4.0 DEVELOPMENT OF WATER QUALITY ANALYSIS AND MODELING FRAMEWORK

4.1 DESCRIPTION AND PURPOSE

The purpose of this study was to design and implement a flow and water quality modeling framework for the Klamath River, specifically from Link dam (RM 255) to Turwar, California (RM 6). The modeling framework provides a key tool for analyzing water quality in the Project area, determining how the Project contributes to or controls water quality conditions in and downstream of the Project area, and assessing compliance with water quality standards/regulations. The modeling results will be used to support subsequent assessment of possible PM&E measures where necessary. Important questions related to Project operations are (1) whether and how these operations might contribute to water quality conditions, and (2) whether and how these operations might feasibly contribute to water quality improvements.

4.2 OBJECTIVES

The objectives addressed by this study are as follows:

- Develop a framework plan for completing the modeling and analysis
- Use models to help assess water quality compliance in the Project area
- Use models to help determine how the Project contributes to or controls water quality conditions in and downstream of the Project area
- Use models to support subsequent assessment of possible PM&E measures related to water quality, where necessary

4.3 RELICENSING RELEVANCE AND USE IN DECISIONMAKING

Water temperature and multiparameter water quality models are key tools in assessing water quality and determining the effect of Project operations on water quality conditions. A number of factors, many outside of PacifiCorp's control, contribute to these conditions. This study assessed modeling needs, identified model scenarios to be assessed, and constructed and applied models to Project operations. Results from this modeling are used to assess the effect and control of Project operations on water quality conditions.

Relicensing of the Project requires 401 Certifications from relevant agencies confirming that the Project complies with requirements of the Federal Clean Water Act. The modeling study helps PacifiCorp assess water quality conditions and potential Project effects as they relate to water quality objectives and standards promulgated by those agencies. In addition, this task helps PacifiCorp assess water quality conditions as they relate to the objectives of other agencies regarding water quality conditions that support aquatic resources, such as fish and wildlife, and recreation.

4.4 METHODS AND GEOGRAPHIC SCOPE

4.4.1 Development of the Modeling Framework

The analytical and modeling needs assessment and scoping process addressed the following technical issues and factors that are key to scoping, constructing, and applying models.

- A number of methodologies and models are available for assessing water temperature and water quality, including not only simulation modeling, but also various empirical data-based methods (Figure 4.4-1).
- Water temperature and water quality circumstances in each Project reach are quite different.
- Specific steps for correlating analyses (including modeling) to compliance with water quality objectives and standards must be met (including specific parameters, metrics, scenarios, locations, and time steps to be used).
- The analytical needs and tools to be used by PacifiCorp and the Water Quality Work Group to focus on Project operations and effects, and should fit appropriately into, but not duplicate or replace, basinwide analytical needs and tools to be developed by other entities (e.g., total maximum daily load (TMDL) planning).

On the basis of stakeholder comments on the study plan and discussions at stakeholder meetings, PacifiCorp developed a modeling framework that provided details on the modeling and analysis tools used to assess Project water quality effects and potential management scenarios. The modeling framework is described in an attachment to Study Plan 1.3 (Water Quality Analysis and Modeling Process) and in Appendix 4A of this report.

The selected models have the capability to examine a variety of Project operation scenarios. PacifiCorp and the Water Quality Work Group identified three basic scenarios to be examined: (1) existing operations conditions; (2) steady flow (i.e., run-of-river) operations condition; and (3) hypothetical without-Project conditions.[1] The models were also used to examine potential water quality enhancement measures (e.g., selective withdrawal, instream flow releases, and drawdown). Results of these simulations are discussed in Section 4.7.

Stakeholders requested that the model also be used to examine other scenarios, including those that assume removal of certain Project facilities (e.g., removal of Copco and Iron Gate Facilities only; removal of Iron Gate only). These other scenarios are intended to assist stakeholders to complete the System Landscape Options Matrix (SLOM)—a tool used to help determine whether information will be available to FERC to examine potential Project removal alternatives. As of the date of preparation of this document, these other scenarios have not been examined with the models. The other scenarios are not a necessary component of PacifiCorp's evaluation for this license application. However, PacifiCorp plans to complete the SLOM scenarios and present them to stakeholders in April or May 2004.

[1] For example, to demonstrate compliance with the State of Oregon water temperature standard, ODEQ has instructed PacifiCorp that a "without-Project" scenario must be modeled to ascertain "natural" warming. The natural warming provides a baseline against which existing operations (i.e., "with-Project") scenarios are compared to determine potential Project effects.

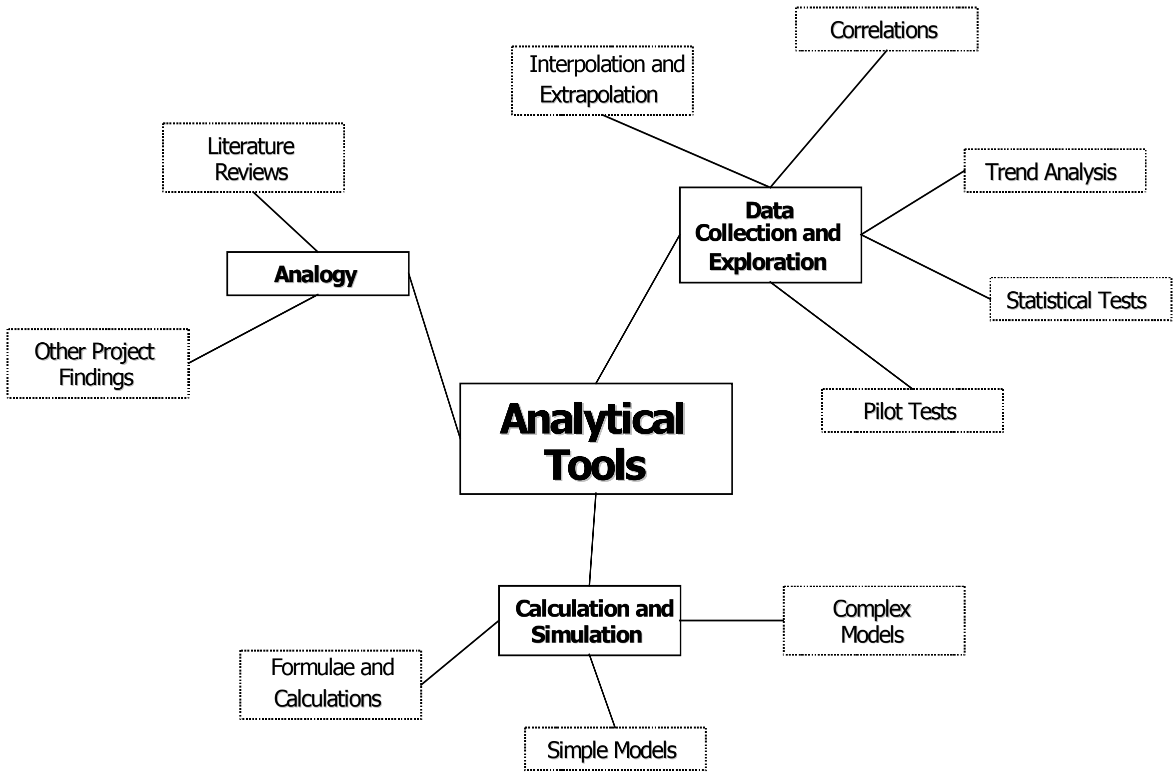

Figure 4.4-1. Potential categories and types of analytical tools used to assess water quality.

4.4.2 Geographic Scope

The geographic scope for water quality analysis and modeling tasks identified in Study Plan 1.3 includes the Klamath River from Link River dam (RM 255) to the mouth of the river near Turwar (about RM 6). The reaches within the Project area from Link River dam to just below the Iron Gate dam and powerhouse (RM 190) will be the primary focus of analysis. It is in this area that PacifiCorp believes Project operations have the most direct and varied potential effects on water quality. However, proposed water quality modeling also includes the reach downstream of the Project from Iron Gate dam (RM 190) to the mouth of the river near Turwar (about RM 6).

4.5 RELATIONSHIP TO REGULATORY REQUIREMENTS AND PLANS

This study helps PacifiCorp address regulatory requirements and planning objectives related to Project effects on water quality. The information derived from this study helps to address FERC certification and 401 requirements (18 CFR 4.51 and 16.8) for information on water quality in the study area and potential effects of Project operations on water quality.

This study, together with other hydrology and water quality studies conducted by or for PacifiCorp (described in other sections of this FTR), provides information that is used to address compliance with the management objectives relating to water quality of various resource agencies, tribes, and other stakeholders, including:

- Federal Clean Water Act regulations

- State of California Water Quality Control Plan for the North Coast Region (Basin Plan)
- State of Oregon Water Quality Basin Plan for the Klamath River
- Federal Endangered Species Act (ESA) regulations
- Tribal natural resources goals and objectives[2] and cultural values
- U.S. Forest Service (USFS) and BLM Aquatic Conservation Strategy objectives under the Northwest Forest Plan
- BLM Resource Management Plans
- USFS Land and Resource Management Plans
- Oregon Department of Fish and Wildlife (ODFW) Fish and Wildlife Habitat Mitigation Policy
- ODFW Klamath Basin Fish Management Plan
- California Department of Fish and Game management goals

This study's information also helps PacifiCorp to develop PM&E measures to meet the intention of the regulations and management objectives related to water quality.

4.6 TECHNICAL WORK GROUP COLLABORATION

PacifiCorp has worked with stakeholders to establish a more collaborative process for planning and conducting studies needed to support Project relicensing documentation. As part of this collaborative process, a Water Quality Work Group has met approximately monthly to plan and discuss water quality studies and results.

A number of comments were received from stakeholders, notably ODEQ and the State Water Resources Control Board (SWRCB), which recommended that PacifiCorp perform detailed water temperature and multiparameter water quality modeling. Both ODEQ and SWRCB recommended numerical modeling capable of dynamic and continuous simulation of water temperature, eutrophication, multiple algal species, algal blooms, pH, DO, nutrients, and sediment kinetics, including sediment oxygen demand, total suspended solids, and turbidity.

PacifiCorp conducted several scoping meetings with interested stakeholders to discuss specific plans for water quality modeling and modeling scenarios to be evaluated. Several items related to analytical and modeling needs and methods were discussed. These items included:

1. Water quality analysis and modeling objectives by parameter, by reach, and over time (includes Project facilities and operations scenarios).

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[2] Including tribal water quality standards as promulgated.

2. The appropriate spatial scope needed for analysis and modeling (i.e., the upstream and downstream boundaries to be considered).

3. Reach-by-reach information summaries to facilitate discussion of PacifiCorp operations in the reach, the extent and quality of existing water quality data, and historical trends in water quality conditions.

4. Other ongoing or planned water quality data collection and modeling efforts (e.g., other PacifiCorp tasks, agency TMDL data collection and modeling, USBR data collection and modeling).

5. The applicability, advantages, and disadvantages of existing and planned models, as well as other alternative modeling approaches.

6. The analytical and modeling steps to be taken by PacifiCorp (and others as appropriate).

Based on discussions at these meetings, PacifiCorp developed the modeling framework to provide details on the modeling and analysis tools used to assess Project water quality effects and potential management scenarios. The modeling framework is described in an attachment to Study Plan 1.3 – Water Quality Analysis and Modeling Process and in Appendix 4A of this document

4.7 MODEL IMPLEMENTATION AND APPLICATION

The flow and water quality modeling framework for the Klamath River from Link dam (RM 255) to Turwar (about RM 6) has been designed and implemented to support studies for the Project relicensing process. The basis for the modeling framework and detailed supporting documentation are provided in Appendix 4A.

The discussion in this section is arranged in terms of three specific modeling tasks:

- Model implementation
- Calibration and validation
- Model application

Model implementation is the process of gathering the appropriate data (geometry, flow, water quality, meteorology) and formatting it for input into the selected models. This step includes selection of default model parameters and general model testing. The end result is a running, but uncalibrated model. At the next stage, model parameters are modified to fit the model to field observations—i.e., calibration. The model is then tested on an independent set of data—validation—to confirm that the model can replicate field conditions for the parameter values determined in calibration. The final stage is model application, in which the calibrated models are applied to selected management strategies or scenarios. Such scenarios may vary flow or water quality conditions, or they may include the addition or removal of Project facilities to identify potential impacts and outcomes.

4.7.1 Model Implementation

4.7.1.1 Selection

Flow and water quality conditions in the Klamath River basin vary dramatically in the approximately 250 miles from Link dam, near Klamath Falls, Oregon, to Turwar, California. There is a wide range of natural and anthropogenic influences in the Klamath River system throughout this region:

- Inflows at Link dam originate in hypereutrophic Upper Klamath Lake.
- There are four major reservoirs on the mainstem Klamath River.
- Diversions and return flows for agriculture, as well as municipal and industrial use, occur in the reach between Link dam and Keno dam.
- The river receives considerable inflow from tributaries as it flows toward the Pacific Ocean.

To address these diverse characteristics, discrete river models and reservoir models were selected. The river models consist of a suite of models produced by RMA. The flow component is represented with RMA-2, a finite element hydrodynamic model capable of modeling highly dynamic flow regimes at short space and time steps. The output from this model—velocity, depth, a representative surface, and bed areas—are passed to the water quality model RMA-11. RMA-11 is a full water quality finite element model, simulating the fate and transport of a wide range of physical, chemical, and biological constituents based on information produced by RMA-2. The suite of river models is applied on a sub-daily time step to capture the short-term response of various parameters, such as temperature and DO. The RMA models are applied in one-dimension for the river reaches. For this application, the variations along the longitudinal axis of the stream are represented, with the vertical and lateral directions averaged.

The two-dimensional longitudinal/vertical hydrodynamic and water quality model CE-QUAL-W2 is applied to system reservoirs (Copco No. 2 is a small reservoir and is not modeled within the framework). Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow water bodies exhibiting longitudinal and vertical water quality gradients, but it can be applied to a wide range of physical configurations. The model is capable of representing a wide range of water quality processes, including physical, chemical, and biological (benthic algae and phytoplankton) processes. The model can simulate selective withdrawal, sediment nutrient release dynamics, nitrogen inhibition under anoxic conditions, internal weirs and curtains, and other useful options to assess a wide range of conditions. To interface with the river model, sub-daily simulation results on the same time scale of the river models are employed.

4.7.1.2 Implementation

The river and reservoir models were implemented for nine discrete river reaches. These reaches are listed in Table 4.7-1 and depicted graphically in Figure 4.7-1. The model implementation process included constructing appropriate system geometry, flow and water quality conditions (boundary conditions, initial conditions, calibration/validation data), meteorological data, and other model parameters.

- Geometry data include a description of the river location, i.e., latitude and longitude, UTM, or similar coordinate system; bed slope; and cross-section data. For reservoirs, bathymetric information and facilities information (e.g., stage-volume data; intake structure configurations and elevations; locations of diversions structures and return points) are required.

- Flow and water quality information include system inflow (e.g., mainstem points, tributaries, return flows), outflow (diversions), reservoir storage change, and facilities operations. Water quality data for all inflows, as well as in-river and reservoir conditions, are required.

- Meteorological data include standard parameters for heat budget calculation within the numerical models—e.g., air temperature, wet bulb temperature (or dew point temperature), solar radiation, cloud cover, wind speed, and/or barometric pressure.

- Other model parameters include selection of time step, spatial resolution, identified periods of analysis, and selection of default model constants and coefficients.

Table 4.7-1. River reaches and representation in the modeling framework.

Reach	Existing Representation	Model
Link River	River	RMA-2/RMA-11
Lake Ewauna-Keno Dam	Reservoir	CE-QUAL-W2
Keno Dam to J.C. Boyle Reservoir	River	RMA-2/RMA-11
J.C. Boyle Reservoir	Reservoir	CE-QUAL-W2
J.C. Boyle Bypass Reach[1]	River	RMA-2/RMA-11
J.C. Boyle Peaking Reach[1]	River	RMA-2/RMA-11
Copco Reservoir[2]	Reservoir	CE-QUAL-W2
Iron Gate Reservoir	Reservoir	CE-QUAL-W2
Iron Gate Dam to Turwar	River	RMA-2/RMA-11

[1] The J.C. Boyle bypass and peaking reaches are modeled as a single reach.
[2] Copco No. 2 is not represented in the framework.

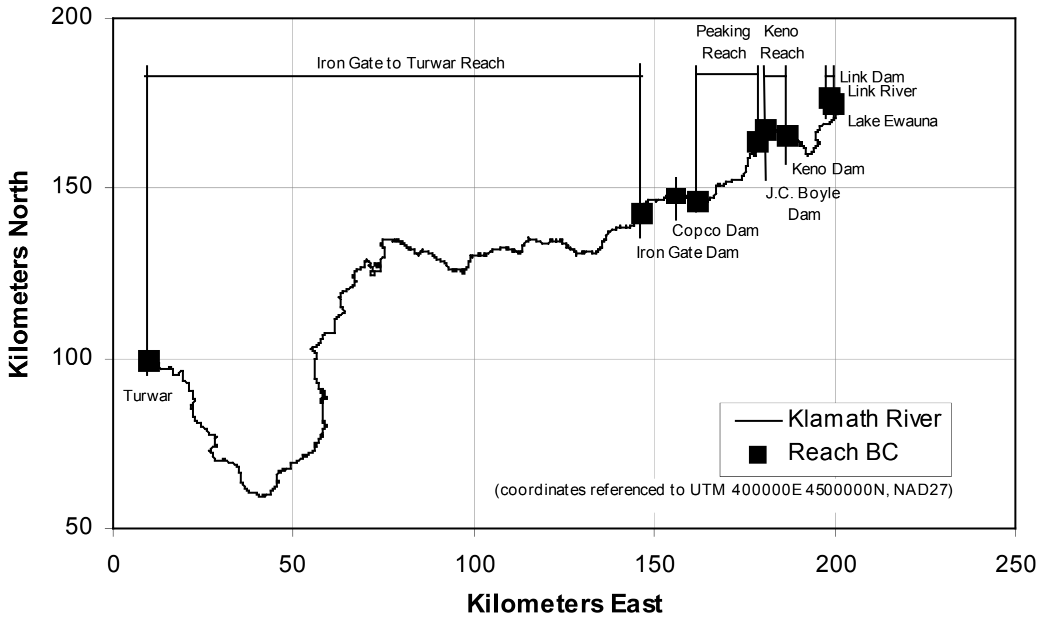


Figure 4.7-1. Designated river reaches and reservoirs.

The objective of the modeling framework is to enable the assessment of individual reaches or a set of reaches, or to simulate conditions throughout the system.

Model implementation for each of the reaches, summarized below, is covered in substantial detail in Section 2.3 of Appendix 4A.

<u>Link River</u>

The Link River reach starts at Link dam and terminates at Lake Ewauna. Two powerhouses discharge into this reach. The river geometry (location, width, and bed elevation/slope), flow and water quality (temperature and constituent concentrations) data, meteorological conditions, and other model parameters are discussed in detail in Section 2.3.1 of Appendix 4A.

<u>Lake Ewauna to Keno Dam</u>

The Lake Ewauna to Keno dam reach extends from the point where Link River enters Lake Ewauna to Keno dam. The impoundment is generally a broad, shallow body of water. System width ranges from several hundred feet to more than 1,000 feet (over 300 m), and a maximum depth of roughly 20 feet (approximately 6 m). There are several discharges and withdrawals in this reach. A total of 18 discharges and seven withdrawals were represented in the model. The reach is modeled with CE-QUAL-W2. The reservoir physical data, flow and water quality data, meteorological data, and other model parameters are discussed in detail in Section 2.3.2 of Appendix 4A.

Keno Reach

The Keno reach extends from Keno dam to the headwaters of J.C. Boyle reservoir. There are no appreciable streams tributary to this reach. The river geometry, flow and water quality data, meteorological conditions, and other model parameters are discussed in detail in Section 2.3.3 of Appendix 4A.

J.C. Boyle Reservoir

The J.C. Boyle reservoir primarily serves to regulate peaking flows for the J.C. Boyle powerhouse (RM 220.4). The reservoir reach extends from the J.C. Boyle headwaters (the end of the Keno reach) to J.C. Boyle dam. One tributary, located at Spencer Creek, is represented in the model. The geometry, flow and water quality data, meteorological conditions, and other model parameters are discussed in detail in Section 2.3.4 of Appendix 4A.

J.C. Boyle Bypass and Peaking Reach

The J.C. Boyle bypass and peaking reach extends from J.C. Boyle dam to the headwaters of Copco Reservoir. Noteworthy features of this reach include diversion of mainstem flows at J.C. Boyle dam for hydropower production, the powerhouse penstock return roughly 5 miles downstream from J.C. Boyle dam, a large springs complex in the bypass section, and hydropower peaking operations downstream of the powerhouse. There are a few small streams entering the reach, the most significant being Shovel Creek. The river geometry (location, width, bed elevation/slope), flow and water quality data, meteorological conditions, and other model parameters are discussed in detail in Section 2.3.5 of Appendix 4A.

Copco Reservoir

The Copco reservoir reach extends from Copco reservoir headwaters (RM 203.1) to Copco dam. There are no tributaries represented in the model: the only inflow represented is Klamath River inflow to the reservoir. The physical data, flow and water quality data, meteorological conditions, and other model parameters are discussed in detail in Section 2.3.6 of Appendix 4A. The small Copco No. 2 reservoir and river reach between Copco and Iron Gate reservoirs is not represented in the modeling framework (the exception is the without-Project scenario, which is discussed in section 4.7.3 of this document and covered in greater detail in Section 4.0 of Appendix 4A).

Iron Gate Reservoir

The Iron Gate reservoir reach extends from the headwaters of Iron Gate reservoir to Iron Gate dam. Three tributaries are represented in the Iron Gate reservoir CE-QUAL-W2 applications: Camp Creek, Jenny Creek, and Fall Creek. The spillway for the dam is modeled as a withdrawal in the last active segment as the spillway structure draws water to the side of the dam, not over or through the dam. Also, due to the shape of the reservoir, two branches were created. Branch one is the main branch and receives water from Copco reservoir (i.e., releases from Copco reservoir). Branch two represents the Camp Creek arm of Iron Gate reservoir. The geometry, flow and water quality data, meteorological conditions, and other model parameters are discussed in detail in Section 2.3.7 of Appendix 4A.

Iron Gate Dam to Turwar

The Iron Gate dam to Turwar reach extends from Iron Gate dam to the mouth of the Klamath River. Several main tributaries flow into this reach: the Shasta, Scott, Salmon, and Trinity Rivers. Several creeks are also included in the simulation. The geometry, flow and water quality data, meteorological data, and other model parameters are discussed in detail in section 2.3.8 of Appendix 4A.

4.7.2 Model Calibration and Validation

All components of the system have been tested and successfully calibrated. Although additional data needs and model testing have been suggested (see sections 4.7.22 and 4.7.29), the framework and its individual components have proved extremely effective at illustrating flow and water quality processes throughout the system. The exercise of system characterization, model implementation, sensitivity testing, and calibration and validation have resulted in a dramatically improved understanding of Klamath River flow and water quality issues, as well as identifying the need for additional data. Available data precluded formal calibration or validation of the models during the winter months. The complete, detailed documentation of the model calibration and validation process is presented in Section 3 of Appendix 4A. A brief synopsis of each reach is outlined below.

4.7.2.1 Link River

This short river reach is fairly insensitive to model conditions, with the exception of when Link dam bypass flows are low and most of the water is passed through the East Side and West Side powerhouses. However, any variability imparted on Link dam releases by conditions within Link River is quickly overwhelmed in the Lake Ewauna to Keno dam reach. This reach has been calibrated and validated.

4.7.2.2 Lake Ewauna-Keno Dam

The Lake Ewauna-Keno dam reach is a dynamic and complex reach to model water quality. This reach is intensively developed for water resources and related activities. There are multiple diversions from the system for industrial and agricultural use, as well as their associated return flows. The Klamath River also is a receiving water body for municipal discharge of treated wastewater. Land use practices, predominantly agricultural, but also municipal and industrial activities, occur adjacent to the river throughout much of this reach. Finally, review of available literature and discussions with stakeholders suggest that historical log rafting and timber industry practices have left considerable organic matter throughout the upper portion of this reach.

Other water resource developments of importance include the impoundment of Upper Klamath Lake for diversion to the USBR project, as well as impoundment of the reach by Keno dam (Keno reservoir). The operations of Link dam, namely actively managing storage in Upper Klamath Lake for summer application within the USBR project, has reduced the frequency and to some degree the magnitude of winter flows through the Lake Ewauna to Keno dam reach. This, coupled with impoundment at Keno dam, has created a slow-moving waterway that favors primary production (as phytoplankton versus riverine forms of algae), as well as deposition. Upstream inputs from hypereutrophic Upper Klamath Lake, together with historical and continued inputs from municipal, industrial, agricultural, and non-point discharges, lead to considerable oxygen demands within this reach.

Given the level of complexity encountered in this reach, model calibration for application to this dynamic reach was generally successful for temperature. For DO, nutrients, and algae, it was apparent that the resolution (i.e., monitoring frequency) of the upstream boundary condition (actually conditions at Link dam) governed processes within this reach. Sensitivity testing of Link dam, as well as other boundary conditions, including sediment oxygen demand (SOD), supported this finding. As such, the model replicates seasonal DO response, but short-term conditions are not always well represented. Model performance for nutrients varies dramatically between 2000 and 2001 applications. With the more complete data set of 2001, the model replicates observed conditions appreciably better than in 2000, when composite upstream boundary conditions were applied. The model has undergone a wide range of testing to assess variable conditions and response to modifying model parameters, and, given the level of available data, can be considered preliminarily calibrated for DO and nutrients.

4.7.2.3 Keno Dam to J.C. Boyle

The Keno dam to J.C. Boyle reach is fairly short, with a transit time of a few hours. The models performed well in this steep river reach, replicating temperature and DO effectively, as well as nutrient concentrations.

4.7.2.4 J.C. Boyle Reservoir

J.C. Boyle reservoir is small reservoir and experiences residence times of less than a day to more than 3 days. As such, it is heavily influenced by inflow water quantity and quality. The system was modeled with CE-QUAL-W2 and has been tested for a wide range of conditions using calendar year 2000 data. (The system was also modeled with Water Quality for River Reservoir Systems (WQRRS) prior to applying CE-QUAL-W2.) The model performs well and is calibrated, but results are sensitive to influent conditions, which are ultimately driven by the boundary condition at Link dam.

4.7.2.5 J.C. Boyle Bypass and Peaking Reach

The peaking reach experiences a highly dynamic flow regime and variable water quality as a result of peaking operations and the influence of a large springs complex. Modeling required representing the physical features of this steep reach, as well as the short duration hydropower operations. The models performed well for all parameters. This reach is calibrated.

4.7.2.6 Copco Reservoir

Copco reservoir receives a peaking flow regime from upstream Klamath River inflows, as well as providing peaking flows at Copco dam for a significant portion of the year. The reservoir was modeled for calendar year 2000, and performance was generally good for both temperature and DO. The model is considered calibrated; however, it is sensitive to the upstream boundary condition—inflow from the Klamath River—which in turn is somewhat sensitive to the conditions at Link dam.

4.7.2.7 Iron Gate Reservoir

Iron Gate reservoir receives a peaking flow regime from upstream Copco reservoir and re-regulates the river to provide a stable flow regime below Iron Gate dam for a significant portion of the year. The reservoir was modeled for calendar year 2000, and performance was generally good for both temperature and DO. The model is considered calibrated; however, it is sensitive to the upstream boundary condition—inflow from Copco reservoir—which in turn is somewhat sensitive to the conditions at Link dam.

4.7.2.8 Iron Gate Dam to Turwar

The Iron Gate dam to Turwar reach is the longest single reach in the modeling framework. Multiple tributaries and variable meteorological conditions add complexity to this generally steep reach. Sufficient information was available to calibrate the models throughout the reach for water temperature, DO, and inorganic nutrients.

4.7.3 Model Application

Upon completion of model calibration, system conditions from Link dam to Turwar (a distance of approximately 250 miles) were simulated. The models were applied to four systemwide scenarios: existing conditions (EC), steady flow (SF), and two without-Project scenarios (WOP and WOP II). These scenarios were intended to bracket the range of potential physical and operational conditions within the Project area. For each scenario, the models were applied for a full calendar year for the years 2000 and 2001.

The existing conditions scenario represents the baseline status and is used for comparing conditions without peaking hydropower operations (steady flow scenario) and a river system without hydropower facilities (without-Project scenarios). The WOP scenario simply assumes conditions in the absence of hydropower facilities. Because Project reservoir storage is assumed to be absent, this scenario results in significant flow fluctuations (particularly in the Keno reach) from USBR irrigation project operations. The WOP II scenario is an effort to smooth river flows to produce a hydrograph that does not exhibit the fluctuations caused by USBR project operations. More detailed descriptions of these scenarios are provided in section 4.7.3.2.

These analyses are intended to examine large-scale system response over periods when critical water quality conditions tend to occur (spring-fall) in the Klamath River basin. More detailed analysis focusing on critical reaches, specific operations, and limited time periods are addressed separately. Basic assumptions for each scenario are listed in Table 4.7-2 and discussed in the following text.

The basic output extracted from each scenario was hourly time series data at multiple locations for temperature and DO, although all other parameters are available at the hourly output frequency. Processed output for all three scenarios included data for daily mean, daily maximum, daily minimum, monthly mean, and 7-day maximum average.

Table 4.7-2. Basic scenario assumptions.

Scenario	Geometry/ Bathymetry	Meteorology	Hydrology for Boundary Conditions	Water Quality for Boundary Conditions	Operations
Existing Conditions (EC)	Base	Base	Base	Base	Base
Steady Flow (SF)	Base	Base	Base	Base	Modified
Without-Project (WOP)	Modified	Base	Base	Base	No operations
Without-Project II (WOP II)	Modified	Base	Modified[1]	Base	No operations

Base – refers to baseline conditions or those applied to the existing condition scenario.
Modified – identifies whether any basic data information was modified for the identified scenario.
Modified[1] – refers to modifications from Iron Gate dam to Keno dam.

4.7.3.1 Model Coordination

The models are applied in series, starting with the uppermost reach—Link River—and passing the water quality output from one reach to the next. The flow conditions are generally not passed from reach to reach because historical values are used. Exceptions include reaches where there is no upstream flow record (i.e., measured flow) above Copco reservoir, where the hydrodynamic model is used to route peaking flows on an hourly basis down to Copco reservoir; these flows are then used in the CE-QUAL-W2 simulation of Copco reservoir. For certain scenarios (e.g., without-Project), flows are passed from one modeled reach to the next because flow conditions cannot be explicitly specified. Further details of the flow records used in modeling each reach are presented in Section 2.3 of Appendix 4A.

