CHAPTER 3. ANALYTIC APPROACH

3.1 Introduction

This chapter describes the analytic approach for developing the Klamath River TMDLs for California and the development of the proposed recalculated SSO for DO in the mainstem Klamath River. 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 testing process. Appendix 6 *Model Configuration and Results – Klamath River Model for TMDL Development*, presents the model configuration and testing results in detail. Section 3.3 describes the application of these models for Klamath River TMDL development. Appendix 7 *Modeling Scenarios – Klamath River Model for TMDL Development* (details how each of these scenarios was configured, associated assumptions, and presents the results. Results of these scenarios are also summarized in Chapters 4 and 5.

3.2 Modeling Approach

3.2.1 Hydrologic 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, model results can be directly compared to ODEQ, Regional Water Board and Tribal water quality criteria.

The original PacifiCorp Model consisted of several model components used in series, including the 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 Lake Ewauna), Keno Dam to J.C. Boyle Reservoir, Bypass/ Peaking 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. EFDC 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 results 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

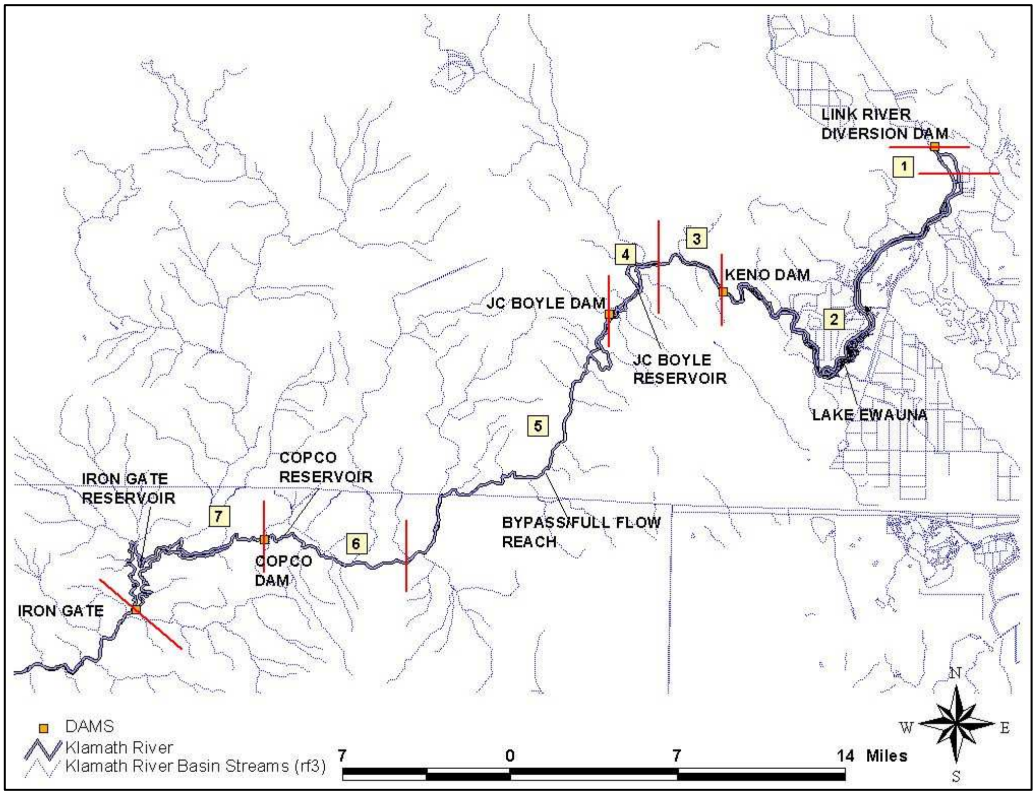

Figure 3.1: Model segments in Oregon and Northern California

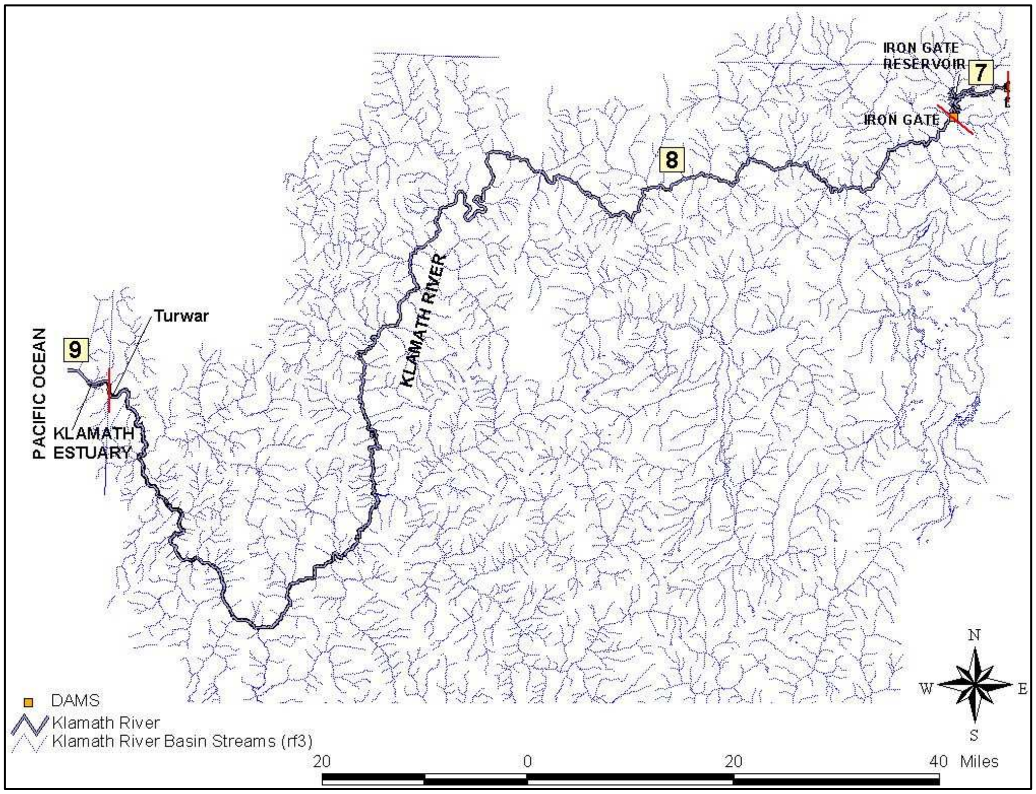

Figure 3.2: Model segments in California

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, 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, and are detailed in Appendix 6. In combination, the RMA/CE-QUAL-W2 and EFDC models as applied for Klamath River TMDL development, are referred to as the Klamath River TMDL models.

