CHAPTER 3. ANALYTIC APPROACH

3.1 Introduction

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

3.2 Modeling Approach

3.2.1 Primary Models Applied

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

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

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

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

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

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

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

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

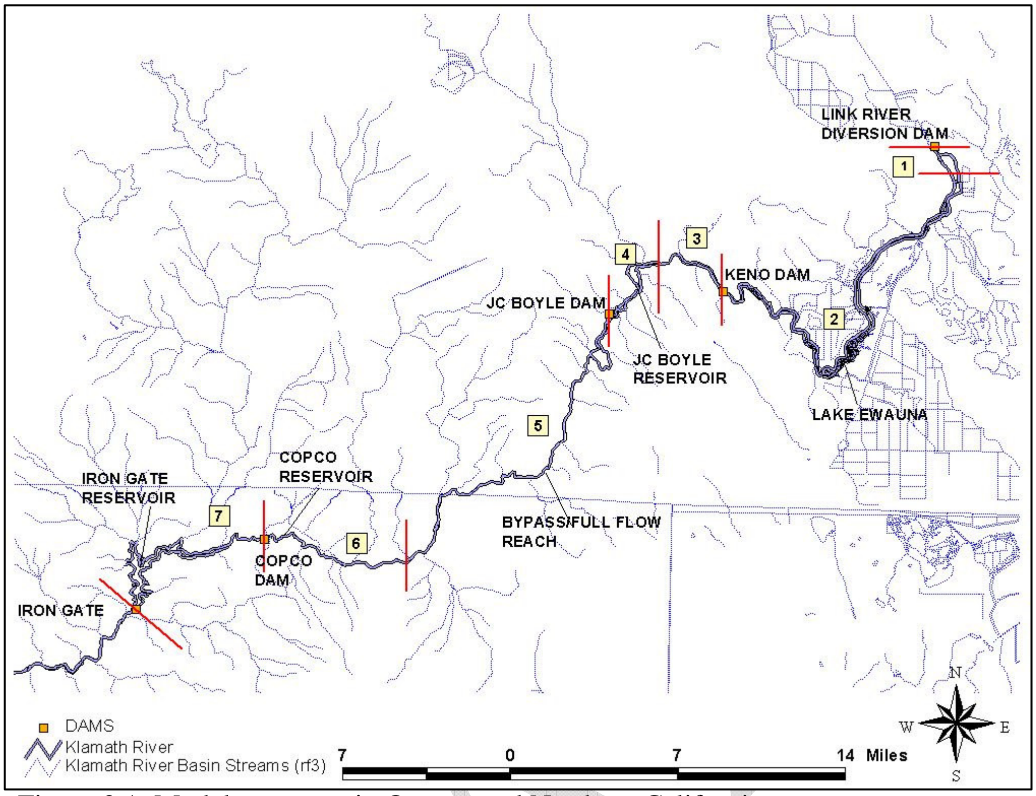

Figure 3.1: Model segments in Oregon and Northern California

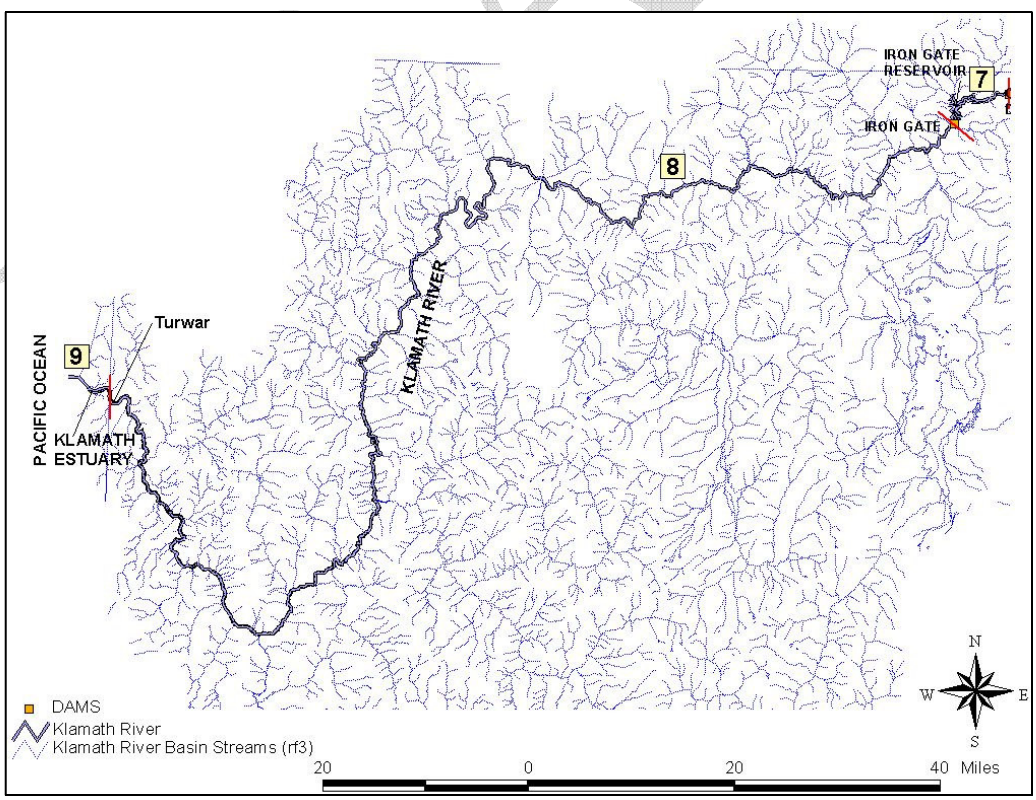

Figure 3.2: Model segments in California

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

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

3.2.1.1 Model Configuration and Testing

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

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

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

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

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

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

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

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

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

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

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

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

The upper Klamath River model (Model Segments 1 through 8) was calibrated using data from the year 2000. This year was selected for calibration because relatively good boundary condition data and in-stream data were available in the upper portion of the system. Data were available, but not to the same extent, for the lower portion of the system (particularly downstream of Iron Gate Dam). Selection of this year was deemed appropriate because water quality conditions in the upper portion of the system drive the response downstream. Although this was an average hydrologic year in terms of flow, simulating the entire year inherently tests the model's ability to represent a range of hydrologic regimes and associated water quality impacts. The model was also corroborated using data from the year 2002, which was a relatively low hydrologic year in terms of flow, for Model Segments 1 through 5. Again, considerably more data were available for the upper portion of the system in 2002 than for other years. The model was not run downstream (Segments 6 through 9) for 2002 primarily due to limited resources (i.e., cost) and limited boundary data. Boundary condition data are limited in terms of representing the full temporal, spatial, and parameter variability. Thus, it is very likely that evaluation of additional calibration would be more tied to data limitations/ uncertainty than model performance. The estuarine portion (Model Segment 9) was calibrated using data from the year 2004, because bathymetric data and data for key water quality parameters were available. Water quality data were collected as part of an intensive monitoring effort. Insufficient data were available to calibrate for the year 2000 or 2002 in the estuarine portion of the Klamath River. Calibration and corroboration results are presented in Appendix 5.

3.2.1.2 Assumptions, Limitations, and Uncertainty

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