Water quality is passed downstream between all simulated river reaches. The river models (RMA) and the reservoir model (CE-QUAL-W2) do not represent all water quality parameters in the same fashion. The river models represent organic matter as organic nitrogen and organic phosphorus, while the reservoir model represents organic matter as refractory and labile dissolved and particulate organic matter. A stoichiometric equivalent is used to convert the fraction of organic matter or nutrients when passing information from one model to the next. Specifically, organic nitrogen from RMA-11 is converted to dissolved labile organic matter for input to CE-QUAL-W2 (the nitrogen fraction of organic matter is assumed to be 0.08 [U.S. Army Corps of Engineers-Hydrologic Engineering Center, 1986]). No attempt is made to partition the organic matter among the refractory and labile or the dissolved and particulate compartments due to a lack of sufficient field data. When passing information from CE-QUAL-W2 to RMA-11, the derived constituent for total organic nitrogen and total organic phosphorous are employed; however, the algal component of organic nitrogen and phosphorous are removed from this value so as not to double count the algal fraction (the nitrogen and phosphorous fractions of algae are assumed to be 0.08 and 0.005, respectively [Cole and Wells, 2002]).

4.7.3.2 Model Scenarios

Existing Conditions Scenario

The EC scenario models the actual conditions in the Klamath River during 2000 and 2001. All projects were assumed to be in place and operating under historical 2000 and 2001 conditions. All input information is that recorded in 2000 or 2001, calculated from records, or estimated for 2000 and 2001 conditions. The models used in this scenario were RMA2 / RMA11 for the river reaches and CE-QUAL-W2 for the reservoirs.

The geometry (or bathymetry) and meteorology and the hydrology and water quality data for boundary conditions for each reach of the EC scenario followed the basic modeling framework outlined in Section 2.3 of Appendix 4A. The same was true for Project operations.

Steady Flow Scenario

The SF scenario models alternative flows to those recorded in 2000 and 2001. All projects were assumed to be in place but were not assumed to be operating under historical 2000 and 2001 conditions. Instead, the SF senario assumes that reservoirs were operated with approximately no change in water surface elevation and that generation flows were approximately constant, rather than peaking at J.C. Boyle and Copco No. 1 and No. 2 powerhouses.

Calculations started by assuming the dam releases from Iron Gate reservoir were the same as those used in the EC scenario, calculating overall smoothed existing conditions accretions/ depletions for each reach, and then moving upstream using a water balance method between each reservoir up to Link dam. The models used in this scenario were RMA2 / RMA11 for the river reaches and CE-QUAL-W2 for the reservoirs. As with the EC scenario, the geometry, meteorology, hydrology, and water quality for each reach of the SF scenario followed the basic modeling framework outlined in Section 2.3 of Appendix 4A.

However, the Project operations for each reach of the SF scenario were not the same as those described in the basic modeling framework. In the SF scenario, the reservoirs were operated with approximately no change in water surface elevation for the entire year.

The smoothing method used for the accretion/depletion calculation was to take the average flow for the day of interest and the following 6 days. The calculations for the unsmoothed accretion/ depletion are also presented in Appendix 4A (Table 95). The SF scenario dam release calculations are presented in Appendix 4A (Table 96). Spring flows in the J.C. Boyle bypass reach were assumed to be a constant 225 cfs for these calculations. Releases from Iron Gate and J.C. Boyle reservoirs were assumed to be 50 cfs (for the fish hatchery) and 100 cfs (the current minimum flow requirement), respectively. The East Side and West Side turbine flows were calculated as a percentage of daily flow from Upper Klamath Lake. The percentage of daily flow was determined per day from EC flows.

As these calculations assumed no daily change in storage in each of the reservoirs, the starting and ending elevations of the reservoirs were those recorded in each reservoir on January 1, 2000 and 2001.

Below Iron Gate reservoir, all flows were assumed to be the same as those used in the existing conditions scenario.

Without-Project Scenario

The WOP scenario models the Klamath River as though there were projects in the Klamath River downstream of Link dam. The models used in this scenario were RMA2/RMA11.

The geometry for the river reaches of the WOP scenario followed the basic modeling framework outlined in the implementation documentation, in Appendix 4A (see section 2.2). The reservoirs were replaced with river reaches, with the geometry of the reaches estimated from the deepest points in the reservoir bathymetries. River widths within the reservoirs were a linear interpolation between the river width in the element immediately preceding the reservoir and the river width in the element immediately following the reservoir. All other river widths were the same as those used in the EC scenario. For other element information, such as length, a uniform grid was used, creating elements of the same length for the entire river. Through this process, the EC river miles were preserved, except for Copco reservoir, where the river was lengthened to capture the sinuosity of the old riverbed under the reservoir.

The meteorology, hydrology, and water quality data for boundary conditions for each reach of the WOP scenario followed the basic modeling framework outlined in Appendix 4A (see Section 2.3).

Water quality data also followed the basic modeling framework outlined in Appendix 4A.

Unlike the SOD exerted in the reservoirs, there is little oxygen demand in the river bed due to scouring. Therefore, the SOD that is present in the EC scenario is not present in the form of bed BOD in the without-Project scenario. Sensitivity testing using the modeling framework illustrates that low DO conditions in the Lake Ewauna/Keno reach are most likely due to the oxygen demand imparted to the system from Upper Klamath Lake; therefore, the response is more akin to an oxygen sag in this reach than an overwhelming SOD load. SOD plays a role in water quality conditions; however, at this time it is generally presumed to be modest compared to inputs from Upper Klamath Lake.

No Project operations were present in the WOP scenario as all projects had been removed.

Without-Project II Scenario

All conditions in the WOP II scenario are the same as those for the WOP scenario with the exception of the hydrology. The primary purpose of this scenario was to smooth out the flow variability being routed down the river during summer periods (Figure 4.7-2). These variations, which are most prominent between Julian day 200 and 250, originate with USBR project operations and maintenance of Keno reservoir at a stable water surface elevation during operations. The fluctuation from USBR operations can, over the span of a few days, exceed 500 cfs. The original WOP scenario assumed that all USBR project operations were consistent with historical conditions—in which case the flow variations that occurred were historically "re-regulated" by system reservoirs that were routed down the river. Stakeholder input identified this as an unrealistic without-Project operation and requested that attempts be made to smooth the hydrograph that was routed down the river.

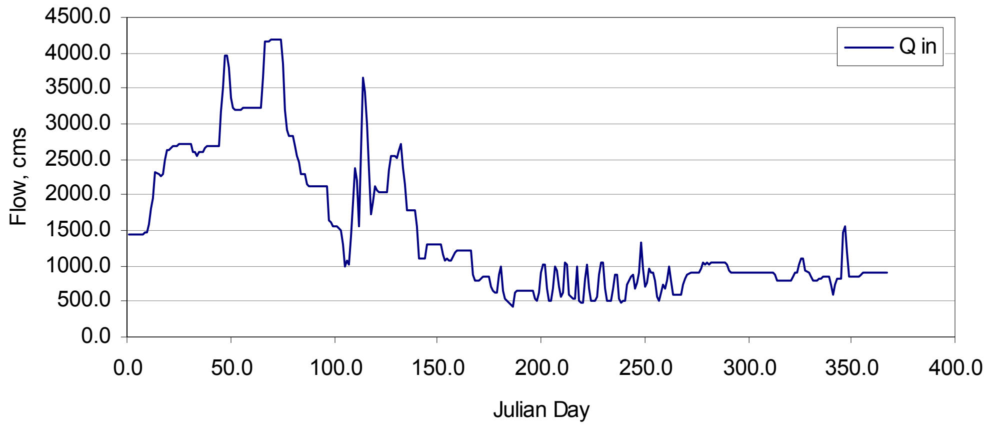


Figure 4.7-2. Keno dam WOP flow, 2000.

To address this issue, a 7-day running average flow was calculated at Keno dam (Figure 4.7-3). Using a water balance on the Link dam to Keno dam reach, several attempts were made to identify flow boundary conditions within this reach to achieve a smooth hydrograph at Keno dam. These attempts failed to attain a hydrograph that was acceptable. Challenges include the variable transit times through the reach from the various inflow points (Link dam, Lost River diversion channel, Klamath Straits Drain, and return flow location), a process further confounded by the impacts on transit time due to diversions from various points. Lumping inputs and outputs was initially considered to simplify the transit time issue, but, due to the variable timing and water quality of the various waters, this was deemed unacceptable because the results would be difficult to interpret and the results could not be readily compared with the other global scenarios.

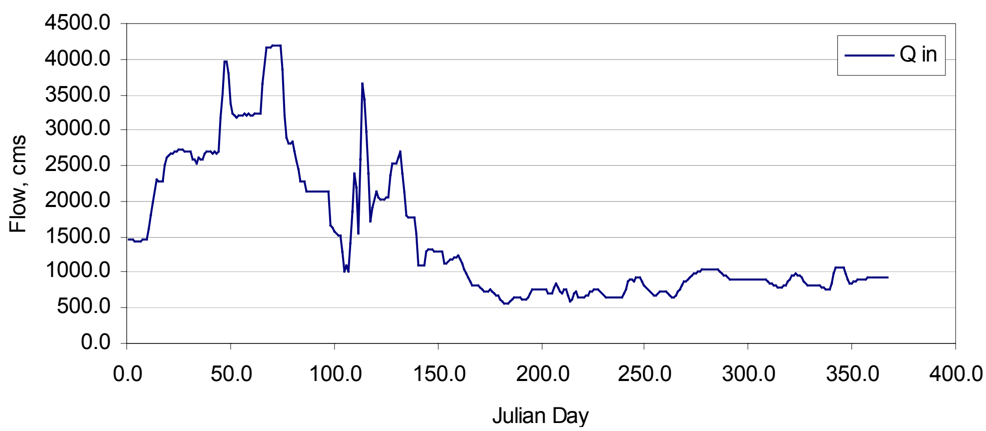


Figure 4.7-3. Keno dam WOP II flow (smoothed), 2000.

With stakeholder input, it was decided to use WOP scenario water quality conditions at Keno dam and route those results down the river from Keno dam to Turwar using the smoothed hydrograph presented in Figure 4.7-3. This assumption presumes that the results with a smoothed hydrograph are similar to those without smoothing. (The flow and water quality results for all locations above Keno dam are identical.) WOP and WOP-II flows at Keno dam for 2001 are presented in Figures 4.7-4 and 4.7-5. The impacts of smoothing in 2001 were modest because USBR operations were offline.

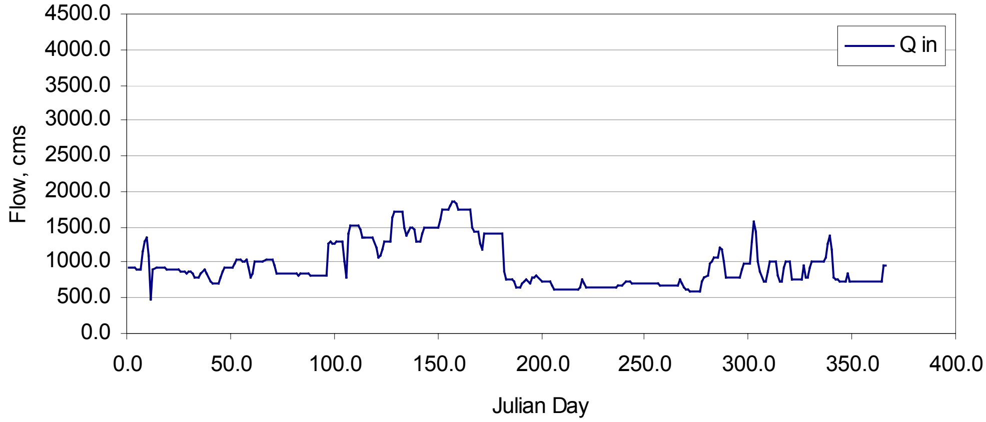


Figure 4.7-4. Keno dam WOP flow, 2001.

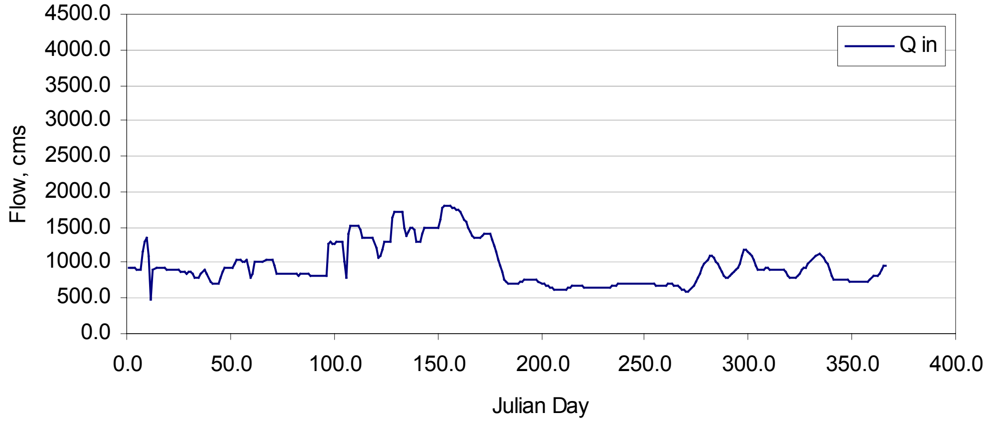


Figure 4.7-5. Keno dam WOP II flow (smoothed), 2001.

4.7.4 Water Quality Modeling Results to Date

The model framework produces a substantial amount of information. To effectively provide information to the stakeholders, regulators, and various analysts, input was solicited via monthly meetings with the Water Quality Work Group. Specific locations were identified where model output was desired, as well as parameters and summary statistics. Data were produced for 29 locations, primarily for flow, water temperature, and DO. The information is available in both tabular form and graphical form in Appendix 4A. The current graphical output includes the following.

For existing condition, steady flow, and without-Project scenarios:

- Time series (1-hour data) of water temperature and DO
- Daily maximum, mean, and minimum of water temperature and DO

- Longitudinal profiles for river reaches (J.C. Boyle bypass/peaking and Iron Gate dam to Turwar) for the first of each month from April through November of water temperature and DO
- Daily mean flow and water temperature (double y-axis plot)
- Daily mean flow and DO (double y-axis plot)

Comparisons of:

- Daily mean water temperature (existing condition versus other scenarios)
- Daily mean DO (existing condition versus other scenarios)
- Longitudinal profiles of water temperature and DO for the entire river from Link dam to the Klamath River near Turwar for the first of each month from April through November

4.8 RESULTS

This section provides an overview of model results for three of the four basic model scenarios described in section 4.7:

1. Existing operations conditions
2. Steady flow (i.e., run-of-river) operations condition
3. Hypothetical without-Project conditions under existing inflow boundary conditions (WOP)

Results of the other hypothetical without-Project scenario (WOP II), which assumes existing inflow boundary conditions that are smoothed to Keno dam,[3] are available but are not discussed here. The results of EC and SF scenarios, compared to the WOP scenario, provide a more accurate indication of potential Project effects. Because the WOP II scenario assumes changed boundary conditions, model comparisons using the WOP II scenario would include other potential effects not caused by the Project. Calendar years 2000 and 2001 were simulated for all scenarios.

The output from these model runs has been post-processed into a series of Excel™ spreadsheets. The output is hourly for each constituent at each site. Consquently, the output is voluminous and the spreadsheet files very large. Therefore, this output is not provided in this Water Resources FTR. The spreadsheets are provided to the Water Quality Work Group after model results are produced and reviewed for accuracy. These spreadsheets are available upon request from PacifiCorp (Todd Olson, Project Manager, 503-813-6657).

[3] All conditions in the WOP II scenario are the same as those for the WOP scenario with the exception of the hydrology. The primary purpose of this scenario was to smooth out the flow variability being routed down the river during summer periods (see Figure 4.7-2). These variations, which are most prominent between Julian day 200 and 250, originate with USBR project operations and maintenance of Keno reservoir at a stable water surface elevation during operations. The fluctuation over the span of a few days can exceed 500 cfs. The original WOP scenario assumed that all USBR project operations were consistent with historical conditions—in which case the flow variations that occurred were historically re-regulated by system reservoirs that were routed down the river. Stakeholder input identified this as an unrealistic without-Project operation and requested that attempts be made to smooth the hydrograph that was routed down the river.

The results of SLOM model runs of the scenarios are not discussed in this section. The SLOM runs are intended to help stakeholders complete an assessment of whether information will be available to FERC to examine potential Project removal alternatives. As of the date of preparation of this document, the model runs for the SLOM scenarios have not been completed. PacifiCorp plans to complete the SLOM scenarios and present them to stakeholders in early spring 2004. In any event, the SLOM scenarios are not a necessary component of PacifiCorp's evaluation for its license application.

This section is organized to discuss model results by river reaches. The reach designations are:

- Link River (Link dam to Link River at Lake Ewauna) (RM 253.9 to RM 252.7)
- Keno reservoir (RM 252.7 to RM 232.9)
- Keno dam to J.C. Boyle reservoir (RM 232.9 to RM 227.6)
- J.C. Boyle reservoir to Copco reservoir (bypass and peaking reach) (RM 227.6 to RM 203.6)
- Copco reservoir (RM 198.6 to RM 203.6)
- Iron Gate reservoir (RM 190.5 to RM 197.5)
- Iron Gate dam to Turwar (RM 190.5 to RM 5.6)

For the analysis presented below, unless otherwise noted, temperature, DO, and nutrients are mean daily values.

4.8.1 Link River

Results are discussed for EC only. SF and WOP results differ little because of the short reach length and identical flow and water quality boundary conditions at Link dam.

4.8.1.1 Flow

Model results for flow are discussed in Section 5.0 of the Water Resources FTR.

4.8.1.2 Water Temperature

Model results indicate the following:

- Water temperature in Link River illustrates a seasonal response to meteorological conditions and thermal loading. Winter temperatures are cool and rise steadily in response to increased thermal loading as length of day and solar altitude increase. Peak temperatures of around 25°C generally occur around August 1, with temperatures in excess of 20°C from mid-June through mid-September. On a daily basis, the temperature at Link dam is moderated by the relatively large thermal mass of Upper Klamath Lake.

- Cooling proceeds through the fall period in response to reduced thermal loading, shorter day length, and the occurrence of cold fronts passing through the region; however, periods of Indian summer can suspend the cooling trend for several days. Short duration events, such as warm and cool periods, introduce considerable variation during the late spring through fall period.

- Heating in the Link River reach is minor because the transit time—and thus exposure to heating and cooling elements—is short. Figures 4.8-1 and 4.8-2 present water temperatures in the reach for the EC case for 2000 and 2001, respectively. Conditions are similar for the SF and WOP conditions.

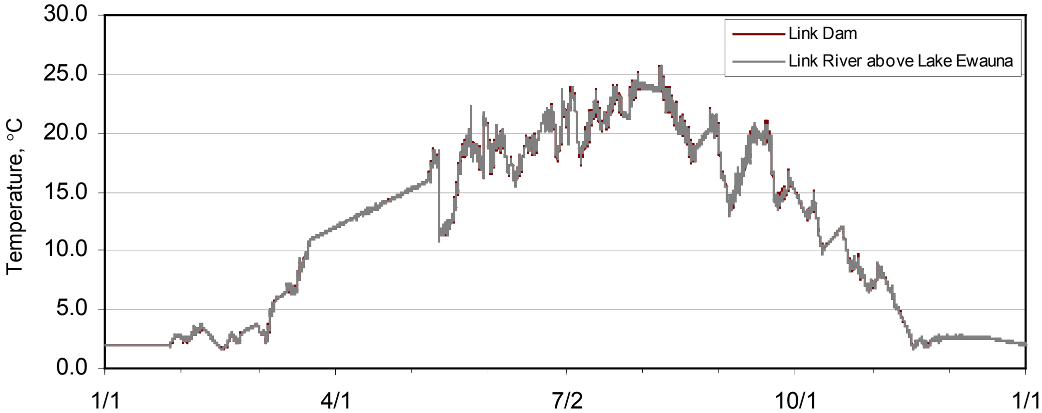


Figure 4.8-1. EC hourly water temperature at Link dam and Link River at Lake Ewauna, 2000.

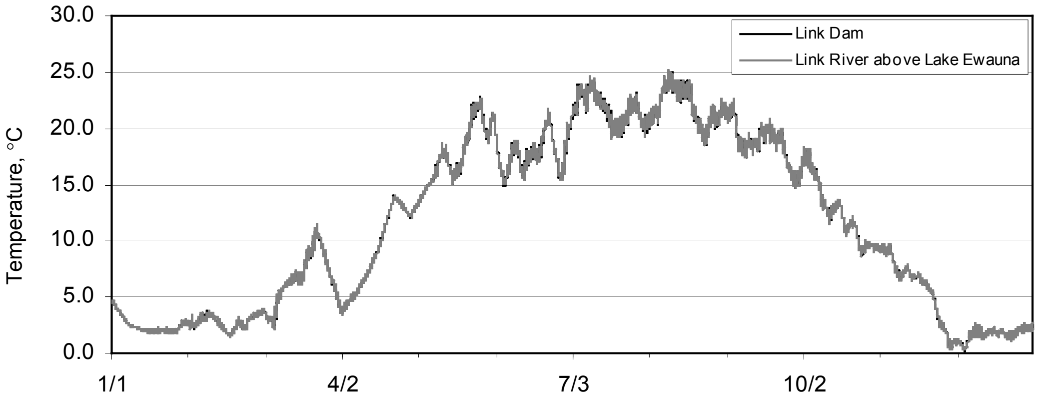


Figure 4.8-2. EC hourly water temperature at Link dam and Link River at Lake Ewauna, 2001.

4.8.1.3 Dissolved Oxygen

Model results indicate the following:

- DO responds to sub-daily, daily, seasonal, and annual conditions. The saturation DO concentration follows the seasonal trend in water temperature. However, short duration conditions, such as diurnal variations in photosynthesis and respiration, as well as large algal population conditions in Upper Klamath Lake (e.g., phytoplankton blooms) affect dissolved oxygen concentrations.

- Figure 4.8-3 shows the modeled boundary condition for calendar year 2000. Because no continuous data were available, saturation DO was used. Comparison with the 2001 condition (Figure 4.8-4) illustrates that this boundary condition to Link River is highly dynamic and responds strongly to conditions in Upper Klamath Lake (at least in the vicinity of Link dam). DO levels are at near saturation from November through March, but deviate in spring and summer months.

- Concentrations typically reach seasonal lows in July and August, often reaching values less than 2 mg/L, or about 20 to 30 percent of saturation. Periods of subsaturation DO can last from days to weeks. Little recovery of DO is realized in the short Link River reach. Thus, during summer periods, depressed DO conditions are transported downstream to Lake Ewauna and Keno reservoir. SF and WOP conditions are similar for Link River.

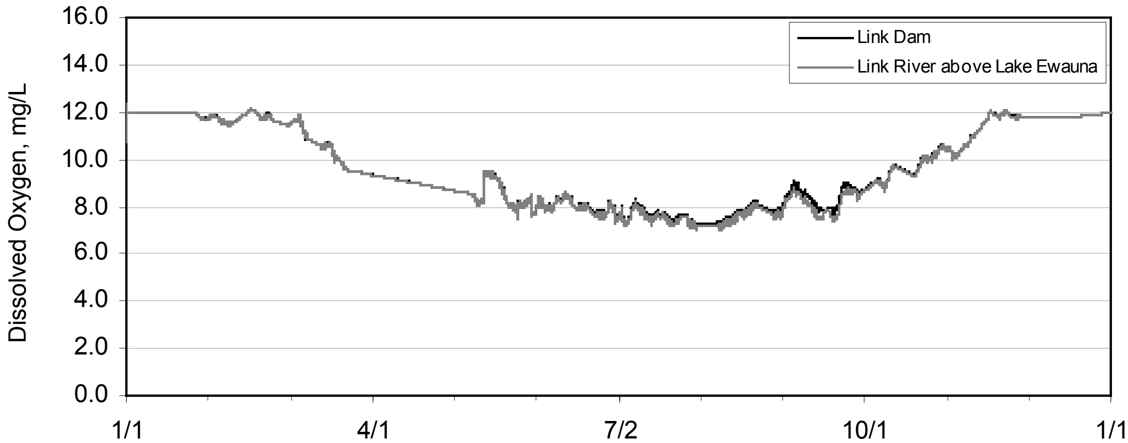


Figure 4.8-3. EC hourly dissolved oxygen at Link dam and Link River at Lake Ewauna, 2000.

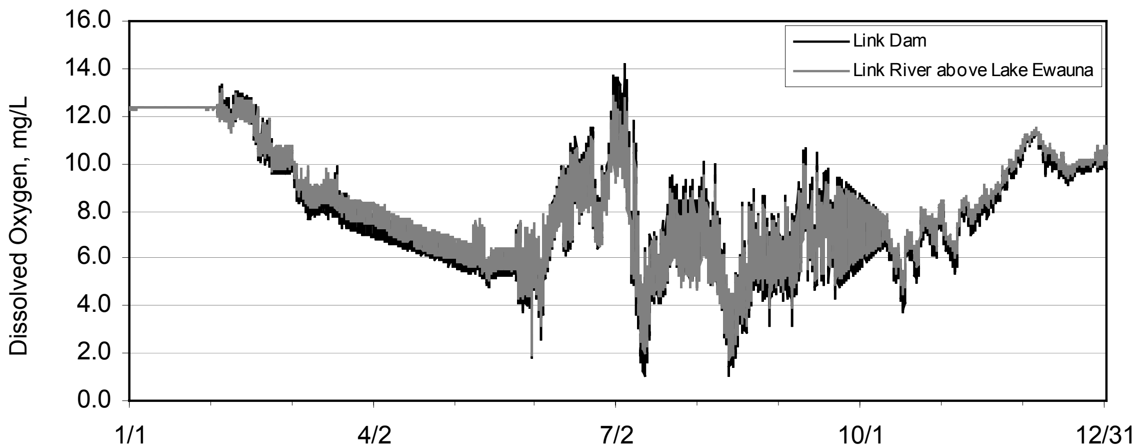


Figure 4.8-4. EC hourly dissolved oxygen at Link dam and Link River at Lake Ewauna, 2001.

4.8.1.4 Nutrients, Algae and Organic Matter

Model results indicate the following:

- WOP, EC, and SF conditions are similar for Link River. Inorganic nutrients (orthophosphate [PO_4^{3-}], ammonia [NH_4^+], and nitrate [NO_3^-]) are seasonally variable in the Link River. Background levels occur in winter, depressed values in the spring during the initial population increases of primary production (algae), and elevated values in summer and fall as algae production levels out, blooms, and dies off.

4.8.2 Lake Ewauna/Keno Dam

Lake Ewauna/Keno dam comprises Lake Ewauna proper and the impounded river reach (Keno reservoir) down to Keno dam. Within this reach there are several municipal and industrial discharges, as well as agricultural diversions and return flows. Some of the major diversions include the Lost River diversion channel, North canal, and ADY canal; major return flow locations include the Lost River diversion channel and the Klamath Straits Drain.

4.8.2.1 Flow

Model results for flow are discussed in Section 5.0 of this Water Resources FTR. Typical flows at Keno dam are on the order of 700 to 1,000 cfs during summer and fall periods. The flow regime during the remainder of the year is largely a function of hydrology and Upper Klamath Lake storage conditions. Residence time in Lake Ewauna/Keno reservoir in the summer period is about 7 to 14 days, depending on river flow levels.

4.8.2.2 Water Temperature

Model results indicate the following:

- Water temperature in the Lake Ewauna/Keno dam reach responds most strongly to seasonal and short-term (days to weeks) meteorological conditions. Because Upper Klamath Lake waters are at or close to equilibrium, deviations from Upper Klamath Lake water temperature conditions are modest.

- The warmest water temperatures are approximately 25°C and often occur in early August (Figures 4.8-5 and 4.8-6). Overall, the impoundment experiences modest diurnal variation (±2°C) due to the thermal mass of the reservoir. However, near surface water temperatures can exhibit higher diurnal variations. Water temperatures are often greater than 20°C from June through September.

- Lake Ewauna/Keno reservoir does not experience seasonal stratification. However, during summer periods, there is weak, intermittent stratification on a daily basis that, under certain conditions (calm winds, low flow), may persist at particular locations.

- SF results were similar to EC for the 2000 and 2001 periods.

- Temperatures for the WOP scenario show a larger diurnal cycle (by approximately 1°C to up to 5°C) than EC and SF do throughout the year, but are most notable in summer months (Figures 4.8-7 and 4.8-8). WOP mean daily temperature was lower by up to 4°C from approximately July through October (Figure 4.8-9). Under the WOP scenario, Keno reservoir is more river-like, and thus a smaller thermal mass is assumed than in the other two scenarios. As such, WOP waters heat and cool more quickly than reservoir waters. Also, the water transit time in the WOP scenario (1 to 2 days) is 7 to 14 days less than in the other two scenarios.

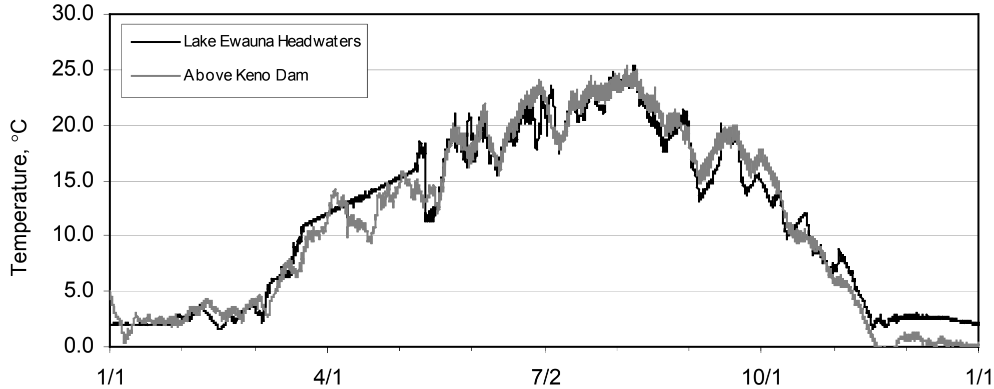


Figure 4.8-5. EC hourly water temperature (at ~1.5 m) in the Keno reservoir reach, 2000.

