BSR run of the Klamath TMDL model and described in Tetra Tech, December 23, 2009. Modeling Scenarios: Klamath River Model for TMDL Development. The estimates of natural receiving water temperatures used in these calculations may be updated as new data or method(s) become available. After opportunity for public comment, any update or improvements to the estimate of natural receiving water temperature must be reviewed and approved by Executive Officer before being used for this purpose.

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