3.2.2 Nutrient Numeric Endpoint Analysis

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

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

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

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

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

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

3.3 Model Application to TMDL Determination

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

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

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

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

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

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

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

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

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

3.3.3 TMDL Compliance

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

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

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

3.3.3.1 Temperature Compliance in Oregon (TOT1 and TOT2)

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

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

3.3.3.2 Temperature Compliance in California (TCT1 and TCT2)

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

TCT2 is based on the same conditions upstream of the Shasta River as TCT1, the only difference being the flows and temperatures of the Shasta, Scott, and Trinity. The tributary temperature increases that are due to resource management (i.e. changes in shading, altered channel geometry, flow diversions, and tailwater return flows) are assumed to occur between June 1 and October 15, except in the Shasta natural conditions scenario, which estimated natural temperatures and flows throughout the year. Consistent with the existing temperature TMDLs, the temperatures depicted for the Shasta, Scott, and Salmon Rivers for the regulatory compliance scenario (TCT2) reflect site-potential riparian shade conditions. The flows depicted for the Scott and Salmon Rivers for TCT2 equal current (year 2000) flows. The flows depicted for the Shasta River for TCT2 however, are 45 cfs greater than current (year 2000) flows, based on the flow goal included in the Shasta River temperature TMDL. Results of these model scenarios are presented in Chapter 4.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

<u>Salmon River</u>

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

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

Trinity River

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

3.3.3.3 Dissolved Oxygen Compliance in Oregon (TOD1 and TOD2)

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

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

3.3.3.4 Dissolved Oxygen Compliance in California (TCD2)

The California dissolved oxygen compliance scenario (TCD2) was based on TOD2. That is, once designations to boundary conditions were made for Oregon in TOD2, they were applied to analysis in California. California tributary boundaries were based on the natural baseline conditions scenario, while flows and temperatures for the Shasta, Scott, Salmon, and Trinity rivers were based on those used for temperature compliance in California (TCT2).

3.3.4 Dam Impacts (T4BS1)

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

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