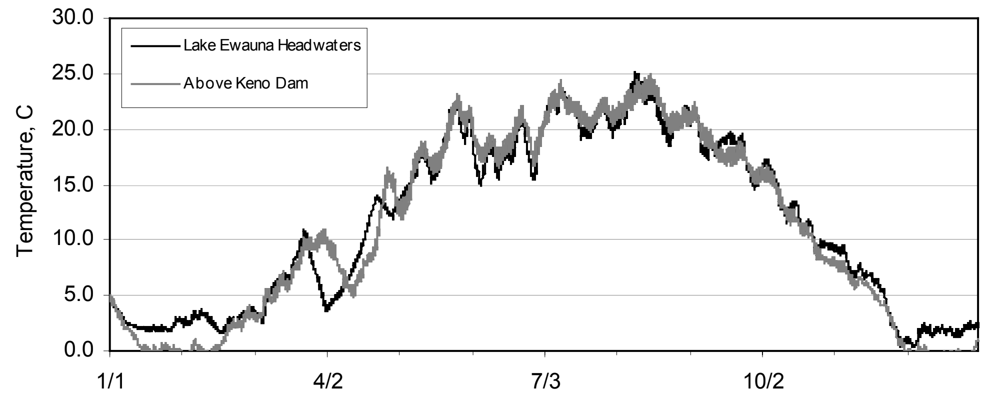


Figure 4.8-6. EC hourly water temperature (at ~1.5 m) in the Keno reservoir reach, 2001.

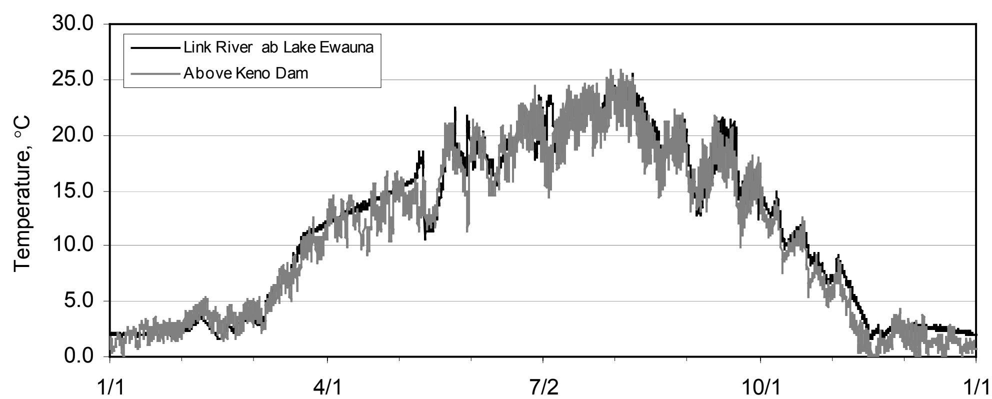


Figure 4.8-7. WOP hourly water temperature in the Keno reservoir reach, 2000.

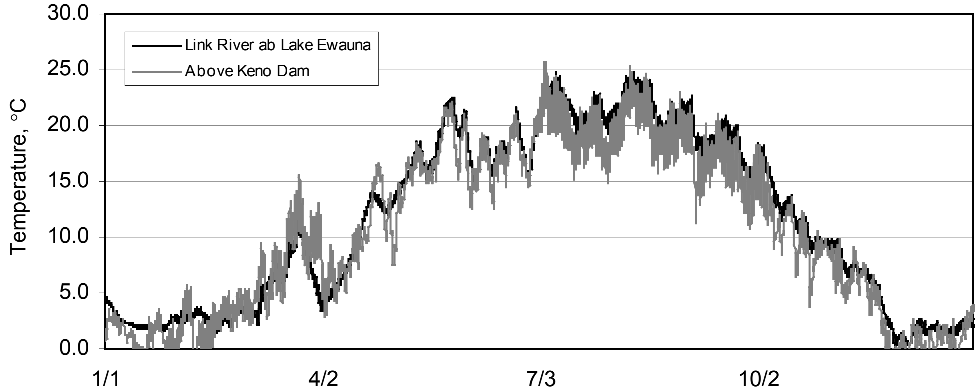
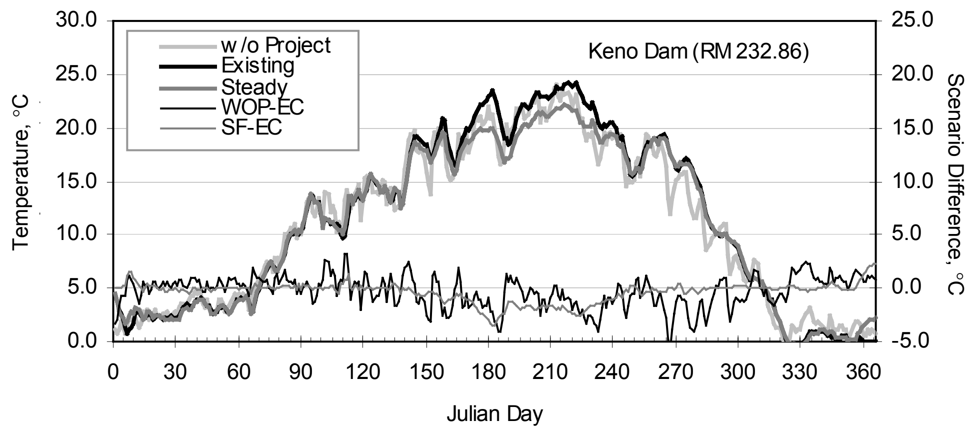


Figure 4.8-8. WOP hourly water temperature in the Keno reservoir reach, 2001.



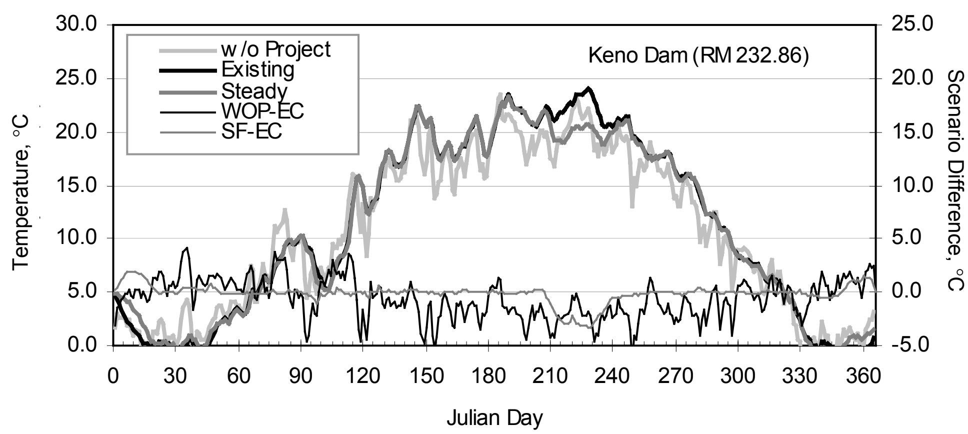


Figure 4.8-9. EC versus SF and WOP mean daily water temperature at Keno dam for 2000 (top) and 2001 (bottom) conditions.

4.8.2.3 Dissolved Oxygen

Model results indicate the following:

- DO in Lake Ewauna/Keno reservoir is highly variable during the year (Figures 4.8-10 and 4.8-11). From early fall through early spring, conditions are generally at or near saturation concentration. During later spring through early fall, DO can be at low values throughout the reservoir. These low levels can persist for days to weeks. It appears that the onset of such conditions is temperature-dependent. This may coincide with the longer day length and increased primary production systemwide. Primary production within the reservoir is appreciable, generally on a par with Upper Klamath Lake; however, there are periods when little oxygen is present and algal populations appear to be diminished.

- It is hypothesized that the condition in Keno reservoir is similar to a DO sag downstream of a point discharge. In this case, the source is Upper Klamath Lake, which imparts a large organic load of living and dead algae. The surface area of Upper Klamath Lake upstream of Link dam is relatively wide—perhaps ten times as wide as Keno reservoir. Thus, Upper Klamath Lake can impart an appreciable amount of algae into Link River and subsequently into Keno reservoir. There is insufficient surface area in Keno reservoir to support the influent algae population (assuming it survives), and thus the algae that are positioned below the photic zone die (along with those algal cells that did not survive transport through Link River) and impart an oxygen demand on the system. This process may begin in Upper Klamath Lake as the waters move toward Link dam and the lake begins to narrow.

- The SF results are similar to EC results, with low DO values at RM 243, but recovery occurs sooner.

- WOP simulations suggest that under a no-impoundment condition DO would differ. Figures 4.8-12 and 4.8-13 illustrate that there would still be depressed DO in the system from roughly June through September; however, this deviation from saturation is only from 1 to 2 mg/L. Exceptions include the deviation in fall 2000 at RM 246 due to Lost River diversion channel inflows, and a period around August 1 in 2001 when there was a large BOD load from Upper Klamath Lake.

- Figure 4.8-14 illustrates a longitudinal profile of this reach for July 15, indicating the DO sag between Link dam (RM 254) and Keno dam (RM 232). The low point occurs around RM 245, followed by slow recovery. This recovery is interrupted by input from the Klamath Straits Drain, which lowered DO concentrations by about 0.5 mg/L. Recovery of DO is nearly complete by Keno dam.

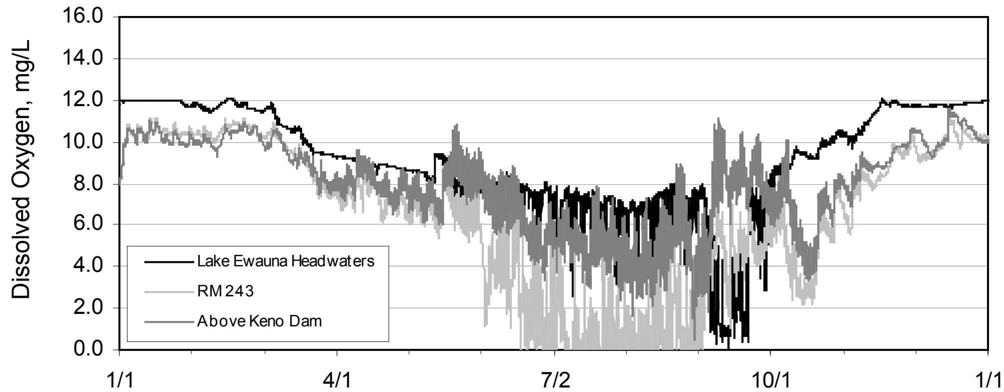


Figure 4.8-10. EC dissolved oxygen (at ≈1.5 m) in the Keno reservoir reach, 2000.

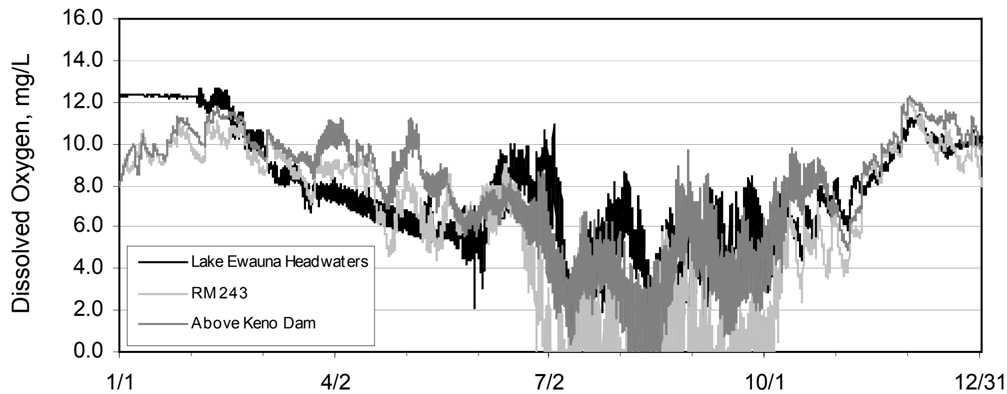


Figure 4.8-11. EC dissolved oxygen (at ≈1.5 m) in the Keno reservoir reach, 2001.

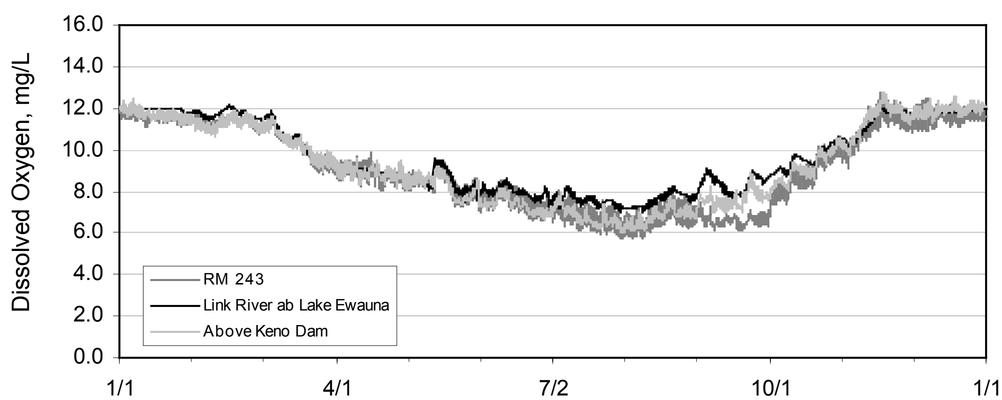


Figure 4.8-12. WOP dissolved oxygen in the Keno reservoir reach, 2000.

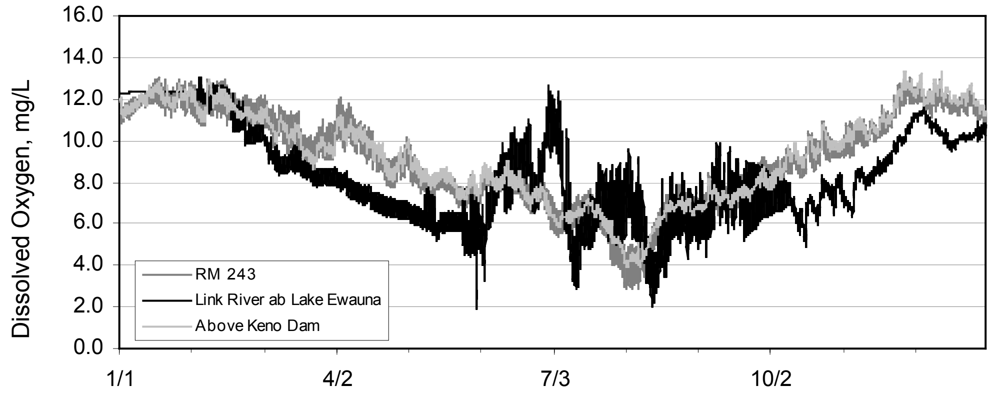


Figure 4.8-13. WOP dissolved oxygen in the Keno reservoir reach, 2001.

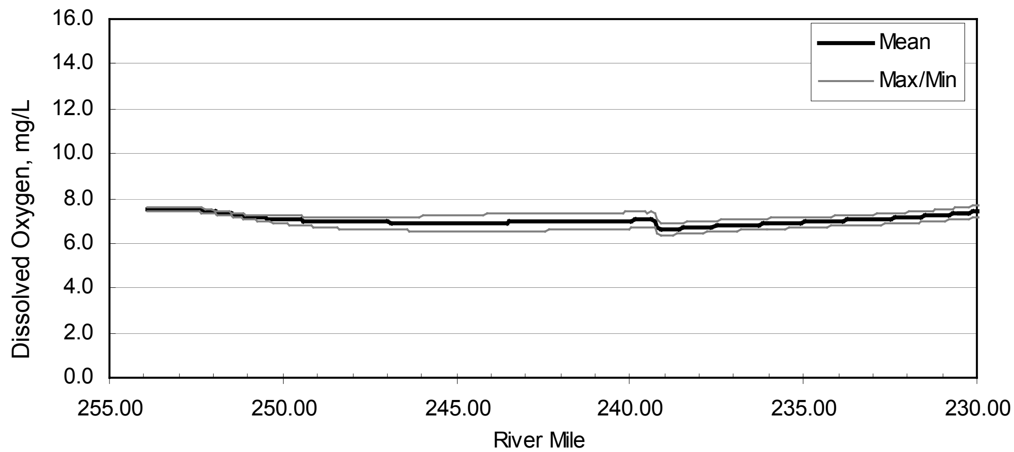


Figure 4.8-14. WOP longitudinal profile of mean, maximum, and minimum dissolved oxygen in the Keno reservoir reach as simulated for July 15, 2001.

4.8.2.4 Nutrients, Algae, and Organic Matter

Model results indicate the following:

- EC and SF nutrient conditions in Lake Ewauna/Keno reservoir exhibit seasonal variations similar to Link River. It is not uncommon for values of ammonia and nitrate to increase by an order of magnitude (to greater than 1.0 mg/L). Increases in orthophosphate are generally less, but still increase several times their springtime levels. Seasonal levels at Keno dam are similar to Link River.

- This reach experiences the typical seasonal increase in algae during spring and summer months with low levels in winter months. The characteristics of this impoundment coupled with the 7- to 14-day transit time between Link River and Keno dam, can result in algal concentrations that differ between upstream and downstream portions of this reach. Algal concentrations can increase, decrease, or remain stable throughout this reach.

- WOP nutrient conditions in Lake Ewauna/Keno reservoir exhibit seasonal variations similar to Link River. However, because the transit time is greatly reduced in WOP, there is only minor variation between Link River and Keno dam in the shape of the time series of model output. Local phytoplankton species probably do not perform well in a riverine environment, but loss in biomass over a day or two is probably modest. Under WOP conditions, water quality conditions borne out of Upper Klamath Lake are transported more quickly downstream.

4.8.3 Keno Dam to J.C. Boyle Reservoir

4.8.3.1 Flow

Model results for flow are discussed in Section 5.0 of this Water Resources FTR. Flow conditions varied under the three scenarios. In all cases, accretions in the Keno reach are assumed to be negligible. There is a small accretion assumed in the reach, but it does not significantly impact the flow and quality is not assigned to it. Under all operations, transit time through the reach is on the order of 4 to 8 hours during summer periods, depending on flow conditions.

EC flow conditions in the Keno reach are controlled by Keno dam and upstream operations. As with Link dam flows, winter flows are driven by hydrologic conditions and storage operations at Upper Klamath Lake. During summer months in 2000, flow below Keno dam varies considerably in response to USBR Klamath Irrigation Project operations. The USBR project was largely off line in 2001, so that the hydrograph at Keno dam illustrates less variability.

The 2000 flow conditions under SF assumptions are smoother than the EC flow conditions. The 2001 flow conditions are similar to EC due to the USBR Klamath Irrigation Project being largely off line.

4.8.3.2 Temperature

EC and SF conditions produce similar temperature traces at Keno dam and the Klamath River above J.C. Boyle reservoir, with a moderated diurnal single below Keno dam and an incomplete diurnal signal above J.C. Boyle dam due to the short transit time through the reach. WOP results indicate a larger diurnal range. However, maximum temperatures and warmest periods of the year are similar for all conditions.

Modeling results indicate the following.

Existing Condition

- Water temperature in the Keno reach is moderated in the vicinity of Keno dam. Keno reservoir, being a relatively large body of water does not experience the same rate of heating and cooling as a smaller river system. The maximum diurnal range below Keno dam is 1°C to 2°C in the summer months, while the diurnal range above J.C. Boyle reservoir approaches 5°C (Figure 4.8-15).

- The warmest portion of the year for the Klamath River above J.C. Boyle reservoir is typically late July through early August, with maximum daily temperatures in excess of 27°C. There is no appreciable heating in this reach (upstream to downstream), as measured by mean daily temperature, because upstream reaches are at or close to equilibrium temperature.

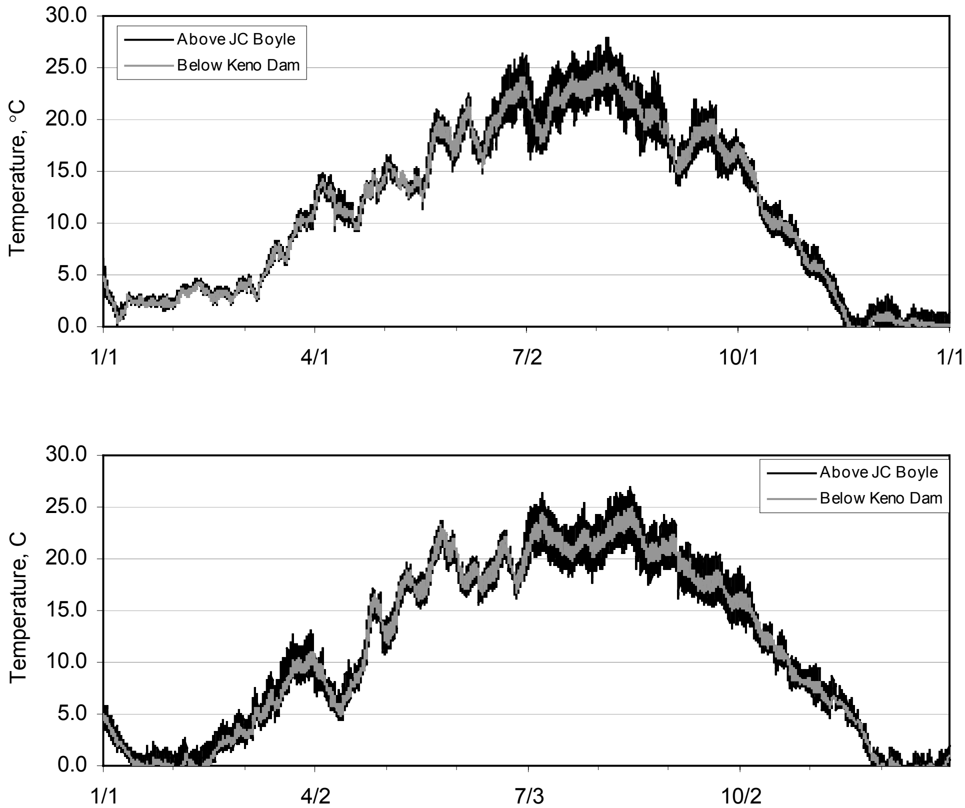


Figure 4.8-15. EC hourly water temperature at Keno dam and above J.C. Boyle reservoir for 2000 (top) and 2001 (bottom) conditions.

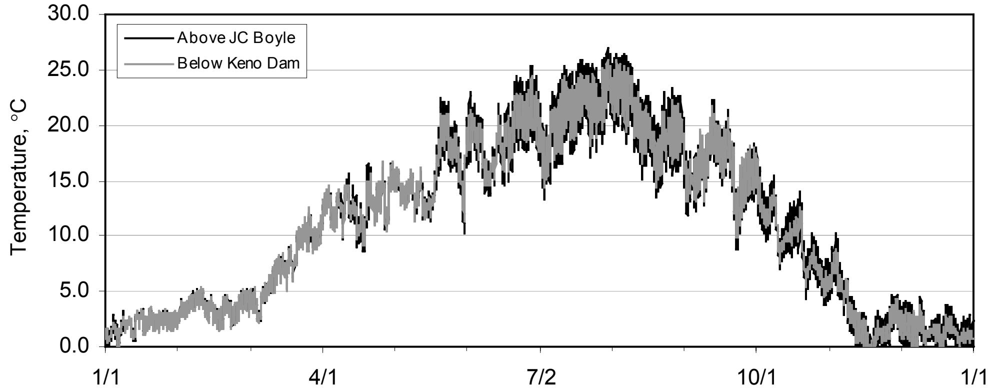
Steady Flow

- The SF simulation results are similar to EC.

Without-Project

- Moving from upstream to downstream, the WOP scenario continues to produce a larger diurnal signal in riverine reaches (Figure 4.8-16). The transit time through this reach is short. Under EC and SF, there is probably insufficient time to attain a full diurnal signal—the diurnal range is often over 5°C for WOP, while it is generally less than 5°C for EC and SF.

- The timing and magnitude of maximum annual temperatures are approximately the same as EC and SF. There is no appreciable upstream to downstream heating in this reach.



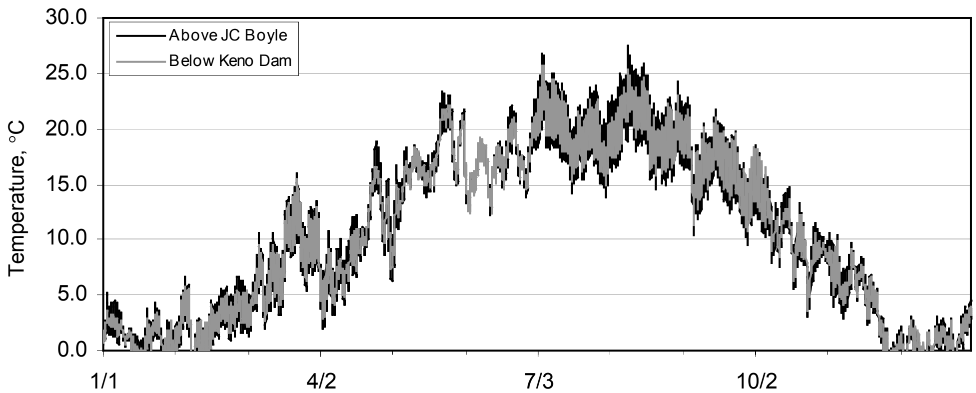
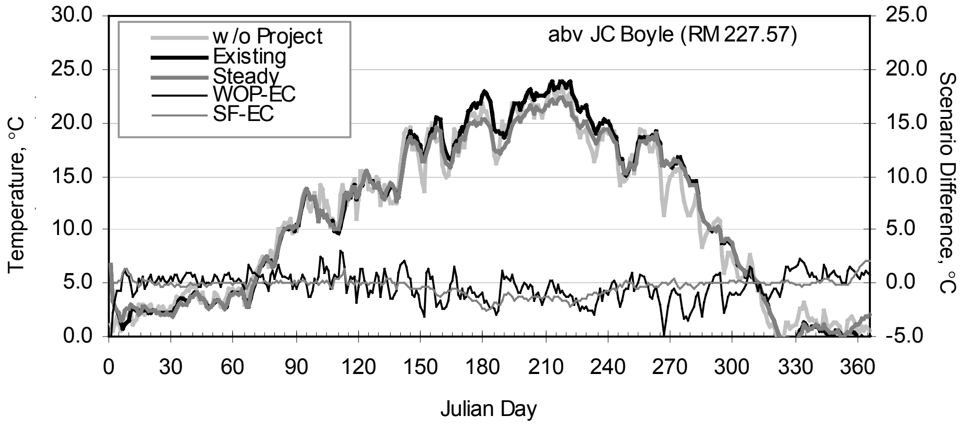


Figure 4.8-16. WOP hourly water temperature at Keno dam and above J.C. Boyle reservoir for 2000 (top) and 2001 (bottom) conditions.

- When scenarios are compared with respect to daily mean water temperature (Figure 4.8-17), the following conditions are noted:
  - There is a slight thermal lag created from Lake Ewauna/Keno reservoir.
  - WOP has a greater diurnal variation than SF and WOP—the river has a smaller thermal mass than Lake Ewauna/Keno reservoir.



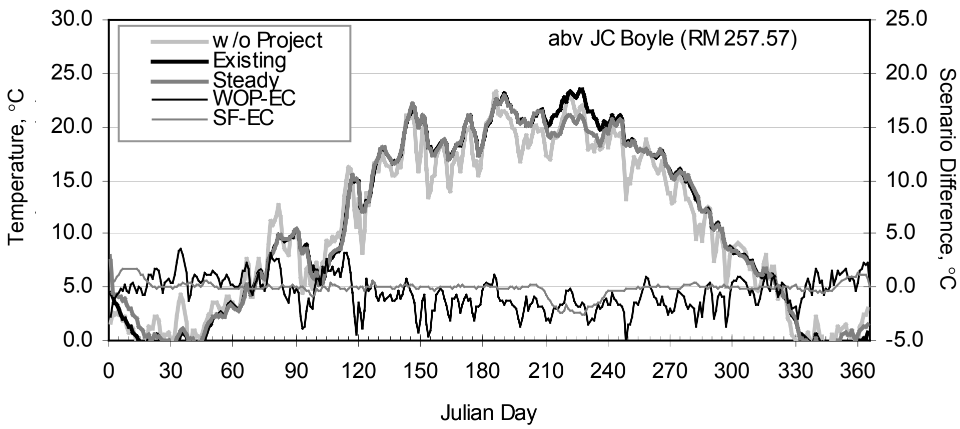


Figure 4.8-17. EC versus SF and WOP mean daily water temperature at Keno reach for 2000 (top) and 2001 (bottom) conditions.

4.8.3.3 Dissolved Oxygen

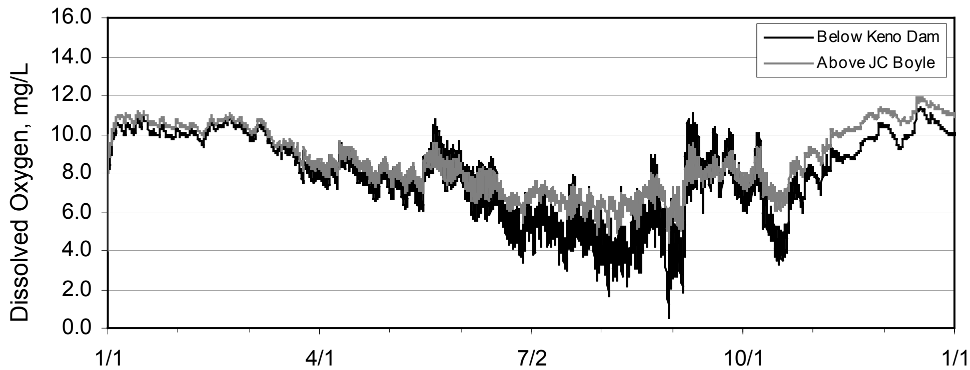
DO concentrations show a persistent recovery to saturation conditions in the Keno reach during summer and fall periods. Mechanical re-aeration is probably the major process leading to recovery of DO levels; however, benthic algae may play a role. The river continues to carry an appreciable load of organic matter in the form of algae (both living and dead cells). Thus, the river does not always retain 100 percent saturation en route to J.C. Boyle reservoir during the warmer, more productive months of the year. Deviations from saturation typically occur between June and September.

Model results indicate the following:

<u>Existing Conditions</u>

- Under existing conditions, DO concentrations show a persistent recovery to saturation conditions in the Keno reach during summer and fall periods (Figure 4.8-18).

- During summer periods the diurnal range at Keno dam is larger than that above J.C. Boyle reservoir, possibly reflecting the appreciable primary productivity in Keno reservoir upstream of the dam as compared with benthic production in the reach between Keno dam and J.C. Boyle reservoir.