The Klamath River TMDL models were also used to develop the proposed recalculated SSO for DO in the mainstem Klamath River (included in this report as Appendix 1), which is a separate Basin Plan amendment that has been closely coordinated with the Klamath River TMDL. The Klamath River SSO for DO will be submitted for Board approval independent of the Klamath River TMDL. The Klamath River SSO for DO is derived from natural background conditions as estimated using percent DO saturation and natural receiving water temperatures. DO concentrations derived from the applicable DO percent saturation criteria are calculated using natural receiving water temperatures. The Klamath River TMDL model was used to create the necessary natural background conditions scenarios.

3.2.1.1 Model Configuration and Testing

The Klamath River TMDL model was configured by designating a set of variables used in the model to define the "state" of a dynamic system (i.e. 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 6.

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) Phytoplankton
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 TMDL model. All tributaries to the river were represented as boundary conditions (i.e., they were not explicitly modeled). For the tidal portion of the Klamath River from Turwar to the Pacific Ocean, which was not included in the PacifiCorp Model, a boundary-fit curvilinear grid was developed to accurately represent the shape of the estuary. In the modeling domain, each cell is represented by up to 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 Conditions: flows, temperature, and constituent values;
- Tributary (or Lateral) Inflow Conditions: Tributary inflows, temperature, and constituent boundary conditions;
- Withdrawal Boundary Conditions;
- Surface Conditions: Atmospheric conditions (including wind, air temperature, and solar radiation).