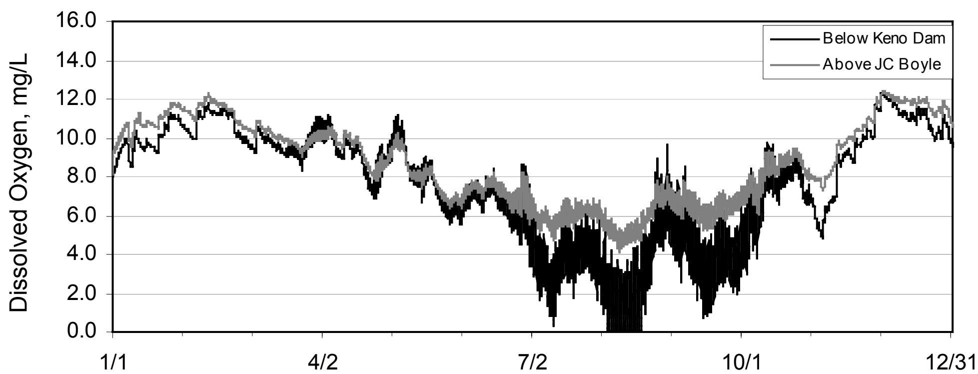


Figure 4.8-18. EC hourly dissolved oxygen at Keno dam and above J.C. Boyle reservoir for 2000 (top) and 2001 (bottom) conditions.

Steady Flow

- Under SF assumptions, DO maintains conditions around saturation in 2000, with deviations primarily due to photosynthesis and respiration, but DO levels are lower (below saturation) during periods of 2001 (Figure 4.8-19).

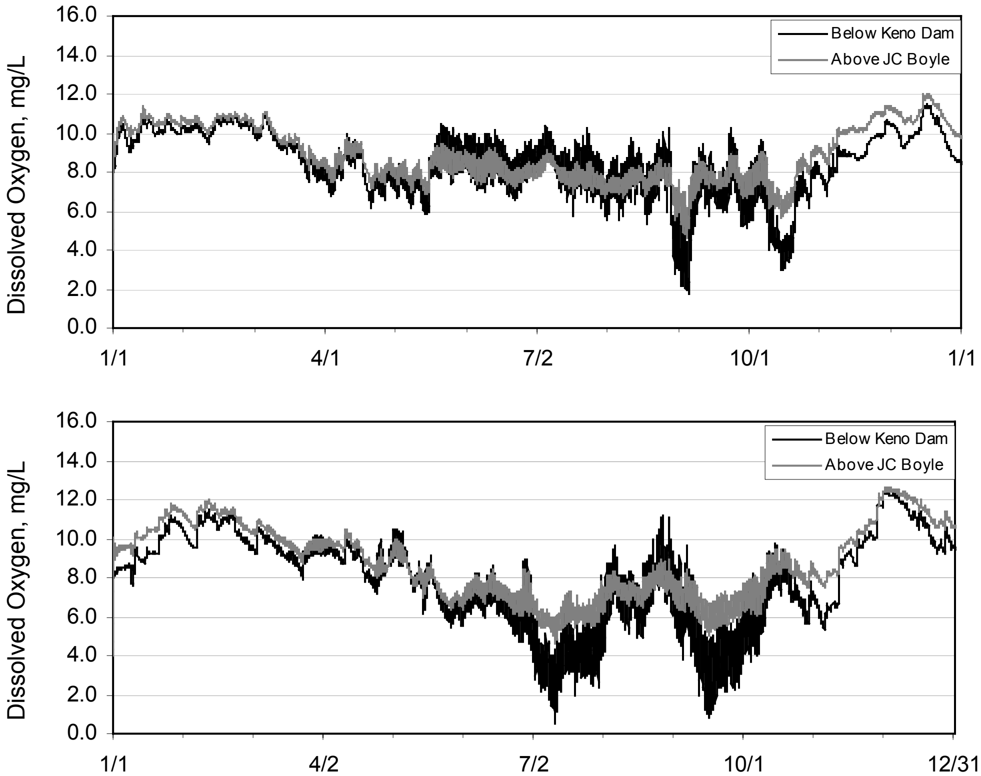


Figure 4.8-19. SF hourly dissolved oxygen at Keno dam and above J.C. Boyle reservoir for 2000 (top) and 2001 (bottom) conditions.

Existing Conditions

- Similar to SF, the diurnal range at Keno dam during summer periods is larger than that above J.C. Boyle reservoir.

Without Project

- The WOP simulations generally follow the seasonal trend of saturation based on temperature and elevation (Figure 4.8-20). However, organic matter from Upper Klamath Lake during mid-summer months does produce conditions that are still just below saturation—even above J.C. Boyle reservoir. This inability to re-aerate to fully saturated conditions is probably a function of benthic algae respiration and the fact that under WOP assumptions travel time to this reach is on the order of a day. Thus, organic matter can reach this location (and impart its oxygen demand) well before appreciable decay occurs.

- Unlike EC and SF, the diurnal range at both the upstream and downstream locations is similar, but is slightly larger at the downstream location.

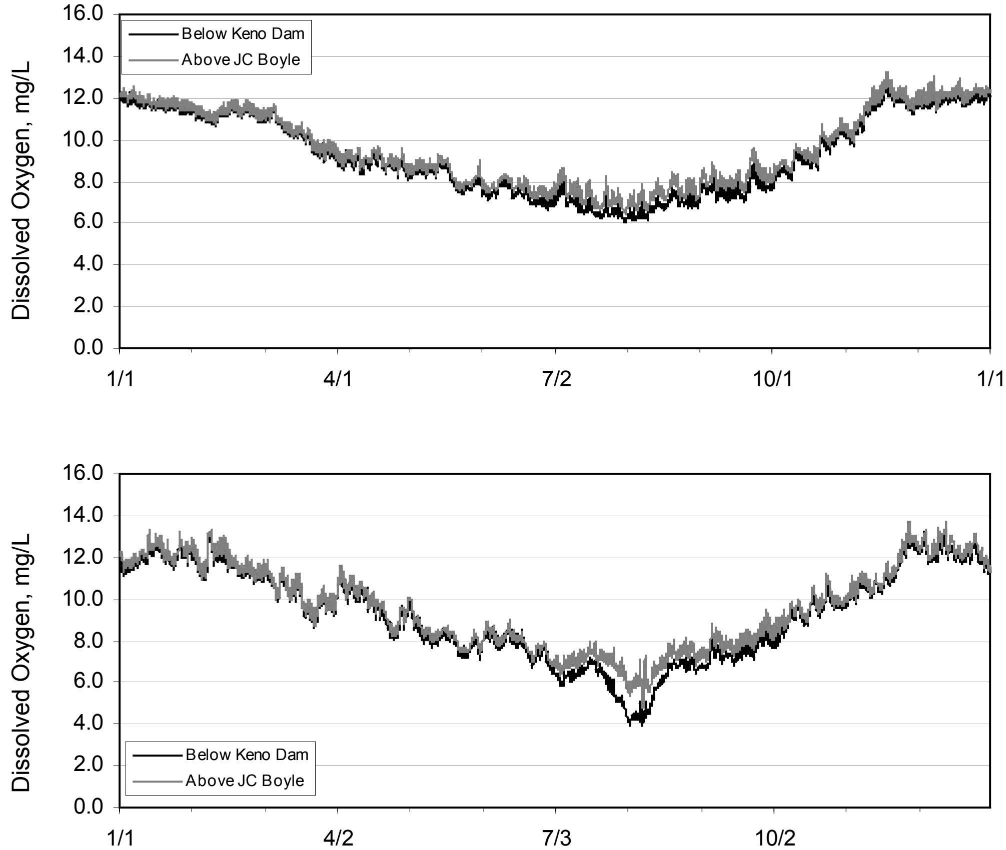
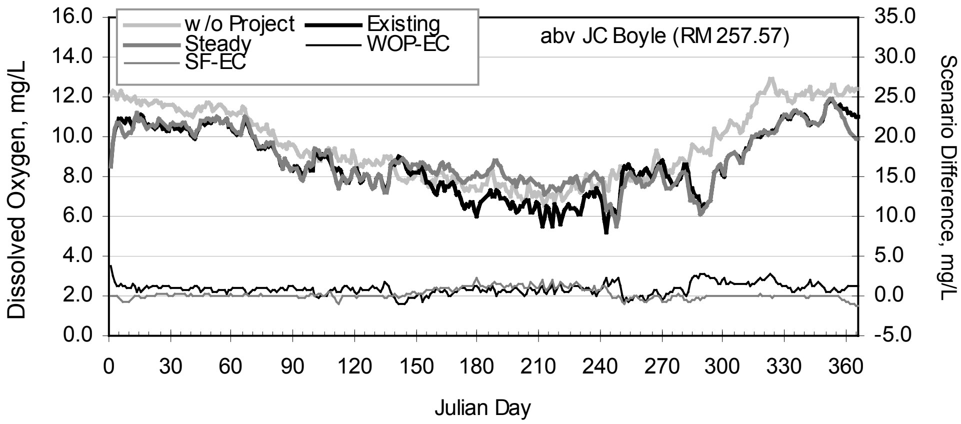


Figure 4.8-20. WOP hourly dissolved oxygen at Keno dam and above J.C. Boyle reservoir for 2000 (top) and 2001 (bottom) conditions.

When comparing scenarios with respect to daily mean DO (Figure 4.8-21), the following conditions are noted:

- WOP typically experiences better DO—this is expected in a riverine environment compared with a lake-like environment, especially in this system with the appreciable load from Upper Klamath Lake.
- SF conditions are very similar to EC conditions.



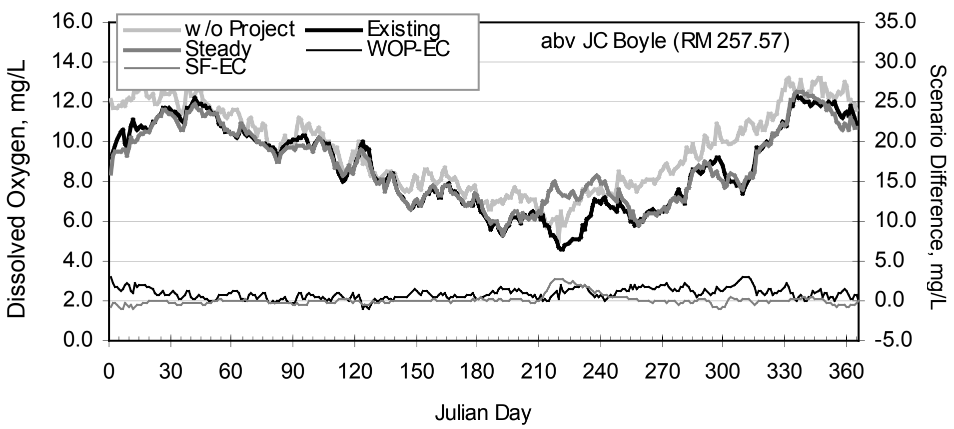


Figure 4.8-21. EC versus SF and WOP mean daily dissolved oxygen in the Keno reach of the Klamath River for 2000 (top) and 2001 (bottom) conditions.

4.8.3.4 Nutrients, Algae, and Organic Matter

Because of the short transit time, there is little change in the nutrient concentration and algal biomass. An important component of this reach is that local lake phytoplankton species will not fare well in river reaches. Nonetheless, releases from Keno dam will convey appreciable organic loads to downstream river reaches.

4.8.4 J.C. Boyle Reservoir

4.8.4.1 Flow

Model results for flow are discussed in Section 5.0 of this Water Resources FTR. Flow conditions varied under the three scenarios. For inflow conditions, refer to upstream reaches. Downstream releases at J.C. Boyle dam include a constant 100 cfs for bypass flows and fish ladder requirements.

4.8.4.2 Water Temperature

In general, J.C. Boyle reservoir undergoes weak, intermittent thermal stratification (Figure 4.8-22). The reservoir typically experiences these conditions from June (Julian day 153) through August (Julian day 245). SF conditions exhibit different stratification dynamics than EC—a similar magnitude of stratification in 2000, but with different timing, and persistent weak stratification in 2001(Figure 4.8-23).

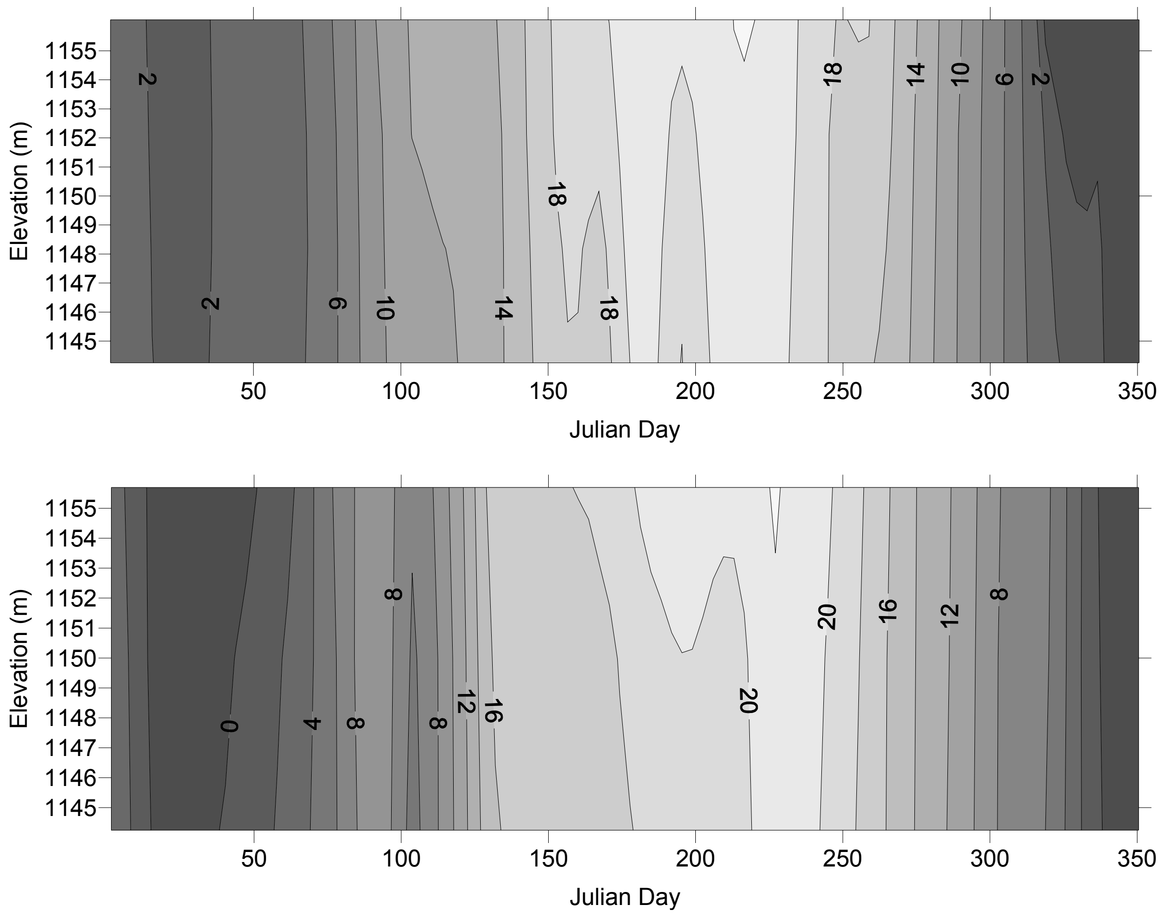


Figure 4.8-22. J.C. Boyle water temperature isopleths EC for 2000 (top) and 2001 (bottom).

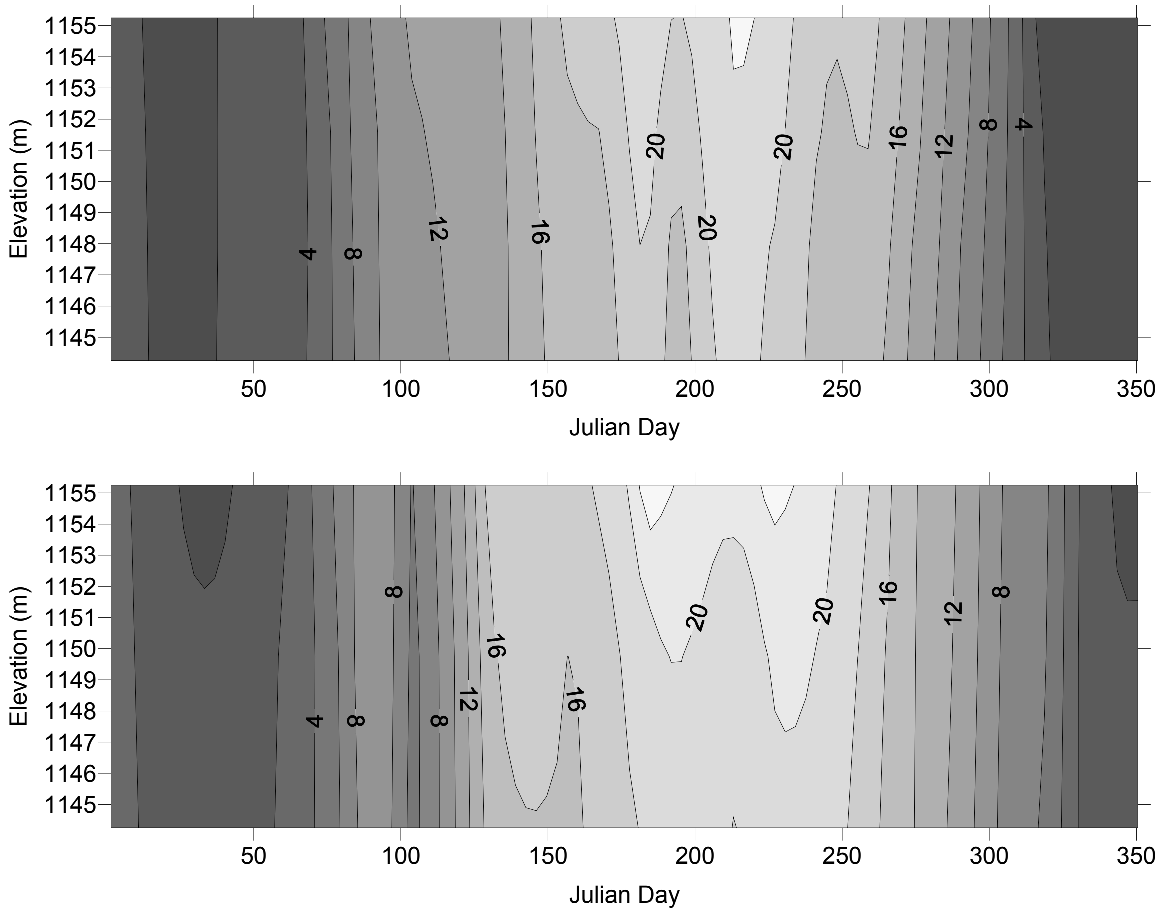


Figure 4.8-23. J.C. Boyle water temperature isopleths SF for 2000 (top) and 2001 (bottom).

<u>Scenario Comparison of Daily Mean Water Temperature</u>

When comparing scenarios with respect to daily mean water temperature (Figure 4.8-24), the following are noted:

- Daily mean water temperatures are generally similar between scenarios; diurnal variation differs.

- The slightly lower water temperature in WOP may be due to smaller surface area leading to less heat loading, but the difference is modest.

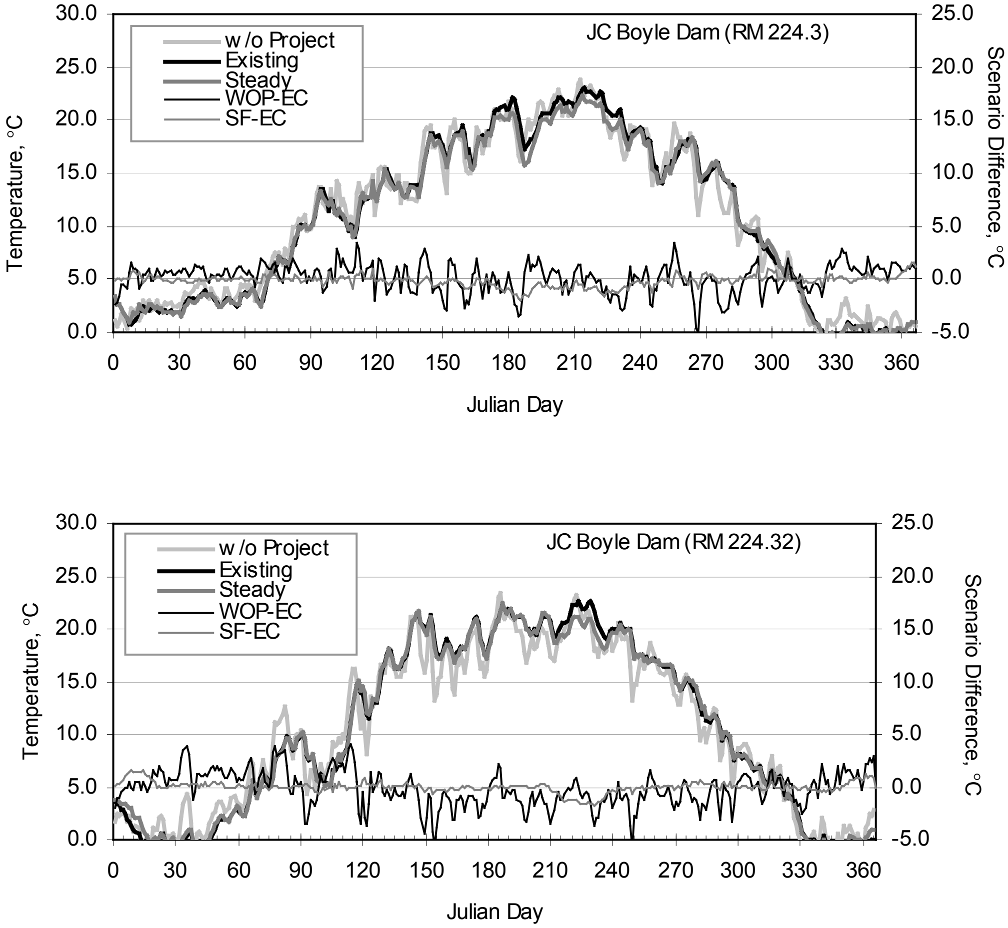


Figure 4.8-24. EC versus SF and WOP mean daily water temperature at J.C. Boyle dam for 2000 (top) and 2001 (bottom).

4.8.4.3 Dissolved Oxygen

Weak intermittent stratification allows anoxic conditions to occur in J.C. Boyle (defined as < 2 mg/L) under EC for about 2 months (Figure 4.8-25). SF conditions appear to ameliorate this condition, probably by minimizing low flow periods, which may allow more persistent stratification to occur (Figure 4.8-26). SF results for 2000 indicate that there were few periods of DO below approximately 6 mg/L. However, SF results for 2001 suggest that under weakly stratified conditions DO levels can reach about 2 mg/L.

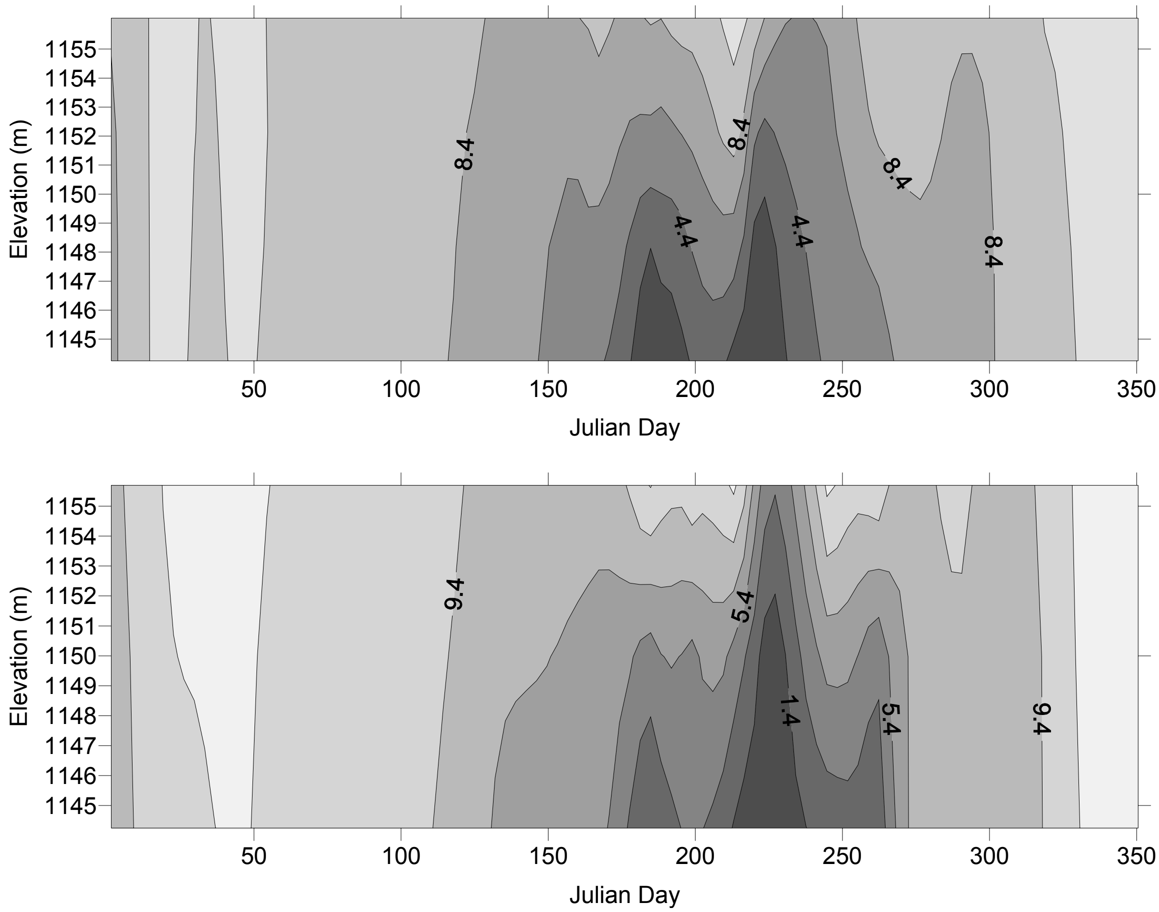


Figure 4.8-25. J.C. Boyle dissolved oxygen isopleths EC for 2000 (top) and 2001 (bottom).

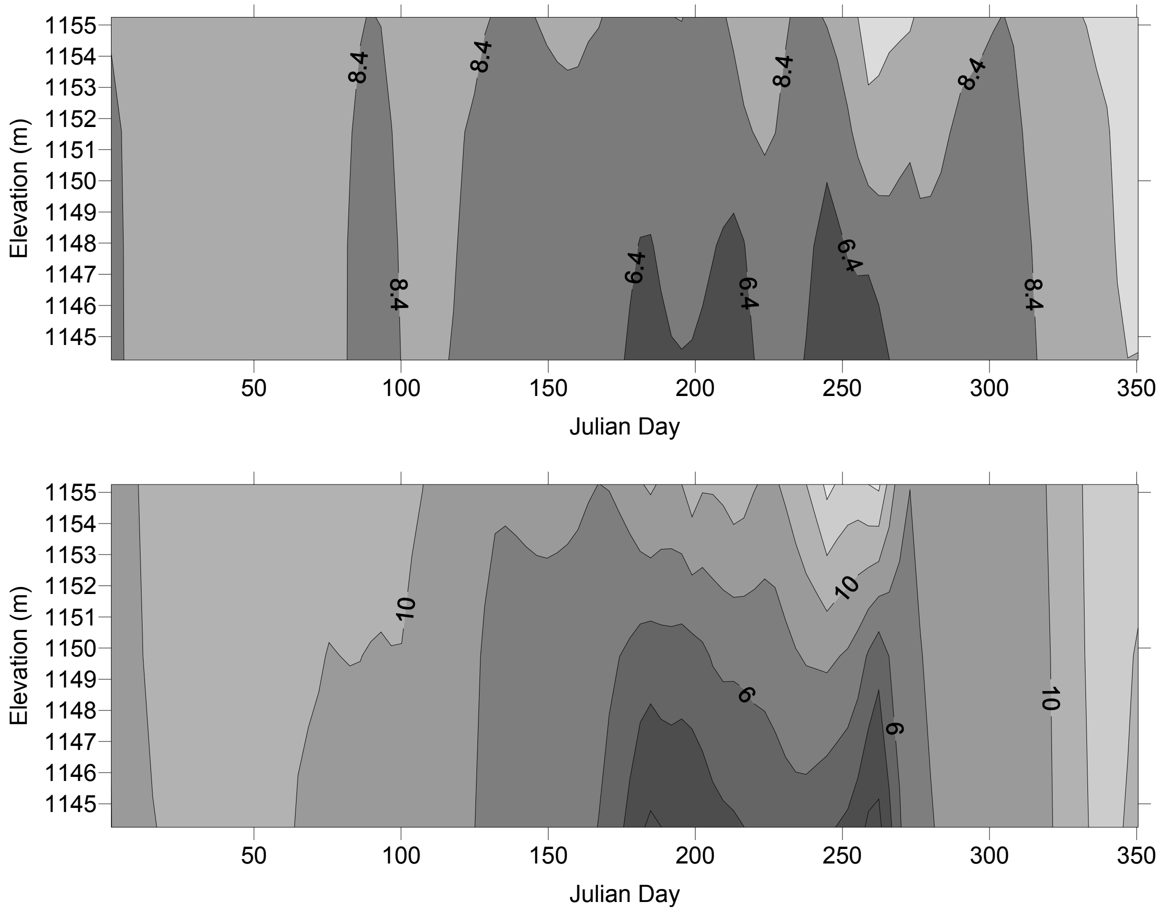


Figure 4.8-26. J.C. Boyle dissolved oxygen isopleths SF for 2000 (top) and 2001 (bottom).

Scenario Comparison of Daily Mean Dissolved Oxygen

When comparing scenarios with respect to daily mean DO (Figure 4.8-27), the following conditions are noted:

- Results are generally similar between scenarios. Generally, by the time waters get to J.C. Boyle reservoir, DO is coming to equilibrium (saturation).
- There is still DO depression (values below saturation) in all runs, probably due to the Klamath River's substantial organic load.

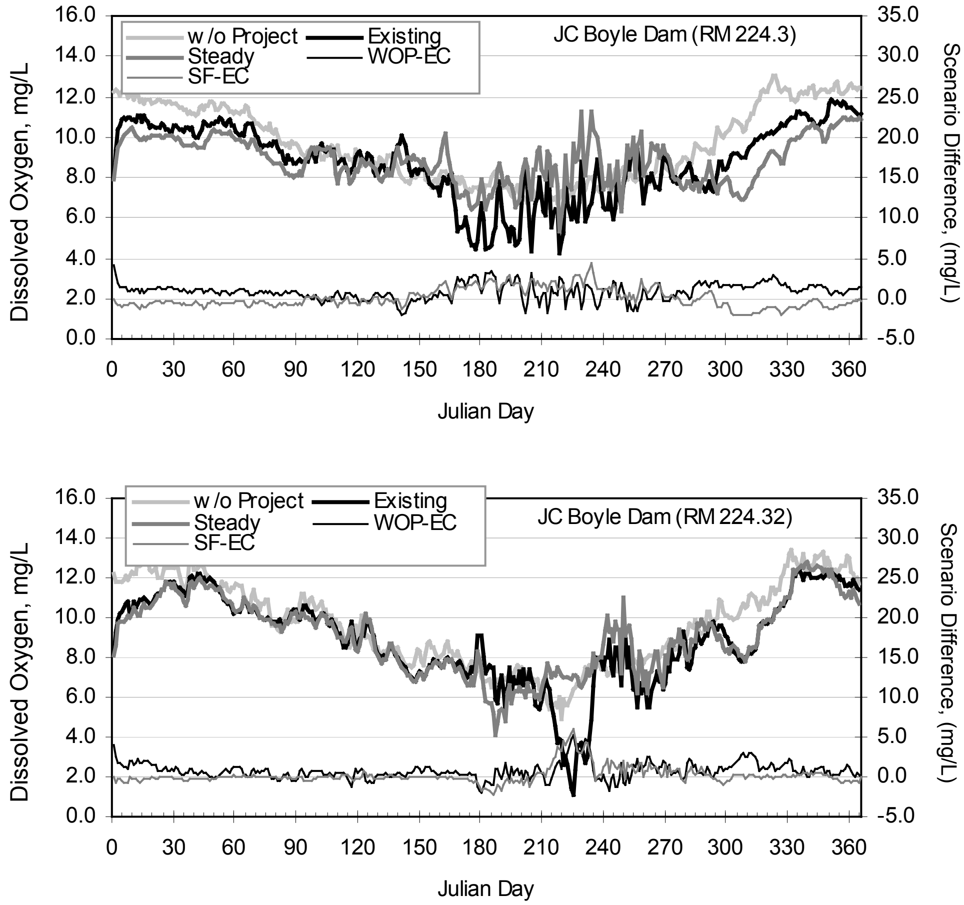


Figure 4.8-27. EC versus SF and WOP mean daily dissolved oxygen at J.C. Boyle dam for 2000 (top) and 2001 (bottom).

4.8.4.4 Nutrients, Algae, and Organic Matter

SF conditions in 2001, when stratification seems to persist, shows the highest algal production. SF conditions in 2000 show the lowest productivity, but are similar to EC 2000 (Figures 4.8-28 and 4.8-29). EC conditions in 2001 fall in between the above two scenarios in terms of production.

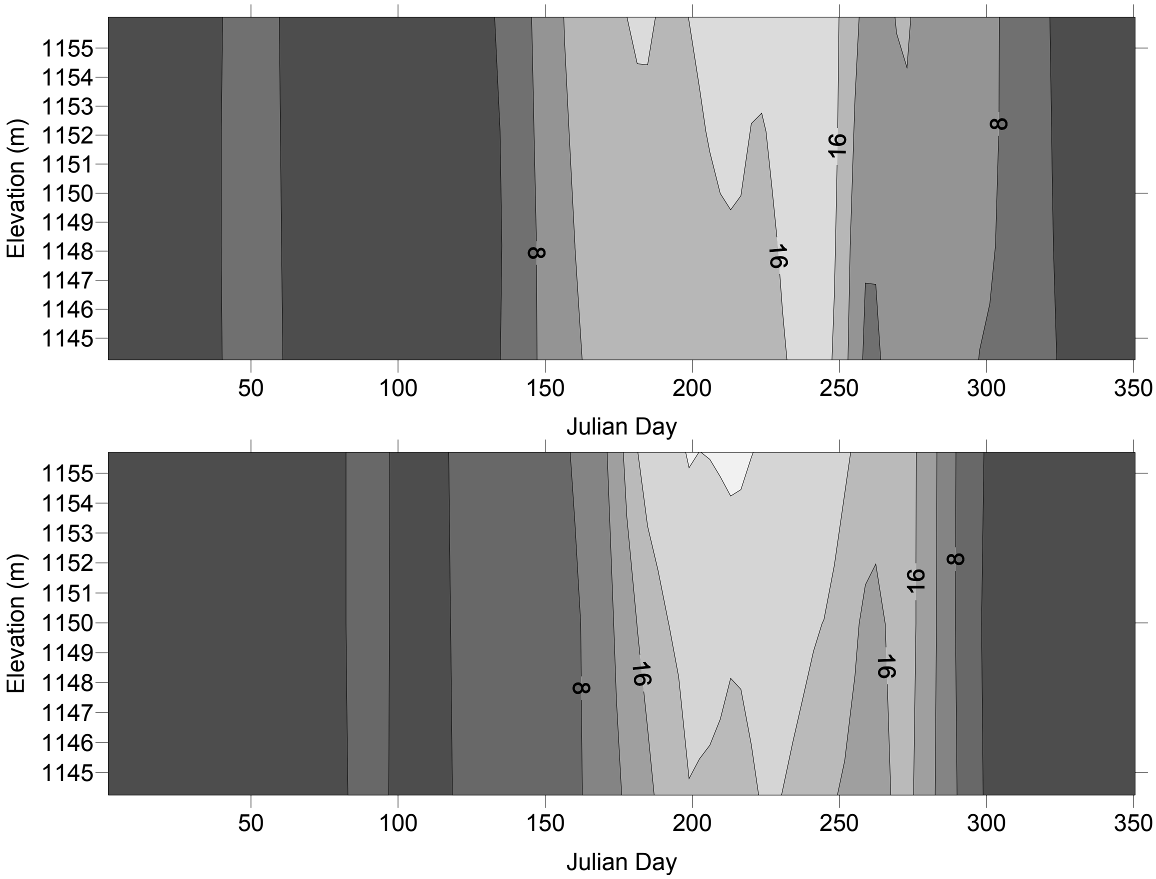


Figure 4.8-28. J.C. Boyle algae isopleths EC for 2000 (top) and 2001 (bottom).

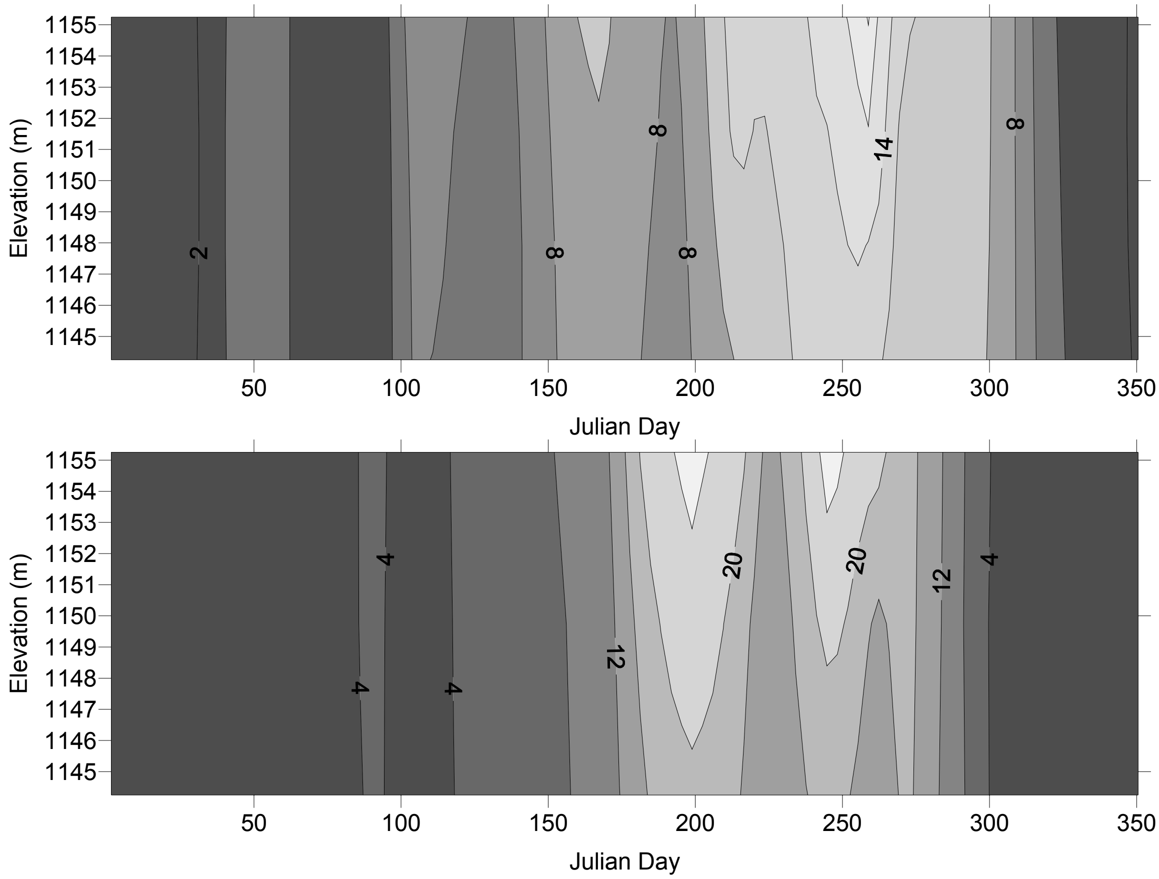


Figure 4.8-29. J.C. Boyle algae isopleths SF for 2000 (top) and 2001 (bottom).

4.8.5 J.C. Boyle Dam to Copco Reservoir (Bypass and Peaking Reach)

4.8.5.1 Flow

Model results for flow are discussed in Section 5.0 of this Water Resources FTR. EC clearly illustrates peaking, while SF and WOP present a much less dynamic flow regime for both 2000 and 2001.

4.8.5.2 Temperature

- EC includes peaking flows, which generally occur during daytime periods. The result is that under peaking flows, flow volume is high, transit time is short, and thus the diurnal range at the end of this reach (above Copco) (see 2001 in Figure 4.8-30) is less than under WOP conditions.
- Under SF conditions (Figure 4.8-31), the diurnal range above Copco is generally larger than EC during summer periods.
- Under WOP conditions (Figure 4.8-32), the diurnal range is broader and more variable, consistent with a riverine versus reservoir environment.

- The water temperatures of the springs in the J.C. Boyle bypass reach are relatively constant throughout the year (at about 11°C). As a result, bypass reach temperatures are cooler from May-September and warmer from November-March than ambient river temperatures in the downsteam peaking reach (Figure 4.8-30) or upsteam Keno reach (see Figures 4.8-5 and 48-6). In February 2000, a spill event in EC and SF significantly cooled down the bypass reach because spill flows were cooler at that time than spring water inflows to the bypass reach.

- WOP maximum temperatures are considerably warmer during summer, with maximum temperature of about 26^{o}C, while the maximum annual temperature for EC or SF is under about 23^{o}C.

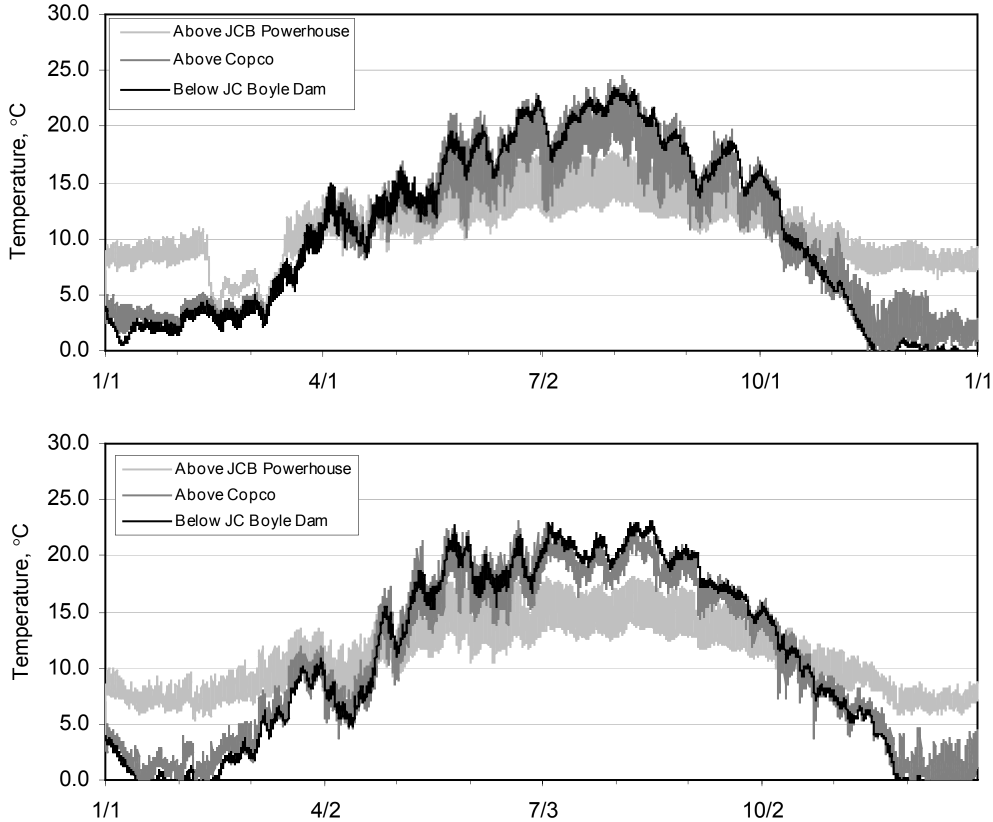


Figure 4.8-30. J.C. Boyle bypass and peaking reach water temperature: EC for 2000 (top) and 2001 (bottom).

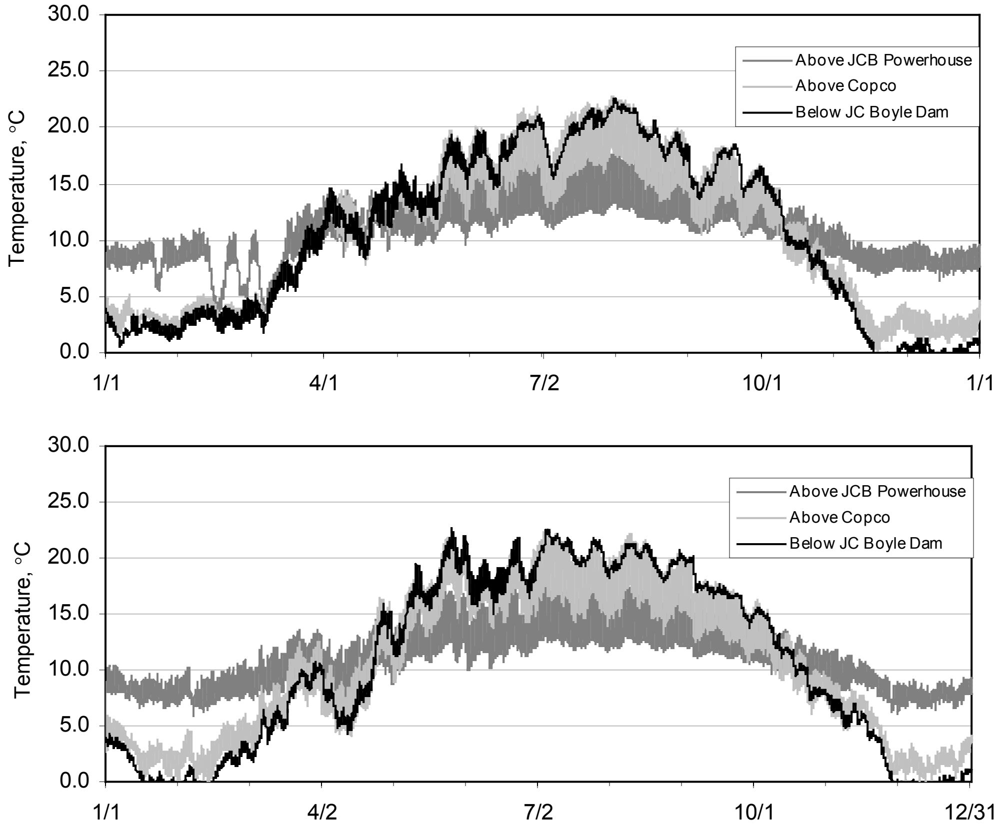


Figure 4.8-31. J.C. Boyle bypass and peaking reach water temperature: SF for 2000 (top) and 2001 (bottom).

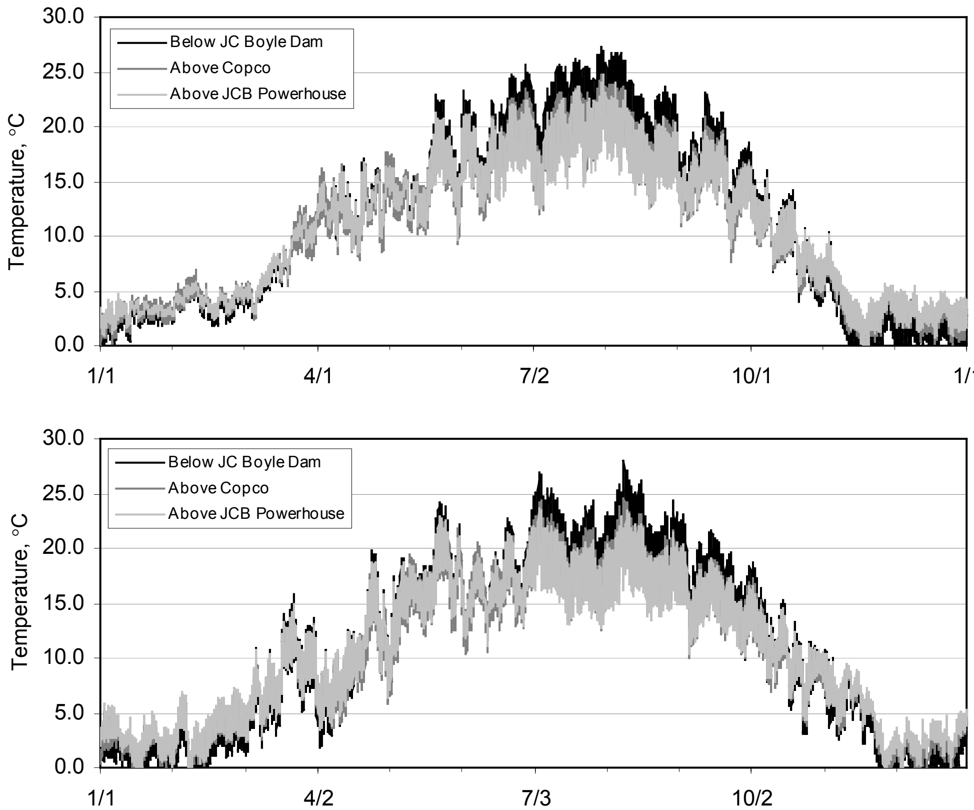


Figure 4.8-32. J.C. Boyle bypass and peaking reach water temperature: WOP for 2000 (top) and 2001 (bottom).

Scenario Comparison of Water Temperature

When comparing scenarios with respect to water temperature, the following conditions are noted:

- Comparing EC and SF indicates that the influence of the springs in the bypass reach are minimized in the WOP case (see examples in Figures 4.8-33 and 4.8-34 of hourly model output for a week in July 2000 and 2001). Note in the WOP case that there is more dynamic weekly response (somewhat of a concave look to the trace in 2000). This is probably due to the lack of reservoirs moderating daylong to weeklong meteorological trends, i.e., the system is responding quicker without reservoirs.

- The springs provide benefits in all scenarios, but in the EC and SF cases they provide appreciable cold water benefits to the J.C. Boyle bypass reach.

- On a daily average basis, the EC and SF scenarios are generally similar (Figures 4.8-35 to 4.8-38). The WOP scenario deviates from EC and SF in the vicinity of the bypass (for the same reasons as stated above) and near the powerhouse. However, as distance from the powerhouse increases (e.g., to Stateline, then further downstream to above Copco reservoir), the effects diminish.

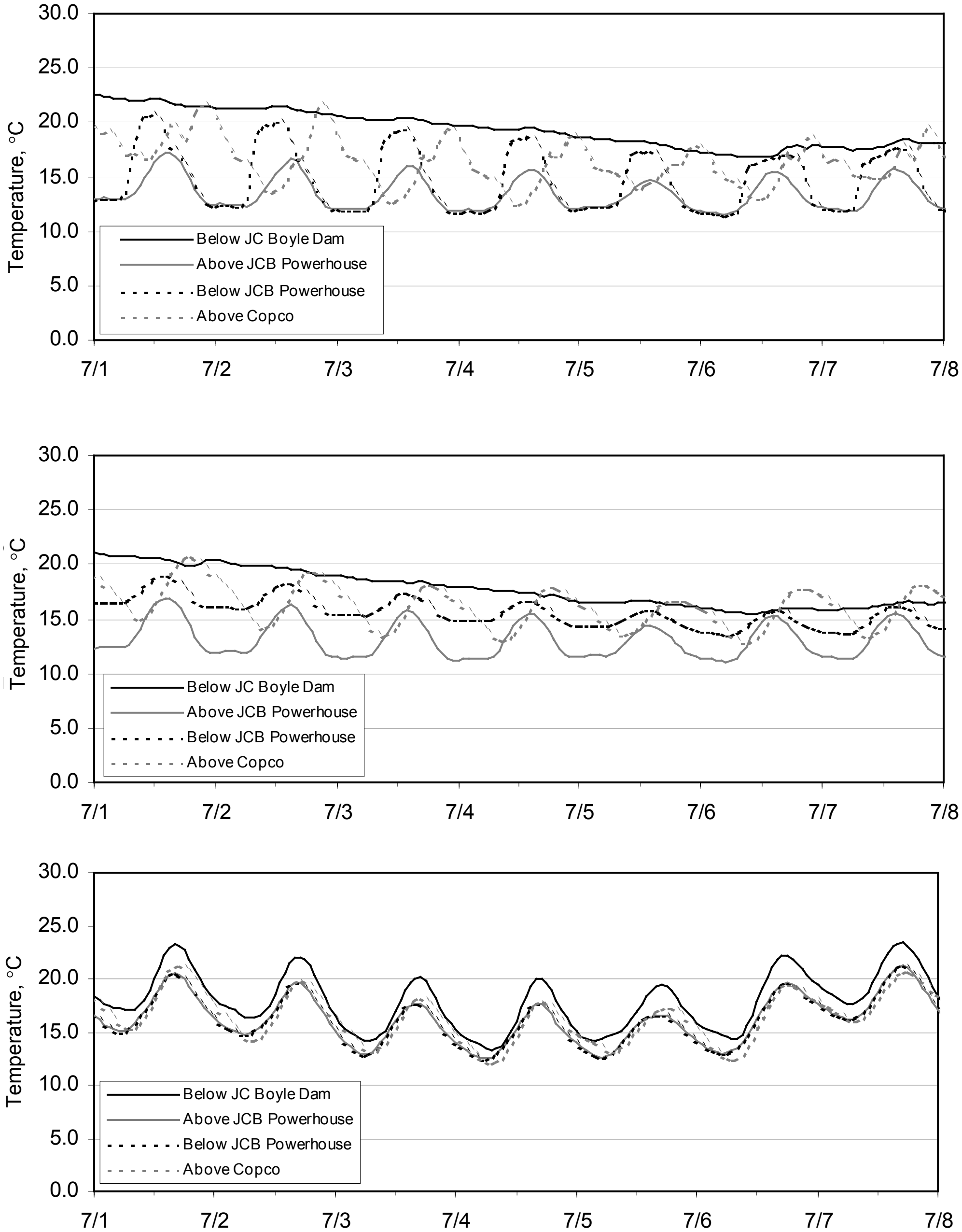


Figure 4.8-33. J.C. Boyle bypass and peaking reach water temperature, 2000: EC (top), SF (middle), WOP (bottom).

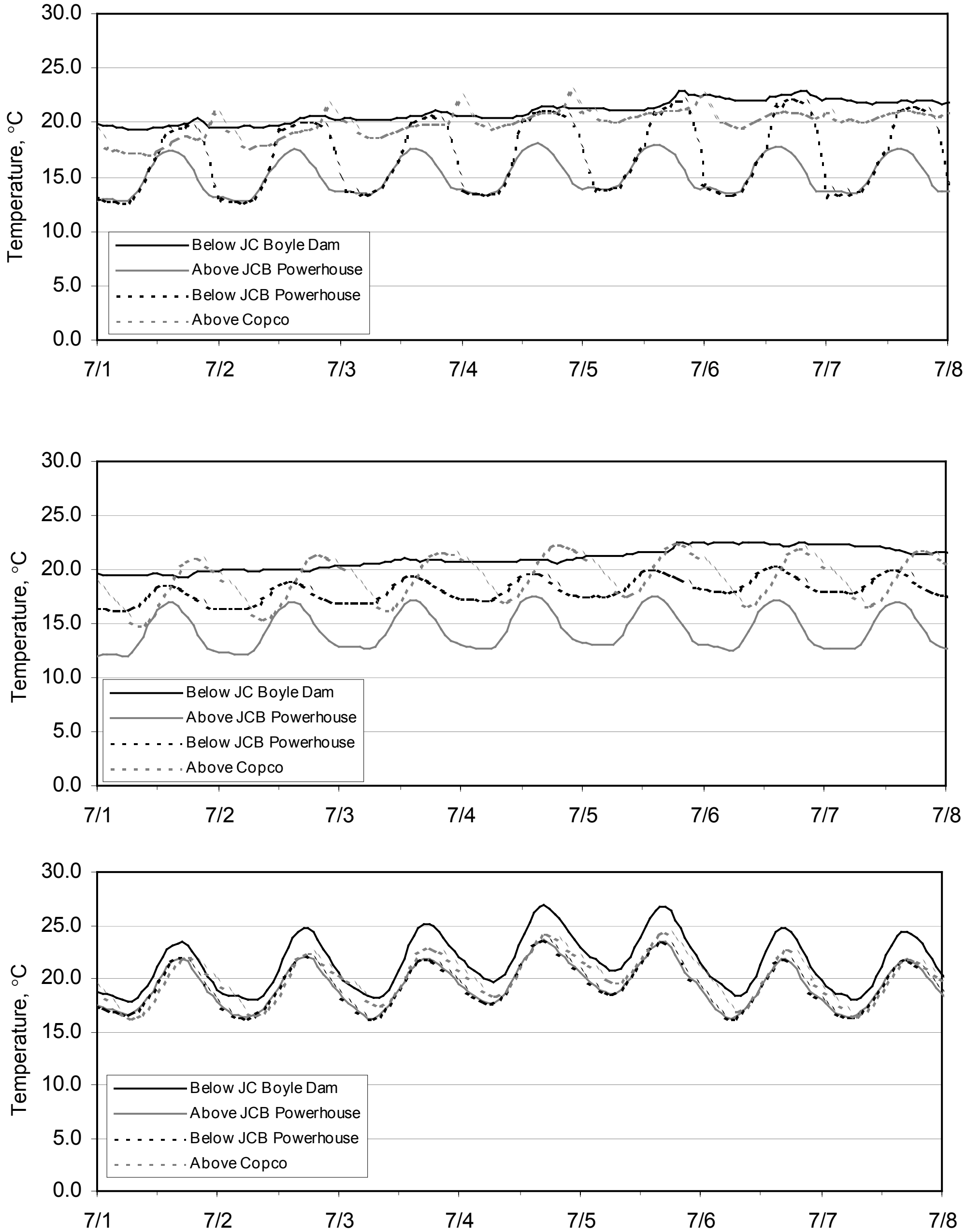
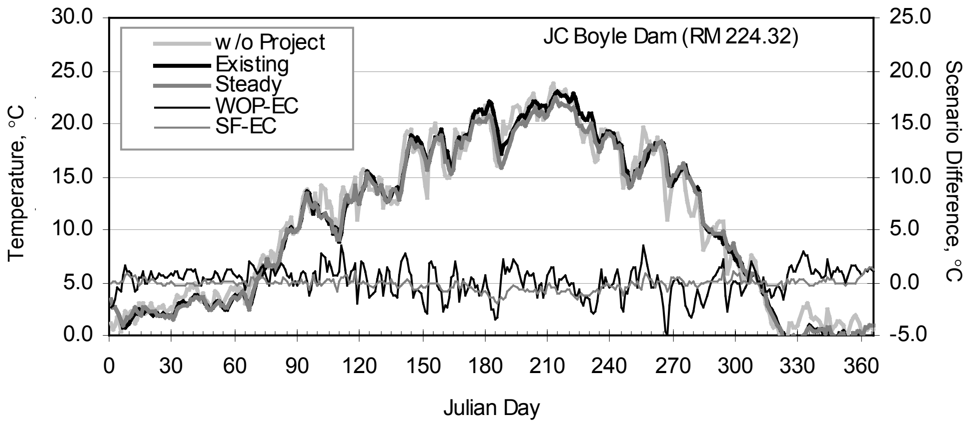


Figure 4.8-34. J.C. Boyle bypass and peaking reach water temperature, 2001: EC (top), SF (middle), WOP (bottom).



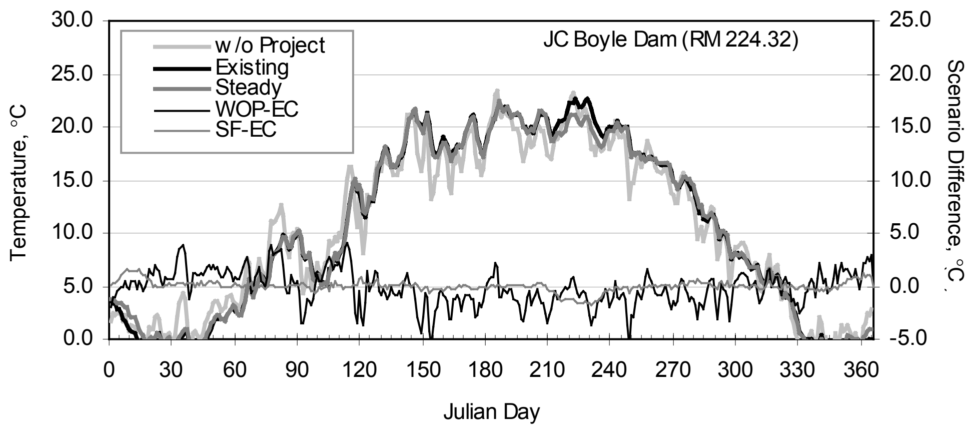


Figure 4.8-35. EC versus SF and WOP mean daily water temperature in the J.C. Boyle bypass reach below J.C. Boyle dam for 2000 (top) and 2001 (bottom).