Once the Klamath River TMDL 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 the best fit of the simulated output to the field observations. The sequence of calibration for the Klamath River TMDL 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 versus field observations for a separate time period to ensure their appropriateness (qualitative and/or quantitative evaluation of a model's accuracy and predictive capabilities).

The Klamath River TMDL model above the estuary (Model Segments 1 through 8 Link Dam to Turwar) 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, Link Dam to slightly downstream of Stateline. 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 boundary data, but also due to cost considerations. In general, boundary condition data are limited in terms of representing the full range of 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, using bathymetric data and data for key water quality parameters collected as part of an intensive monitoring effort in 2004. 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 6.

3.2.1.2 Assumptions, Limitations, and Uncertainty

Like any dynamic water quality model, the Klamath River TMDL models have inherent limitations and uncertainty. Development and application of the Klamath River TMDL model has focused on key best practices identified in EPA's March 2009 "Guidance on the Development, Evaluation, and Application of Environmental Models," including peer review of models; QA project planning, including data quality assessment; and model corroboration. In addition to the key practices noted above, model sensitivity and uncertainty analysis have also been considered. Appendix 6 details model assumptions, limitations, and uncertainty. The Klamath TMDL development team (US EPA Regions 9 and 10, ODEQ, Regional Water Board, and Tetra Tech) finds that the Klamath River TMDL models are suitable tools for establishing Klamath River TMDL allocations and targets.

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 (CA NNE) approach (Tetra Tech 2006) to the Klamath River ([*Nutrient Numeric Endpoint Analysis for the Klamath River, CA* included as Appendix 2 of this report]). The CA NNE approach (Tetra Tech 2006) is a risk-based approach in which algae and nutrient targets can be evaluated based on multiple lines of evidence. The CA NNE approach (Tetra

Tech 2006) also includes 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 (e.g. algal biomass) and nutrient concentrations or loads. These response indicators can be incorporated as targets, which can then be translated into site-specific nutrient targets. Nutrient targets established in this way are supplemental to those established to meet specific numeric criteria, such as water quality criteria for dissolved oxygen.

The CA 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 CA 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 (e.g. *Microcystis aeruginosa* and microcystin) numeric targets for Copco and Iron Gate Reservoirs (Appendix 2 of this report). Application of the CA 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 CA NNE approach (Tetra Tech 2006) is that targets should not be set lower than the value expected under natural conditions. The hydrodynamic model natural conditions baselines scenario (T1BS) predicts TN concentrations in the Klamath River below Iron Gate that are somewhat above the targets estimated by the CA 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 CA 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 (see section 2.3.2.1).

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3.3 Model Application for TMDL Determination

After the Klamath River TMDL Model was fully tested, it was applied to evaluate a series of scenarios to support TMDL development. The scenarios simulated include:

- Natural condition baseline scenario (T1BSR)
- Oregon allocation scenario (TOD2RN)
- California allocation scenario (TCD2RN)
- With-dam TMDL scenario (T4BSRN)

The natural conditions baseline scenario (T1BSR) was run in order to estimate water quality conditions under natural conditions, because some water quality standards for both Oregon Department of Environmental Quality (ODEQ) and California North Coast Regional Water Quality Control Board (RWQCB) are based on natural conditions. The natural conditions baseline scenario (T1BSR) was also used to assess DO percent saturation potential under natural conditions, which became the basis for the proposed DO SSO. The Oregon and California allocation scenarios TOD2RN and TCD2RN, respectively represent compliance with water quality criteria in Oregon and California, respectively. The Oregon and California with-dam TMDL scenario was run in order to quantify the impacts of the dams on water quality and determining appropriate allocations.

Appendix 7 details how each of these scenarios was configured, associated assumptions, and presents the results. Results of these scenarios are also summarized in Chapters 4 and 5.

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CHAPTER 3. REFERENCES

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