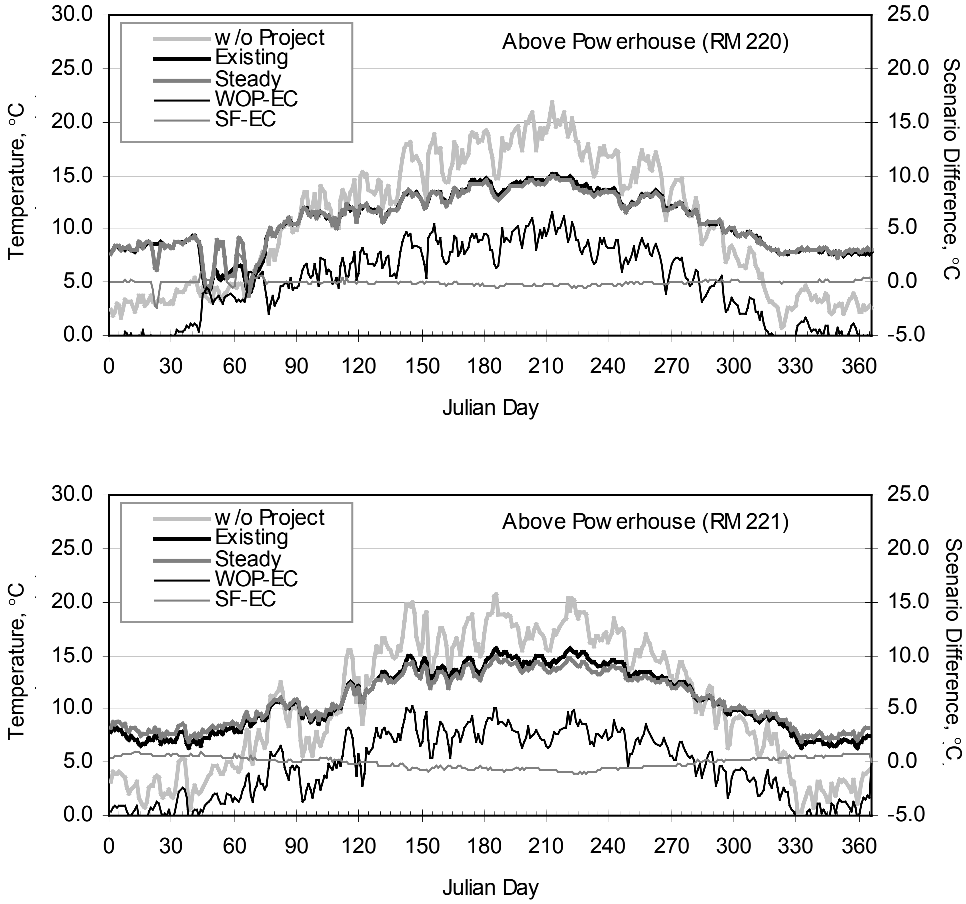
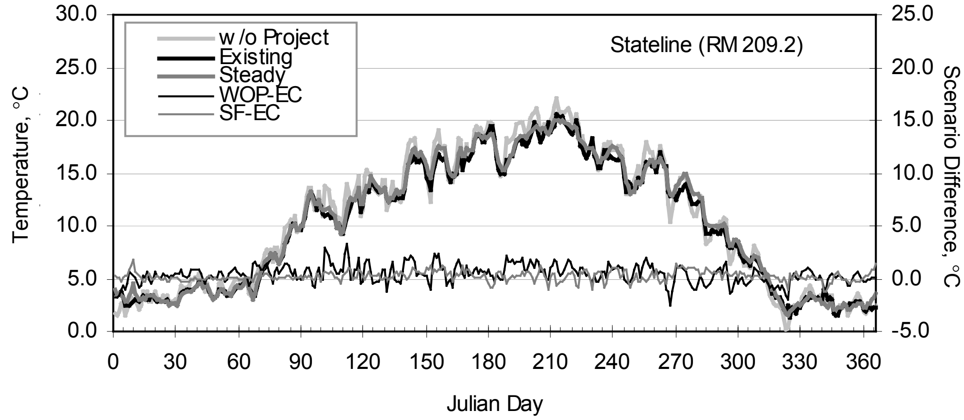


Figure 4.8-36. EC versus SF and WOP mean daily water temperature in the J.C. Boyle bypass reach above the J.C. Boyle powerhouse for 2000 (top) and 2001 (bottom).



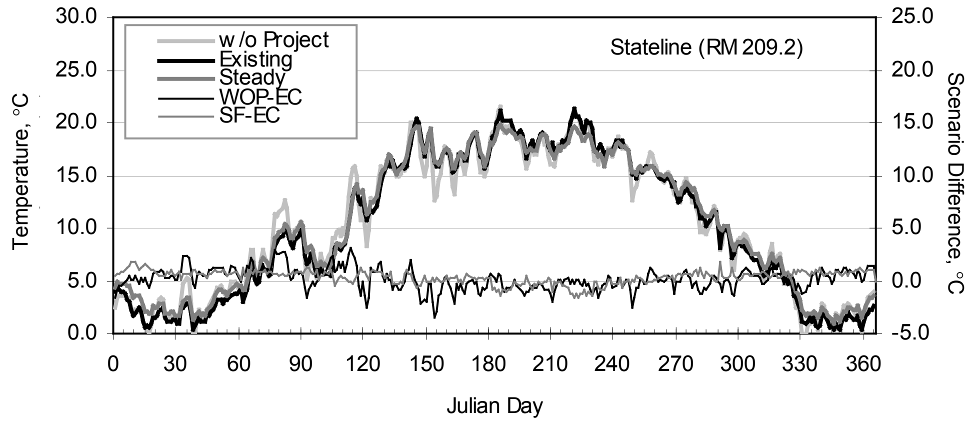
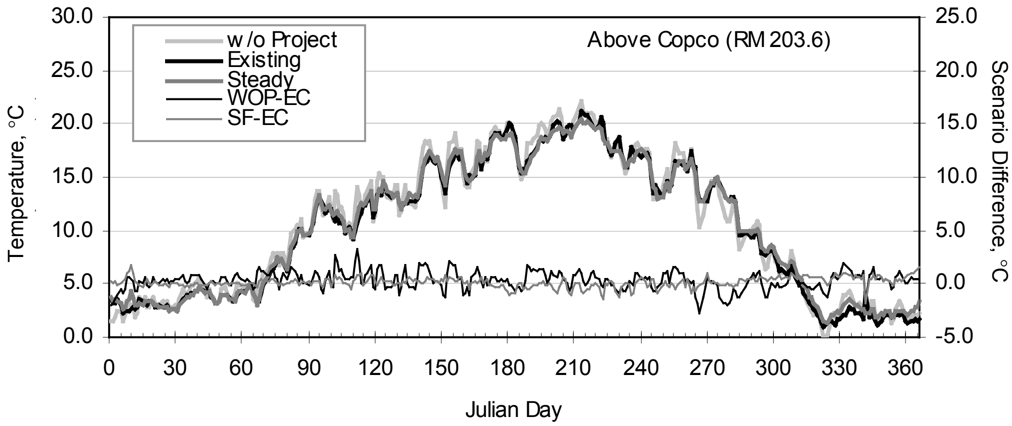


Figure 4.8-37. EC versus SF and WOP mean daily water temperature in the J.C. Boyle peaking reach at Stateline for 2000 (top) and 2001 (bottom).



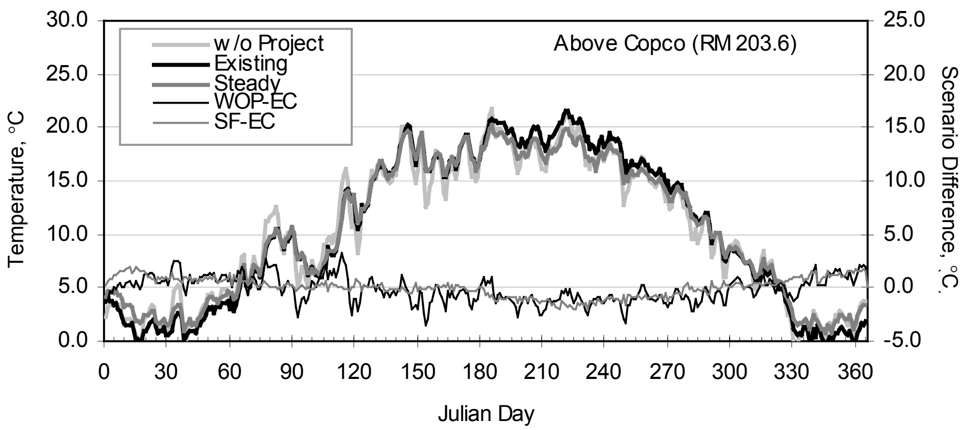


Figure 4.8-38. EC versus SF and WOP mean daily water temperature in the J.C. Boyle peaking reach above Copco reservoir for 2000 (top) and 2001 (bottom).

4.8.5.3 Dissolved Oxygen

- Under EC and SF conditions, the deviations from saturation seen in waters released from J.C. Boyle reservoir return quickly toward saturation with transport through the J.C. Boyle bypass reach (Figure 4.8-39 and 4.8-40). This is similar for both EC and SF, even though EC waters enter the reach with greater deviations from saturation during some summer periods.

- In the J.C. Boyle peaking reach above Copco reservoir, both EC and SF illustrate greater diurnal variability than in the J.C. Boyle bypass reach above the powerhouse, and also have lower overall concentrations in the summer months. This is probably due to gradual warming of the water between the spring-dominated bypass reach and Copco reservoir, and the associated difference in saturation concentration with increased temperature. Some of this lower DO may also be influenced by organic matter loading from upstream.

- WOP conditions are roughly at saturation concentration at all locations (Figure 4.8-41). This concentration is slightly affected by differences in temperature of the water between the spring-dominated bypass reach and Copco reservoir.

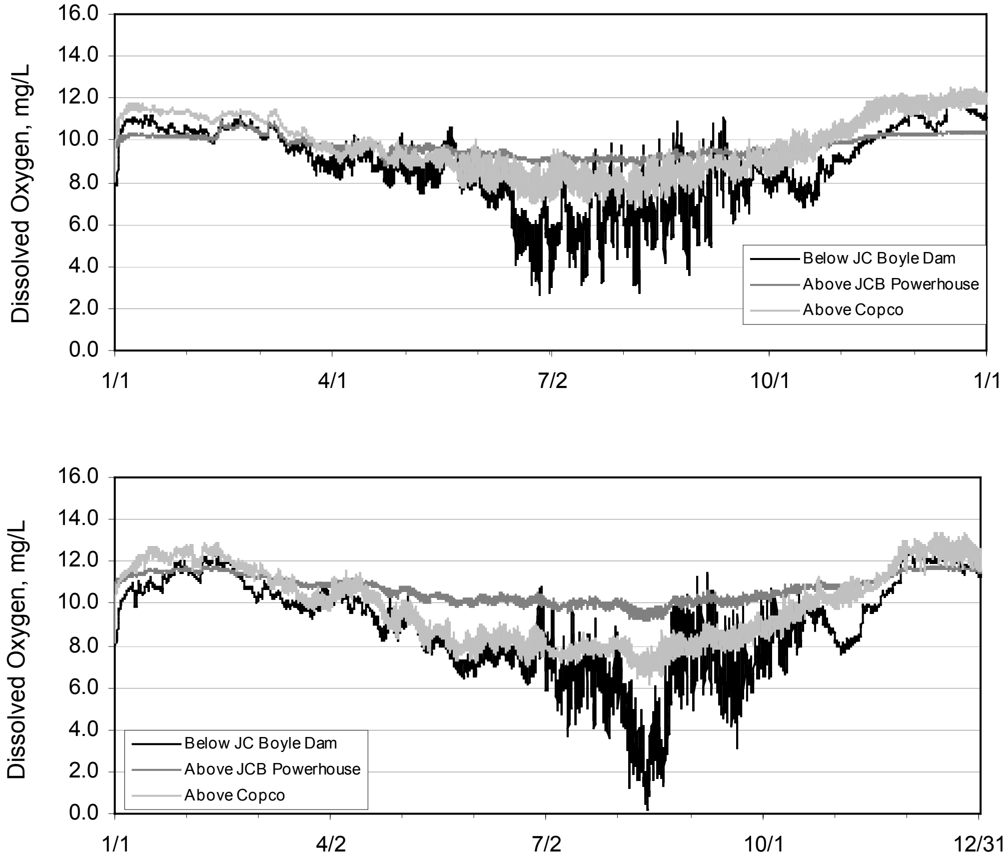


Figure 4.8-39. J.C. Boyle bypass and peaking reach dissolved oxygen: EC for 2000 (top) and 2001 (bottom).

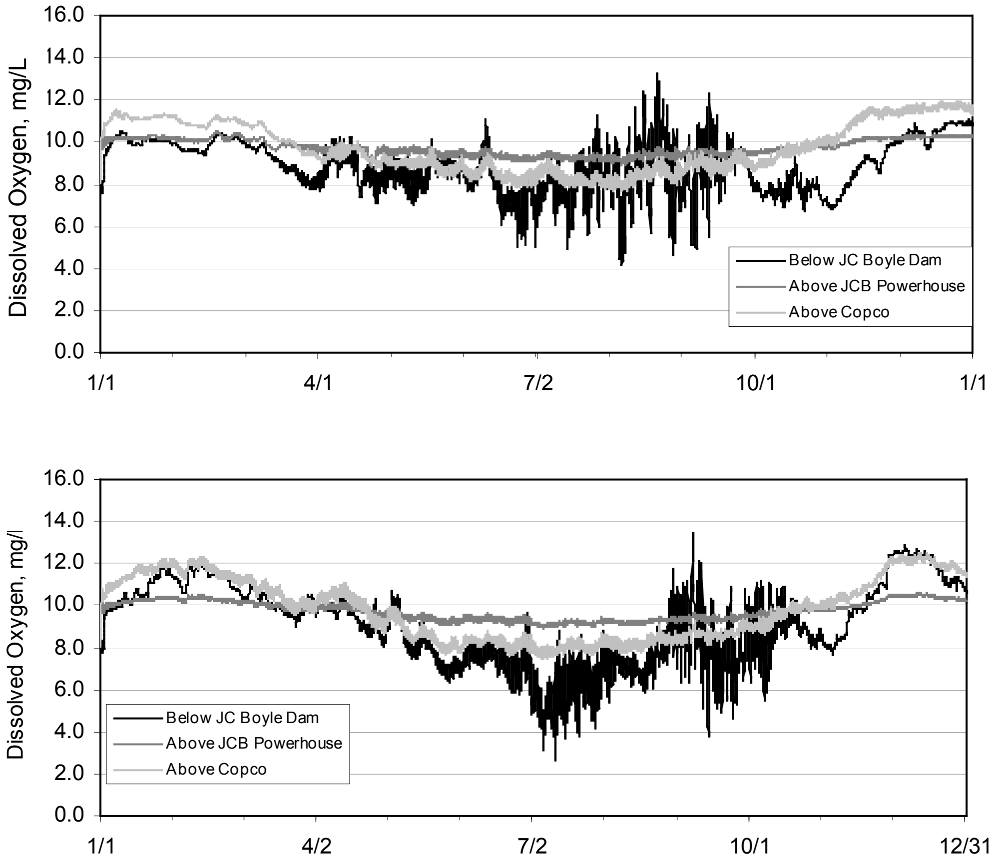


Figure 4.8-40. J.C. Boyle bypass and peaking reach dissolved oxygen: SF for 2000 (top) and 2001 (bottom).

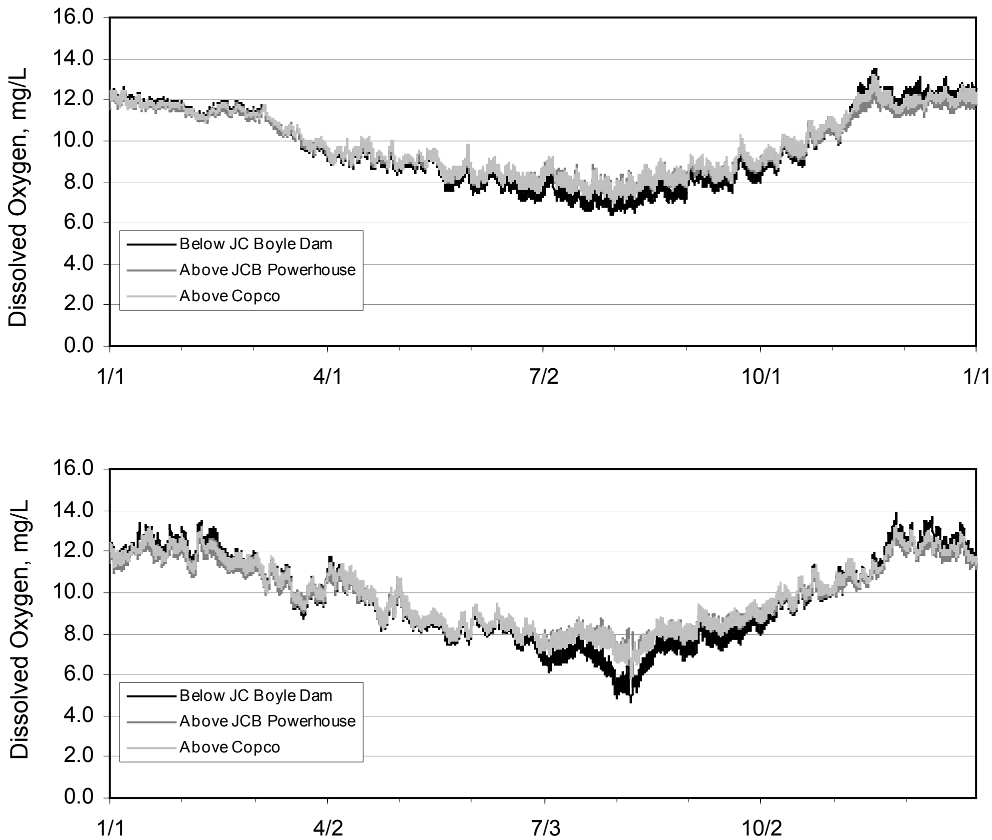


Figure 4.8-41. J.C. Boyle bypass and peaking reach dissolved oxygen: WOP for 2000 (top) and 2001 (bottom).

<u>Scenario Comparison of Daily Mean Dissolved Oxygen</u>

When comparing scenarios with respect to DO, the following are noted:

- As with water temperature, DO is affected by peaking operations (EC), as well as use of the penstock return (SF). Figures 4.8-42 and 4.8-43 show examples of hourly model output for a week in July 2000 and 2001. For EC and SF, higher DO occurs in the bypass reach by allowing spring inflows to dominate the composition of flow in the reach. Although the WOP conditions indicate some lower DO in the bypass reach, overall the DO conditions are generally near saturation. At the J.C. Boyle dam site, there are periods when there appears to be a slightly depressed DO level, but this is probably due to the organic load from upstream being transported by the river.

- On a daily average basis the EC and SF scenarios are generally similar (Figures 4.8-44 to 4.8-47). The WOP scenario deviates from EC and SF in the vicinity of the bypass (for the same reasons as stated above) and near the powerhouse. However, as distance from the powerhouse increases (e.g., to Stateline, then further downstream to above Copco reservoir), the effects diminish.

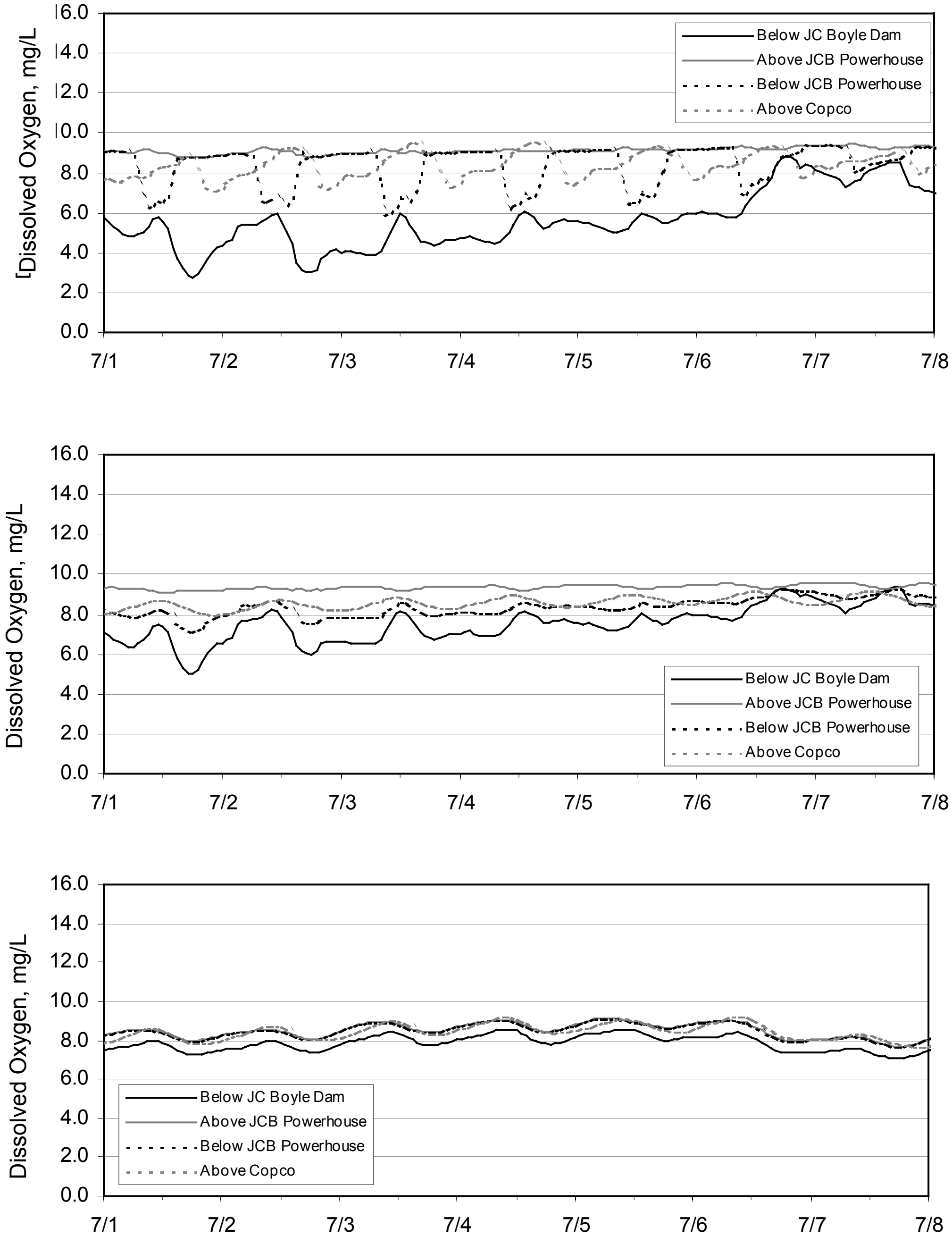


Figure 4.8-42. J.C. Boyle bypass and peaking reach dissolved oxygen, 2000: EC (top), SF (middle), WOP (bottom).

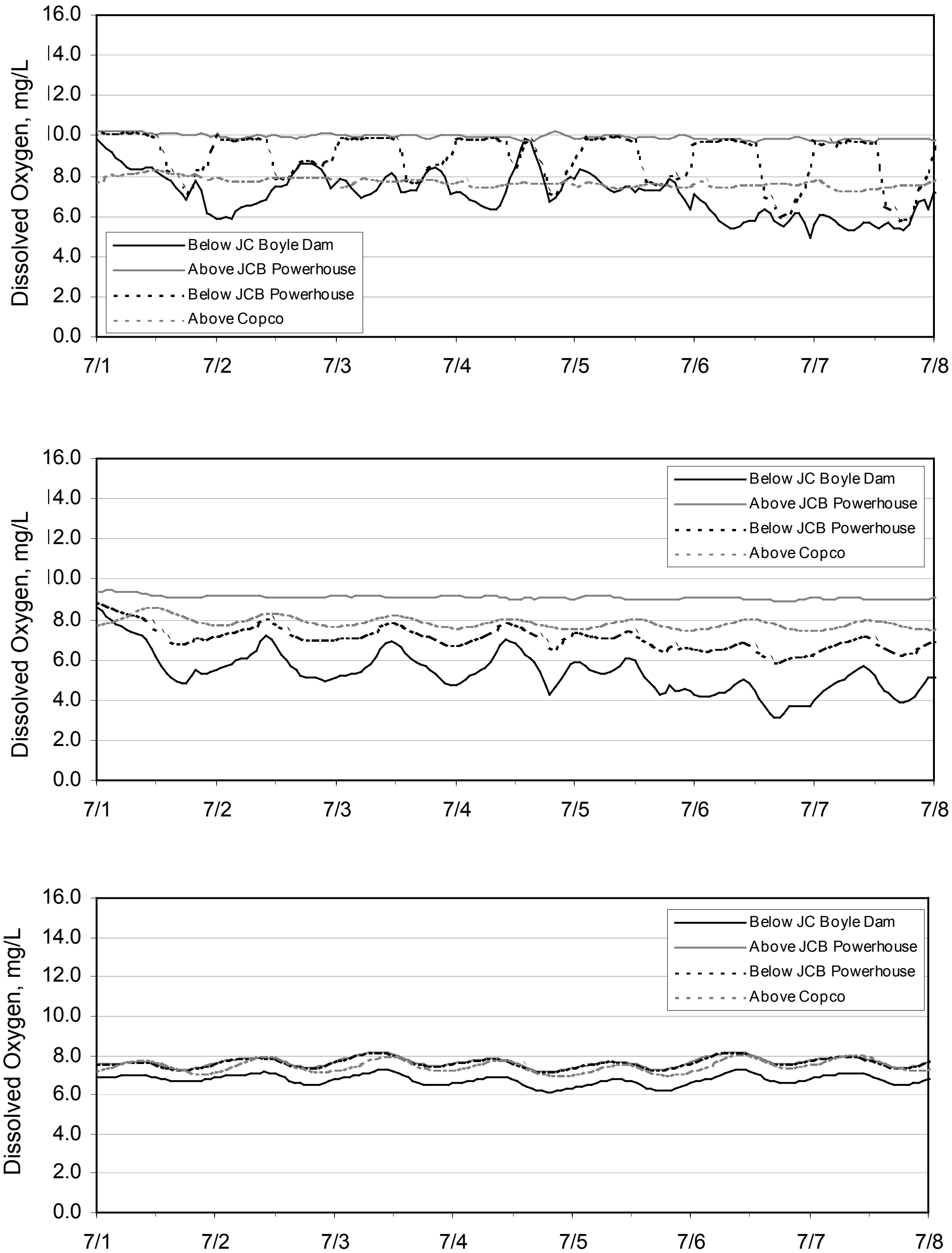
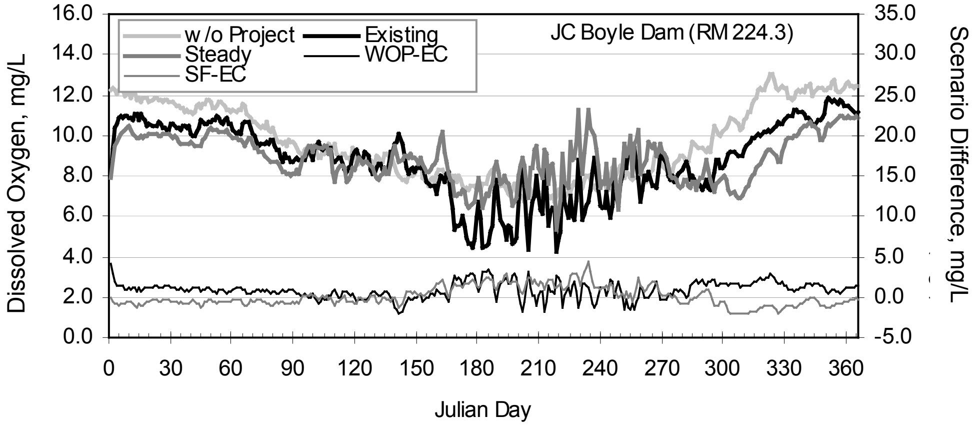


Figure 4.8-43. J.C. Boyle bypass and peaking reach dissolved oxygen, 2001: EC (top), SF (middle), WOP (bottom).



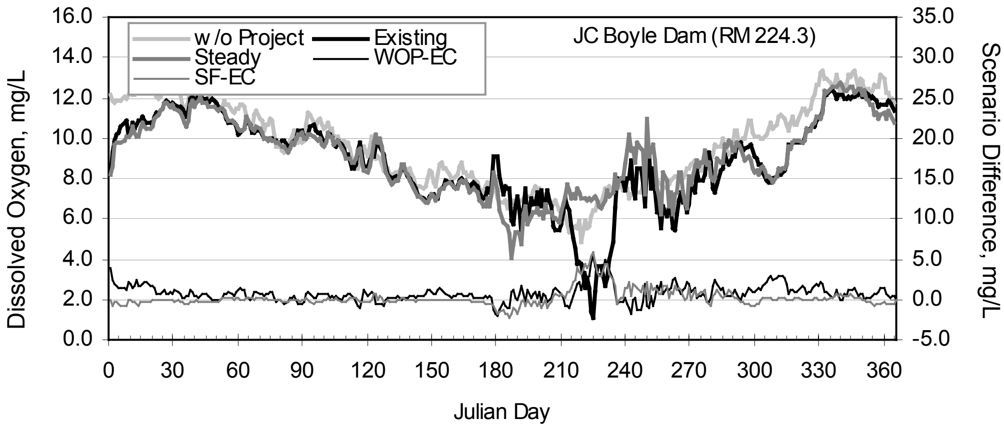
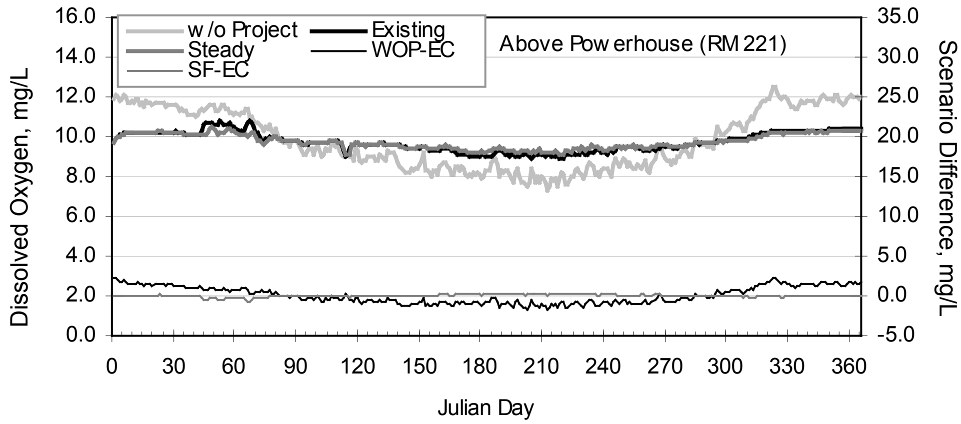


Figure 4.8-44. EC versus SF and WOP mean daily dissolved oxygen in the J.C. Boyle bypass reach below J.C. Boyle dam for 2000 (top) and 2001 (bottom).



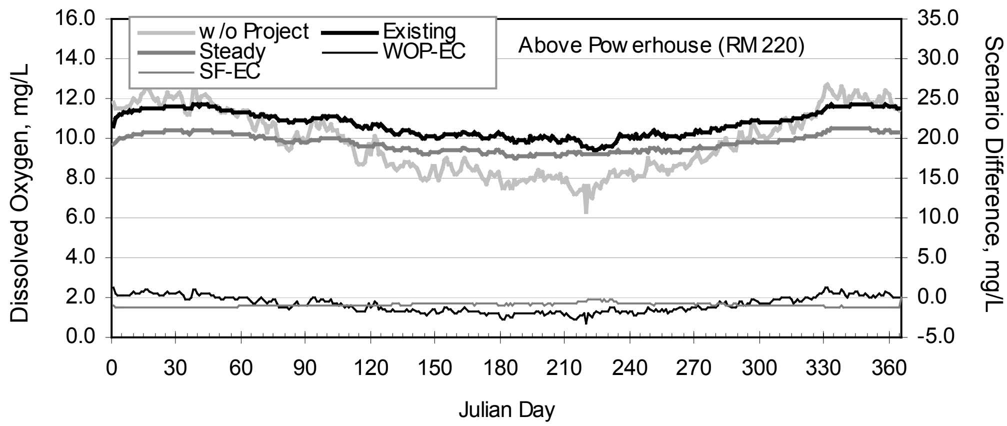
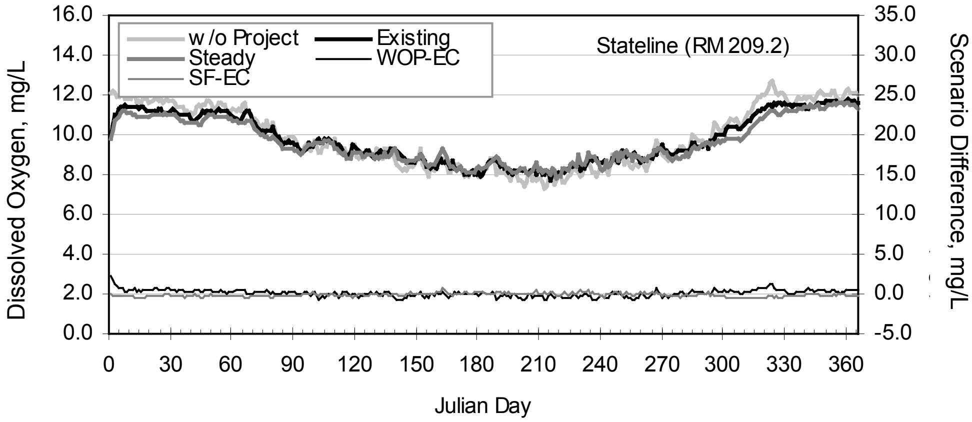


Figure 4.8-45. EC versus SF and WOP mean daily dissolved oxygen in the J.C. Boyle bypass reach above J.C. Boyle powerhouse for 2000 (top) and 2001 (bottom).



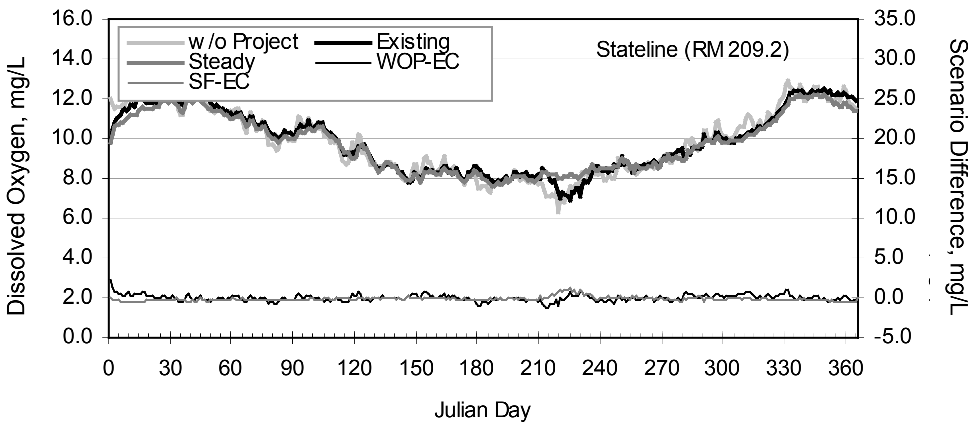
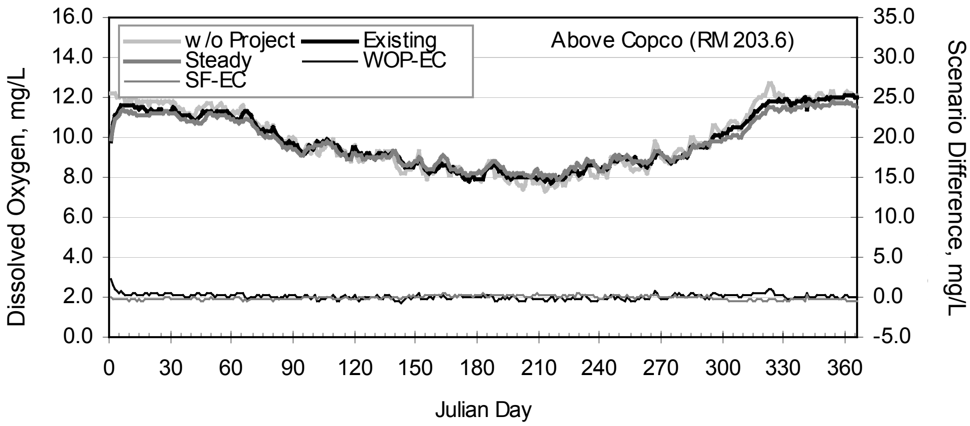


Figure 4.8-46. EC versus SF and WOP mean daily dissolved oxygen in the J.C. Boyle peaking reach at Stateline for 2000 (top) and 2001 (bottom).



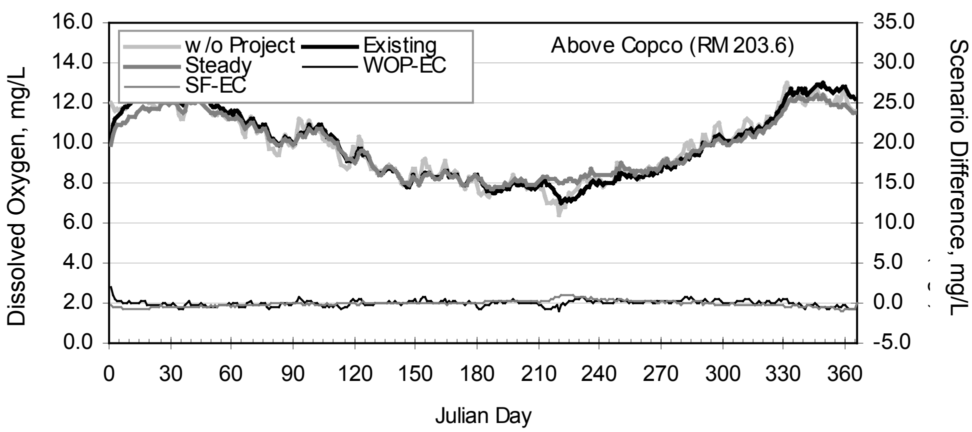


Figure 4.8-47. EC versus SF and WOP mean daily dissolved oxygen in the J.C. Boyle peaking reach above Copco reservoir for 2000 (top) and 2001 (bottom).

4.8.5.4 Nutrients

Nutrient conditions also exhibit variations due to peaking operations. During nonpeaking periods, the reach can be dominated by bypass flows (100 cfs) combined with spring flows (approximately 225 cfs), creating high quality waters. Peaking flows routed through the powerhouse from J.C. Boyle reservoir dominate the composition of flow in the peaking reach during peaking operations. At those times, the peaking reach takes on nutrient conditions similar to J.C. Boyle reservoir and upstream river areas. These water quality conditions are moderated, especially during nonpeaking times, by the spring inflows in the bypass reach (i.e., dilution).

4.8.6 Copco Reservoir

4.8.6.1 Flow

Model results for flow are discussed in Section 5.0 of this Water Resources FTR.

4.8.6.2 Temperature

- Copco reservoir stratification for EC occurs around early March and remains stratified for approximately 200 days (Table 4.8-1, Figure 4.8-48). Maximum difference between epilimnetic and hypolimnetic temperatures is about 10°C. Stratification for SF conditions is similar to EC. (Because there is no reservoir assumed in the WOP scenario, there are no stratification conditions to describe.)

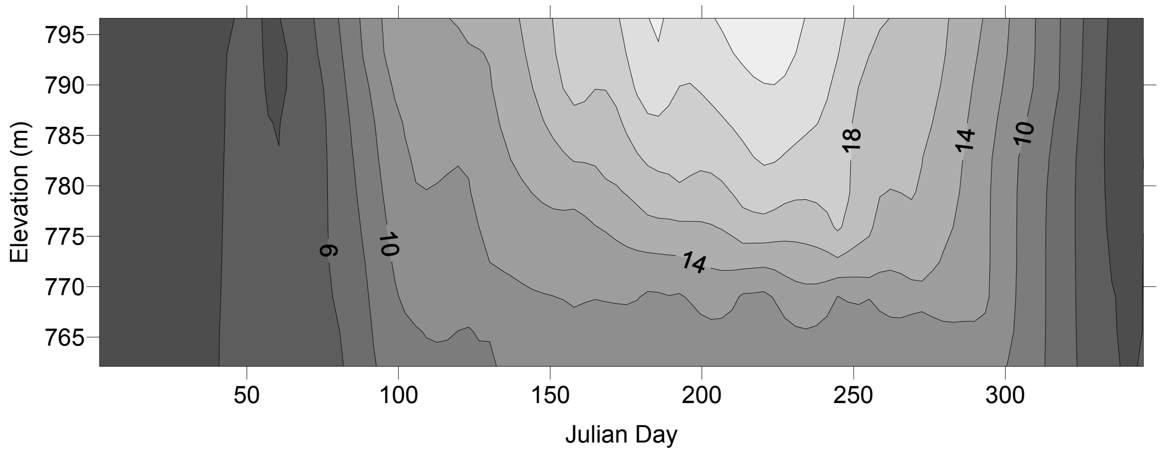
- Copco turns over in mid- to late October (about a month earlier than Iron Gate) due to the ability of the Klamath River upstream to cool relatively rapidly, resulting in denser flows waters that enter the reservoir and plunge or sink. These cool inflows to Copco reservoir in the fall, coupled with convective cooling, serve to break down stratification. Note that bottom waters of Copco reservoir are about 12° to 14°C (significantly warmer than Iron Gate reservoir, which generally has bottom temperatures around 8°C). This is probably the result of variable river inflow during spring and summer (due to peaking at J.C. Boyle powerhouse) and the relatively small volume of Copco reservoir compared to flow-through rates.

- During summer periods, when peaking operations are occurring at J.C. Boyle powerhouse, model simulations and field data indicate that cold waters from the J.C. Boyle bypass reach can arrive at Copco reservoir before the waters from peaking operations do. Thus, throughout the summer there are small, but cold, quantities of water plunging into Copco reservoir. This provides mixing energy that precludes Copco reservoir from stratifying as strongly as Iron Gate reservoir. The end result is that Copco reservoir has a warmer (12° to 15°C) hypolimnion.

- Copco reservoir causes a thermal lag, wherein release temperatures during fall are warmer than under the WOP condition (Figure 4.8-49). This is due to the large thermal mass of Copco reservoir compared to river reaches. River reaches can cool and heat relatively quickly compared to the large, deep reservoir volumes. The inverse, to some degree, occurs in the spring, when increased thermal loading in the reservoir produces temperatures that are slightly cooler than WOP.

Table 4.8-1. Copco reservoir thermal stratification scenario comparison.

Copco	EC		SF		WOP	
	2000	**2001**	**2000**	**2001**	**2000**	**2001**
Onset of Stratification (Julian day)	100	100	100	100	NA	NA
Fall Turnover (Julian day)	300	290	300	290	NA	NA
Duration of Stratification (days)	200	190	200	190	NA	NA
Maximum Stratification Date (Julian day)	220	240	220	230	NA	NA
Maximum Water Temperature Difference (°C)	10	10	10	10	NA	NA
Minimum Hypolimnetic Tw (°C)	12	12	12	12	NA	NA



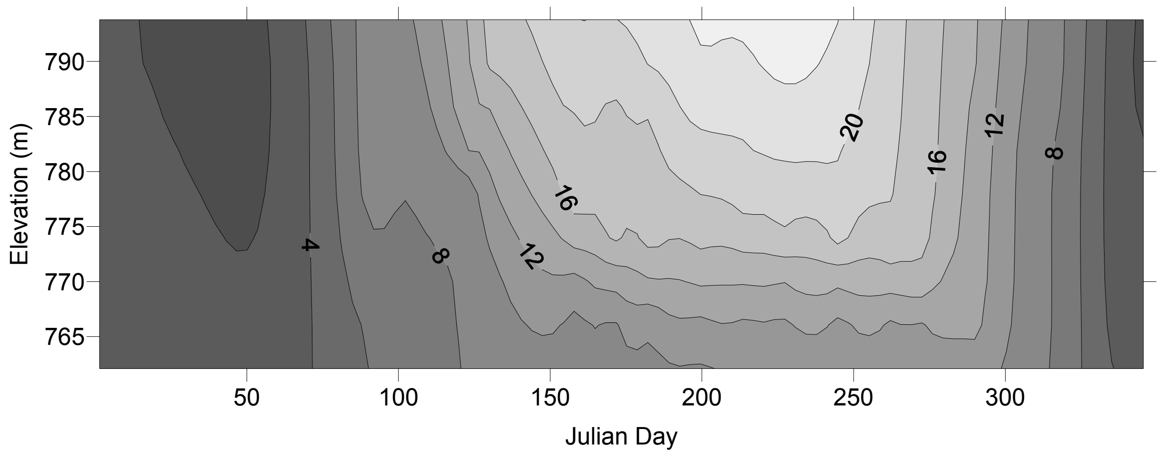
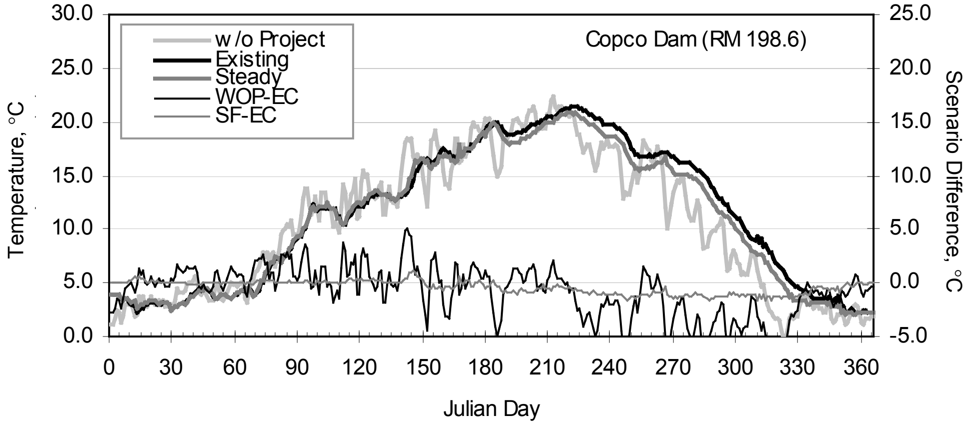


Figure 4.8-48. Copco reservoir temperature (°C) isopleths: EC for 2000 (top) and 2001 (bottom).



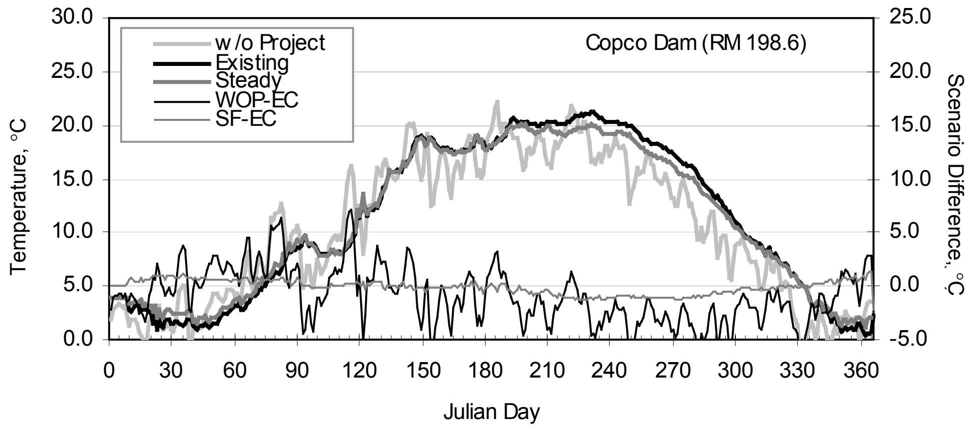


Figure 4.8-49. EC versus SF and WOP mean daily water temperature below Copco dam for 2000 (top) and 2001 (bottom).

4.8.6.2 Dissolved Oxygen

- DO concentrations in Copco reservoir begin to deviate from saturation values around the time of thermal stratification onset and persist for approximately 200 days (Table 4.8-2, Figure 4.8-50). The onset of anoxia (DO less than 2 mg/L) varies, but starts at around mid- to late June and persists until stratification ends in the fall.

- EC and SF both produce low DO levels in release waters. SF performs slightly better, possibly due to a more stable thermocline (Figure 4.8-51).

- WOP DO concentrations at the Copco dam site are at or near saturation most of the year (Figure 4.8-51).

Table 4.8-2. Scenario comparison of dissolved oxygen conditions at Copco reservoir.

Copco	EC		SF		WOP	
	2000	200	2000	2001	2000	2001
Onset of Deviation from Saturation (Julian day)	90	120	90	130	NA	NA
Termination of Deviation from Saturation (Julian day)	310	310	310	310	NA	NA
Duration of Deviation from Saturation (days)	220	190	220	180		
Onset of Anoxia (< 2 mg/L) (Julian day)	150	160	150	160	NA	NA
Termination of Anoxia (< 2mg/L) (Julian day)	290	290	300	300	NA	NA
Duration of Anoxia (< 2 mg/L) (days)	140	130	150	140		
Period of Maximum Anoxia	240	230	220	220	NA	NA

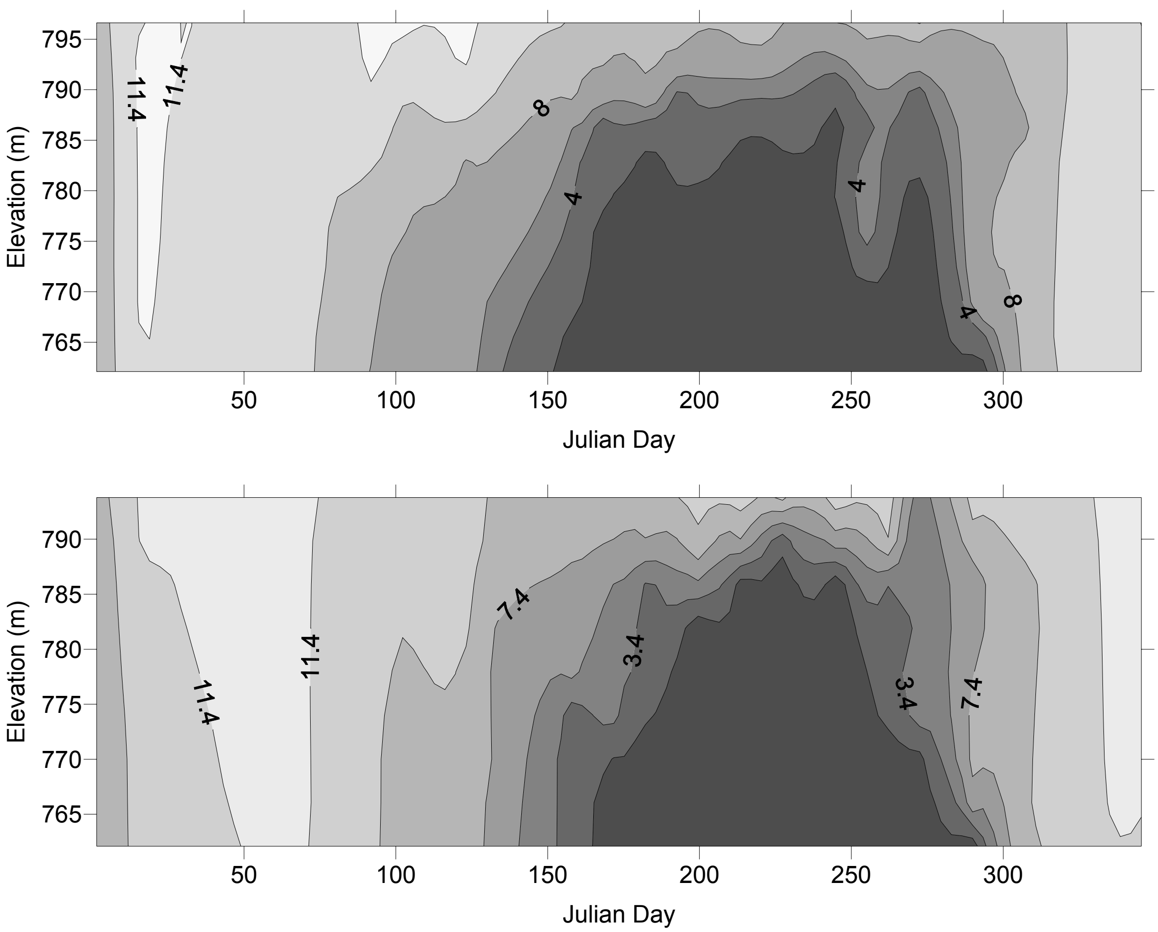
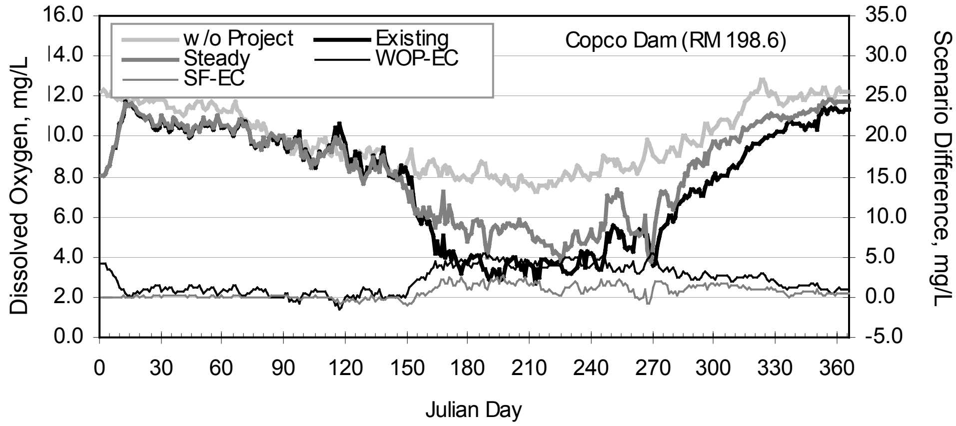


Figure 4.8-50. Copco reservoir dissolved oxygen (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).



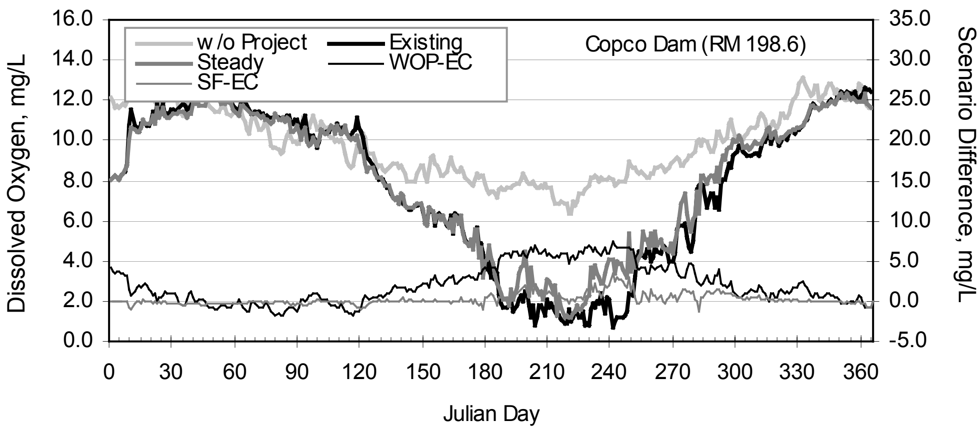


Figure 4.8-51. EC versus SF and WOP mean daily dissolved oxygen below Copco dam for 2000 (top) and 2001 (bottom).

4.8.6.3 Nutrients, Algae, and Organic Matter

In the hypolimnion, the following conditions are noted:

- Orthophosphate and ammonia increase through summer in Copco reservoir due to transport of organic matter into the reservoir from upstream sources, as well as production within the reservoir (Figures 4.8-52 and 4.8-53). This matter settles through the metalimnion to the hypolimnion and breaks down through hydrolysis. Orthophosphate and ammonia are released from sediments under anoxic conditions, which has been identified as an active process through laboratory studies of Copco reservoir sediments.

- Nitrate generally stabilizes in the hypolimnion during the summer months as nitrification inhibition reduces the conversion of ammonia to nitrate (Figure 4.8-54).

- Fall turnover creates isothermal conditions that arrest the aforementioned processes affecting orthophosphate, ammonia, and nitrate in the reservoir.

In the epilimnion, the following conditions are noted:

- Nutrient depletion occurs from about mid-March through October (ramping up in the spring and ramping down in the fall) due to algal growth within this period (Figure 4.8-55).

- Some interesting dynamics include interflow in Copco reservoir. Examining Julian day 250 of 2000, it is apparent that water of a different quality entered the reservoir, probably driven by temperature-dependent density differences. This interflow resulted in increased DO and changes in nitrate and algae concentrations.

WOP nutrient concentrations are similar to upstream concentrations as transit time through this reach without the reservoir is reduced to several hours (versus weeks).

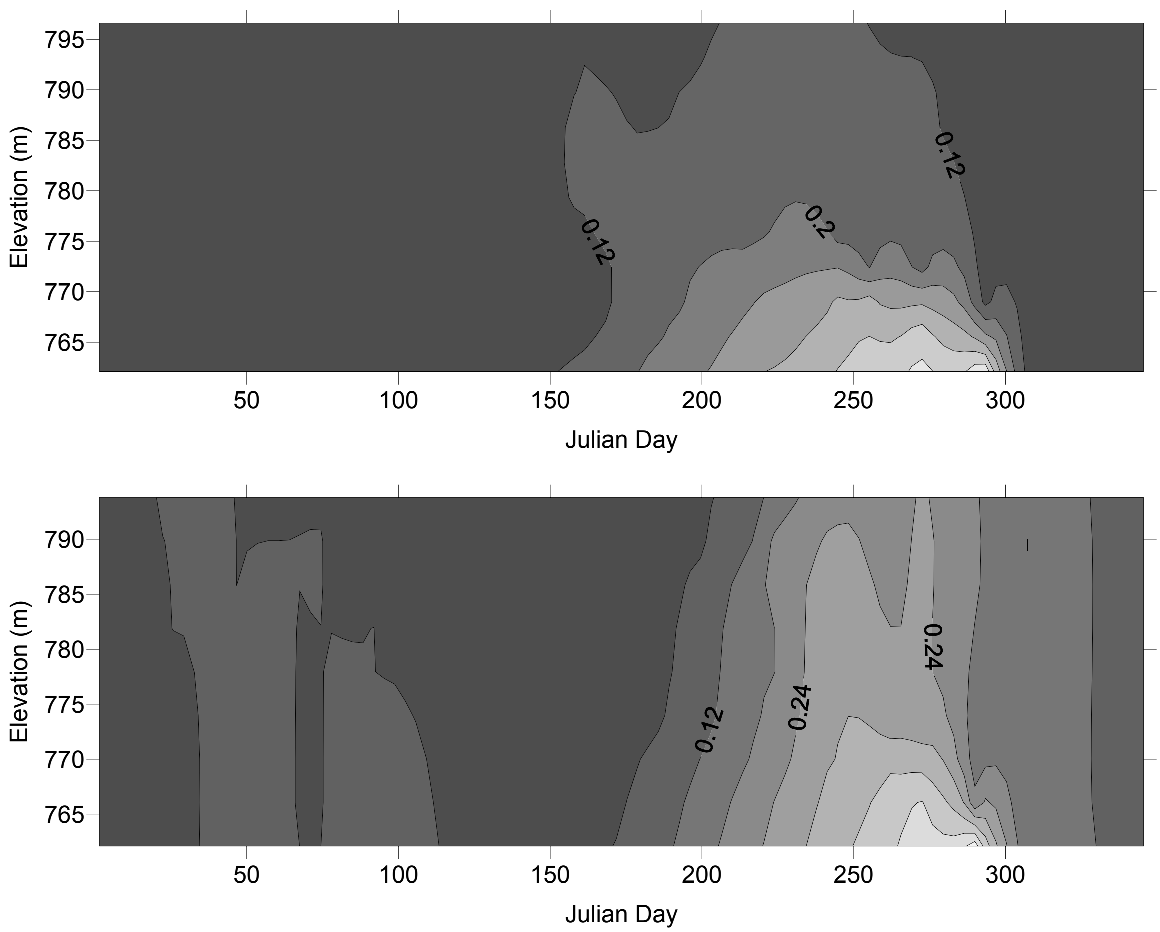


Figure 4.8-52. Copco reservoir orthophosphate (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).

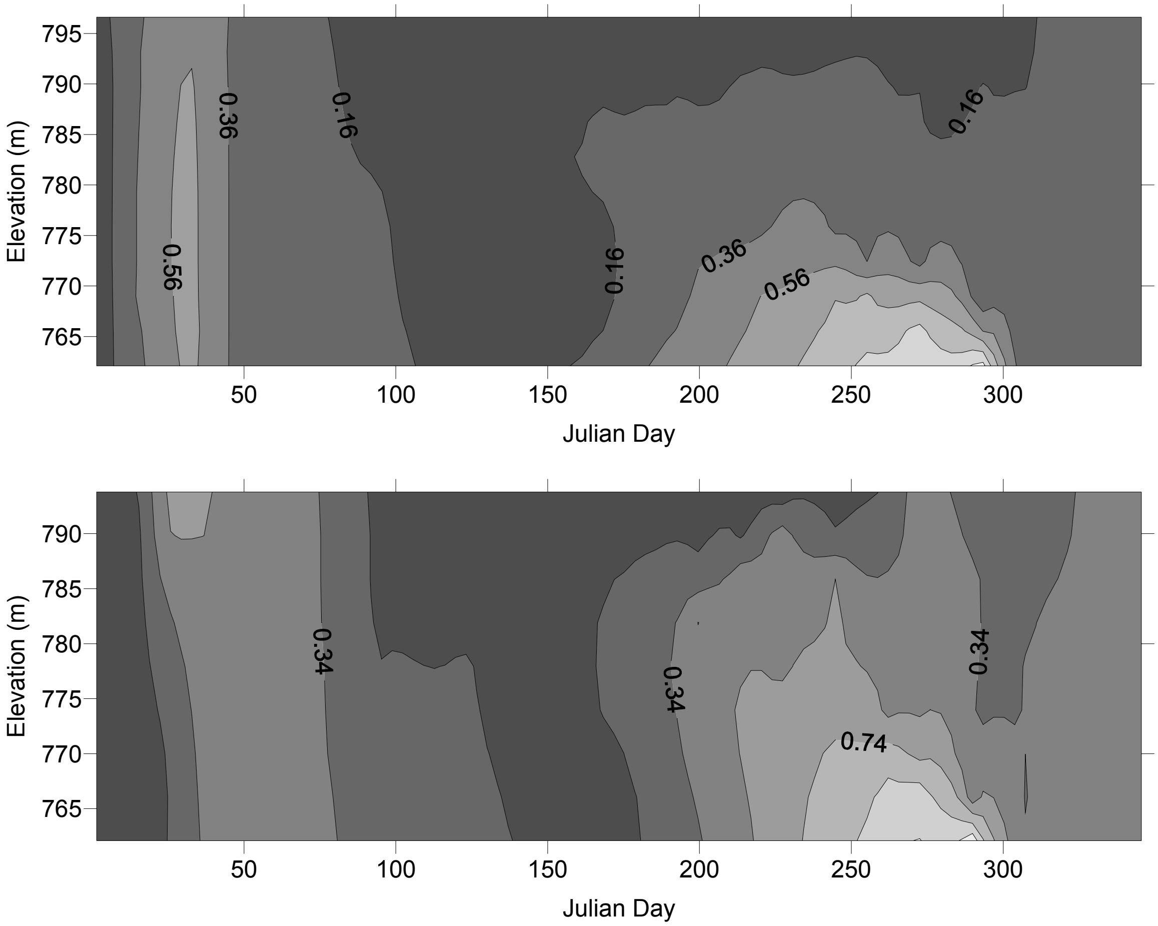


Figure 4.8-53. Copco reservoir ammonia (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).

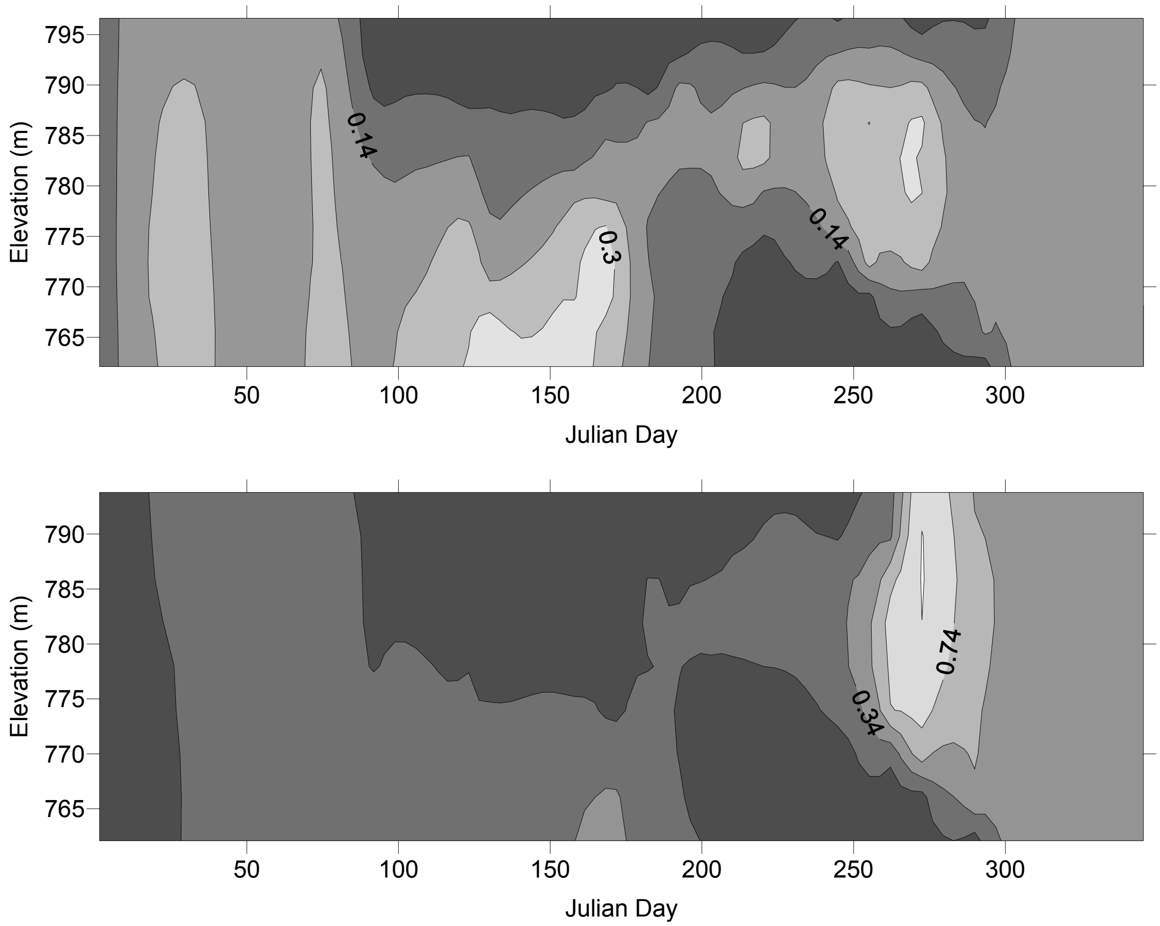
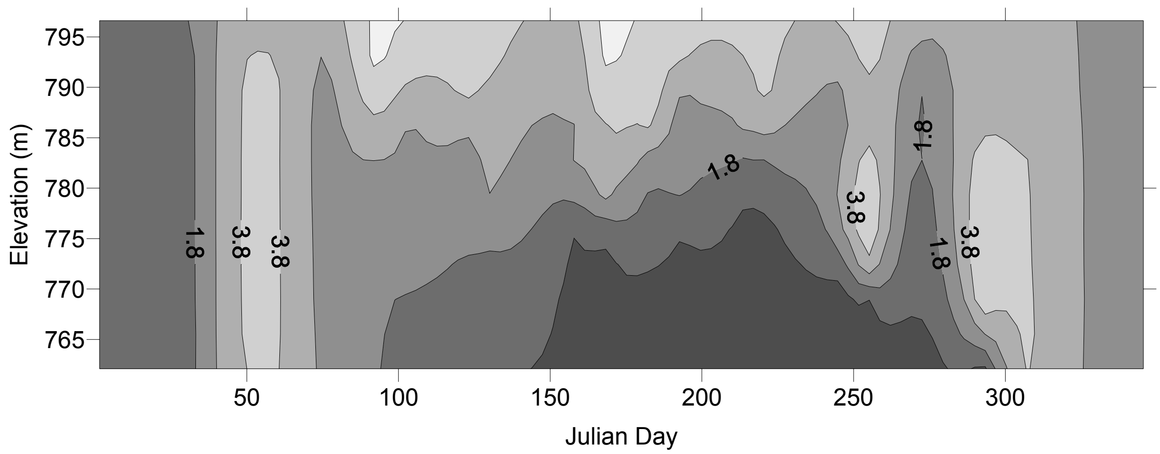


Figure 4.8-54. Copco reservoir nitrate (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).



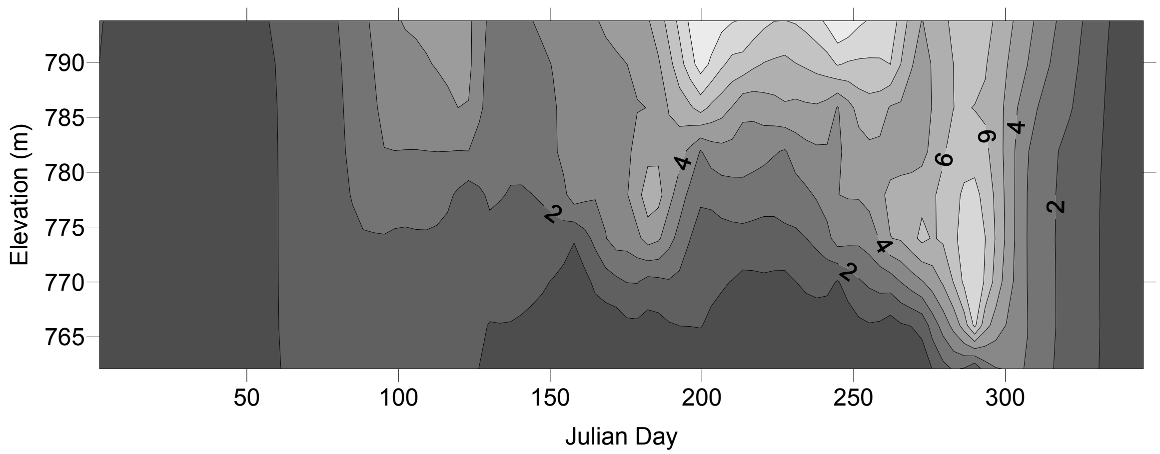


Figure 4.8-55. Copco reservoir algae (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).

4.8.7 <u>Iron Gate Reservoir</u>

4.8.7.1 Flow

Model results for flow are discussed in Section 5.0 of this Water Resources FTR.

4.8.7.2 Temperature

- Stratification in Iron Gate reservoir for both EC and SF occurs around early March and remains stratified for over 200 days, extending well into November (Table 4.8-3, Figure 4.8-56). Maximum difference between epilimnetic and hypolimnetic temperatures is about 16^{o}C.

- Stratification ends in Iron Gate reservoir in mid- to late November (about a month later than Copco reservoir). The river reach between Copco dam and Iron Gate reservoir is too short (about 1.4 miles) to allow the waters to cool sufficiently to provide density-driven flows that would accelerate destratification. The result is that Copco reservoir "protects" Iron Gate reservoir's hypolimnetic cold water supply. Thus, deep water temperatures in Iron Gate reservoir are about 8^{o}C. An appreciable portion of the Iron Gate reservoir cold water pool is used at the downstream Iron Gate fish hatchery.

- Iron Gate reservoir causes a thermal lag, wherein release temperatures during fall are warmer than under the WOP condition (Figure 4.8-57) (akin to Copco reservoir releases). This is due to the large thermal mass of Iron Gate reservoir compared to river reaches. River reaches can cool and heat relatively quickly compared to the large, deep resevoir volumes. The inverse, to some degree occurs in the spring, when increased thermal loading in the reservoir produces temperatures that are slightly cooler than WOP. This is particularly noticeable when examining the short duration warm periods: the WOP temperatures jump up noticeably, while the deep releases from Iron Gate reservoir for EC and SF remain moderate during these events.

Table 4.8-3. Iron Gate thermal stratification scenario comparison.

Iron Gate	**EC**		**SF**		**WOP**	
	2000	**2001**	**2000**	**2001**	**2000**	**2001**
Onset of Stratification (Julian day)	100	100	100	100	n/a	n/a
Fall Turnover (Julian day)	320	325	320	320	n/a	n/a
Duration of Stratification (days)	220	225	220	220	n/a	n/a
Maximum Stratification date	215	220	215	220	n/a	n/a
Maximum Water Temperature Difference (°C)	18	16	16	16	n/a	n/a
Minimum Summer Hypolimnetic Water Temperature (°C)	8	8	8	8	n/a	n/a

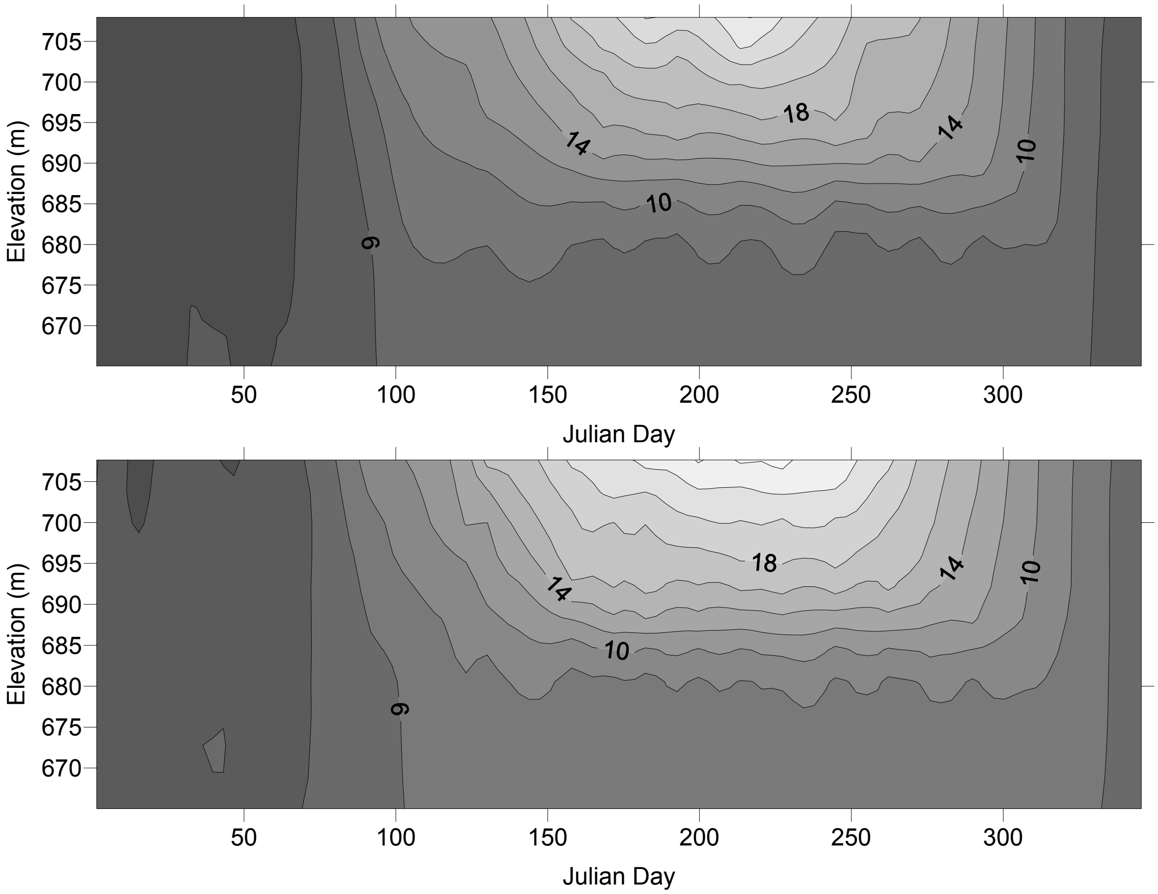


Figure 4.8-56. Iron Gate reservoir temperature (°C) isopleths: EC for 2000 (top) and 2001 (bottom).

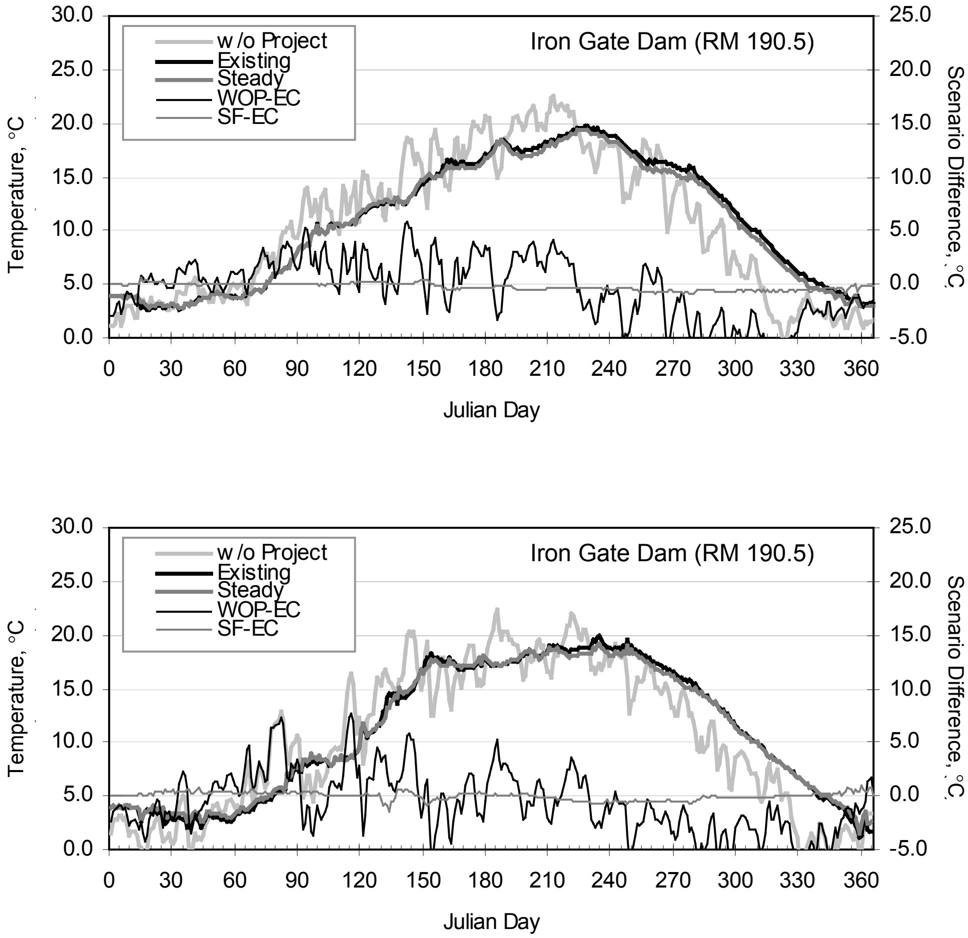


Figure 4.8-57. EC versus SF and WOP mean daily water temperature below Iron Gate dam for 2000 (top) and 2001 (bottom).

4.8.7.3 Dissolved Oxygen

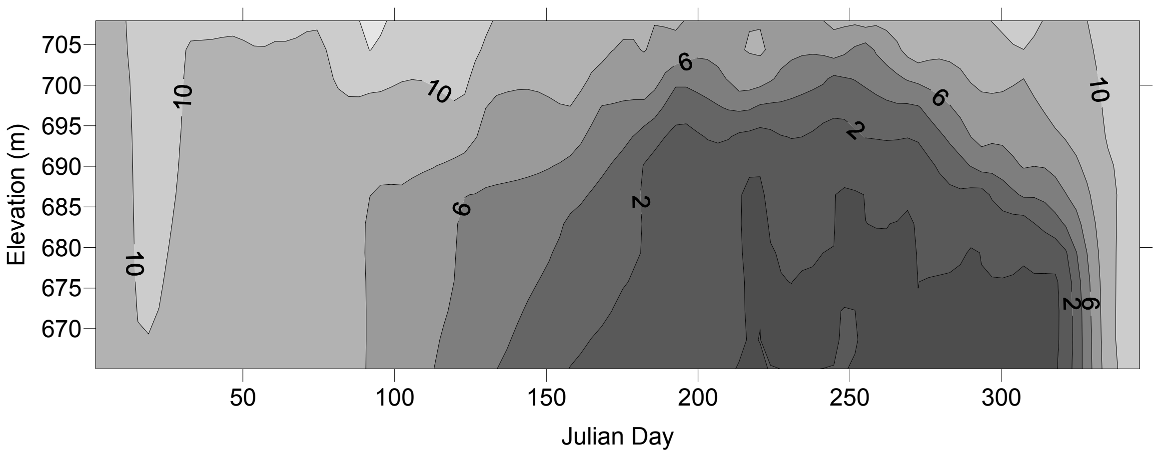
- DO concentrations in Iron Gate reservoir begin to deviate from saturation values around the time of thermal stratification onset and persist for over 200 days (Table 4.8-4, Figure 4.8-58). However, there is considerable variation when oxygen concentrations begin to deviate. The onset of anoxia (DO less than 2 mg/L) varies, but starts at around mid- to late-June and persists until stratification ends in the fall.

- EC and SF both produce low DO levels in Iron Gate release waters (Figure 4.8-59). SF performs slightly better, possibly due to a more stable thermocline.

- WOP DO concentrations at the Iron Gate dam site are at or near saturation most of the year (Figure 4.8-59).

Table 4.8-4. Scenario comparison of dissolved oxygen conditions at Iron Gate reservoir.

Iron Gate	EC		SF		WOP	
	2000	2001	2000	2001	2000	2001
Onset of Deviation from Saturation (Julian day)	90	140	100	140	NA	NA
Termination of Deviation from Saturation (Julian day)	330	330	330	330	NA	NA
Duration of Deviation from Saturation (days)	240	190	230	190		
Onset of Anoxia (< 2 mg/L) (Julian day)	155	200	190	200	NA	NA
Termination of Anoxia (< 2mg/L) (Julian day)	320	320	310	320	NA	NA
Duration of Anoxia (< 2 mg/L) (days)	165	120	120	120		
Period of Maximum Anoxia	200-250	260	250	250	NA	NA



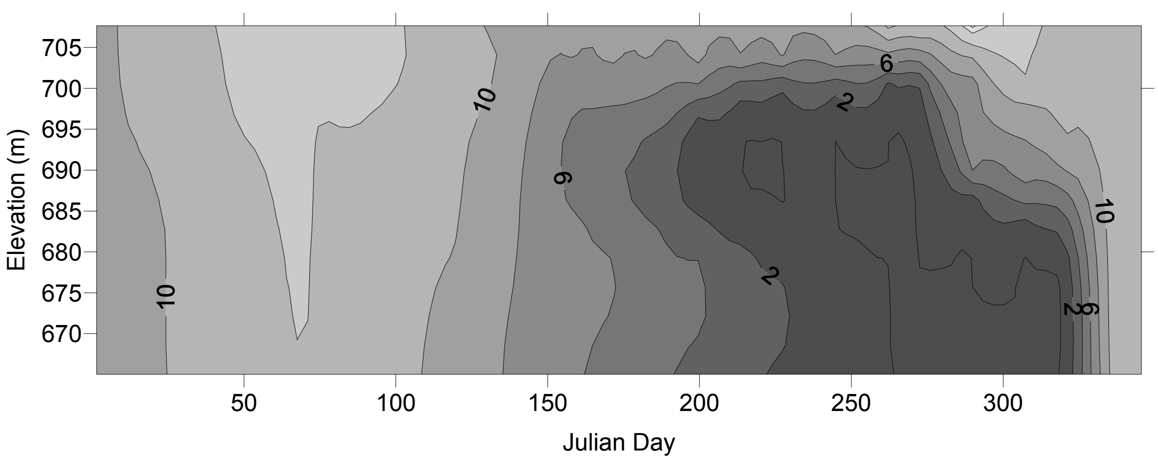
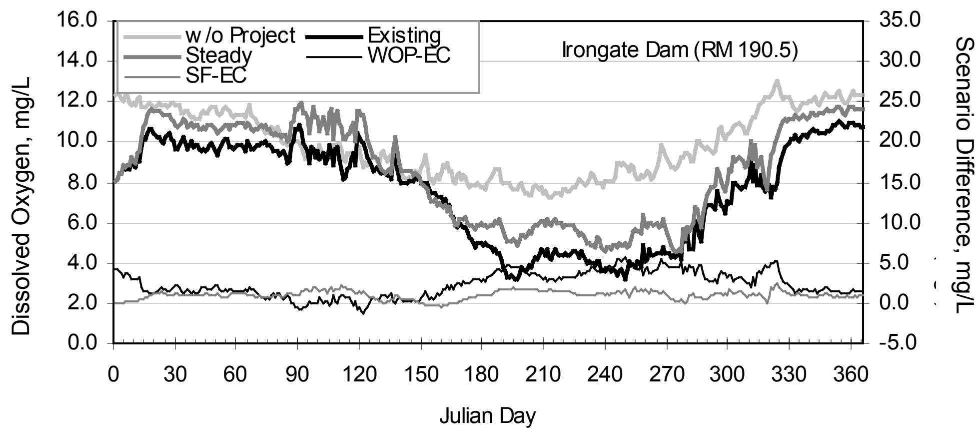


Figure 4.8-58. Iron Gate reservoir dissolved oxygen (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).



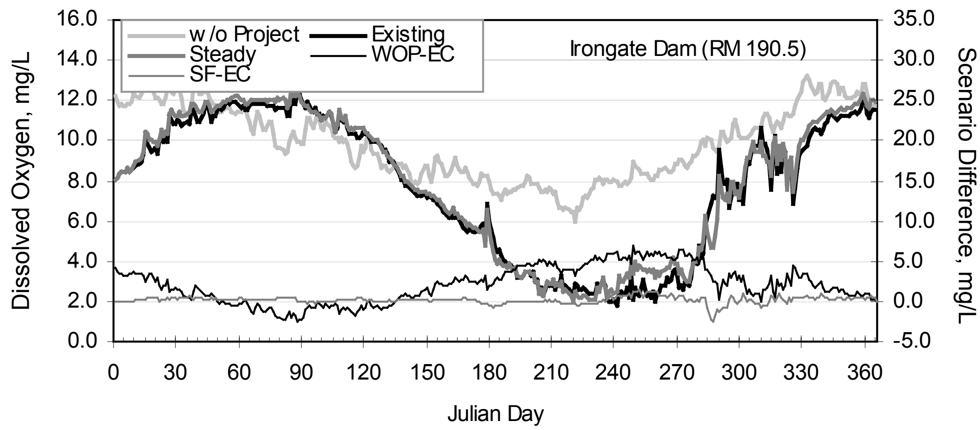


Figure 4.8-59. EC versus SF and WOP mean daily dissolved oxygen below Iron Gate Dam for 2000 (top) and 2001 (bottom).

4.8.7.4 Nutrients, Algae, and Organic Matter

In the hypolimnion, the following conditions are noted:

- Orthophosphate and ammonia increase through summer in Iron Gate reservoir due to transport of organic matter into the reservoir from upstream sources, as well as production within the reservoir (Figures 4.8-60 and 4.8-61). This matter settles through the metalimnion to the hypolimnion and breaks down through hydrolysis. Orthophosphate and ammonia are released from sediments under anoxic conditions, which has been identified as an active process through laboratory studies of Iron Gate reservoir sediments.

- Nitrate generally decreases in the hypolimnion through the summer months as nitrification inhibition reduces the conversion of ammonia to nitrate (Figure 4.8-62).

- Fall turnover creates isothermal conditions that arrest the aforementioned processes affecting orthophosphate, ammonia, and nitrate within the reservoir.

In the epilimnion, the following conditions are noted:

- Nutrient depletion occurs from about mid-March through October (ramping up in the spring and ramping down in the fall) due to algal growth in this period (Figure 4.8-63).

- Interflows, such as those identified in Copco reservoir, are not expected in Iron Gate reservoir because releases from Copco reservoir are from depth and thus do not exhibit high variability. Also, the distance between reservoirs is too short (about 1.4 miles) to provide appreciable cooling during late summer or fall months.

WOP nutrient concentrations are similar to upstream concentrations because transit time through this reach without the reservoir is reduced to several hours (versus weeks).

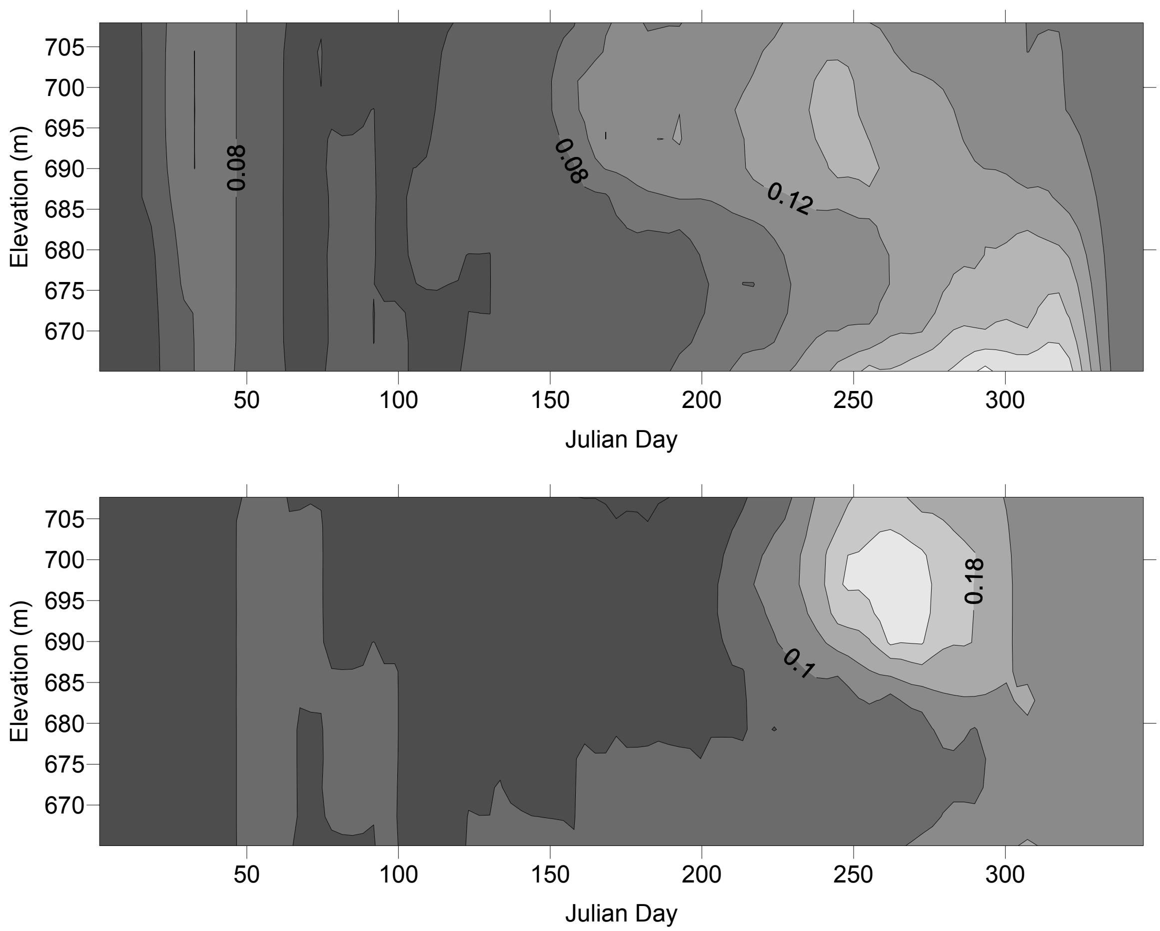


Figure 4.8-60. Iron Gate reservoir orthophosphate (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).

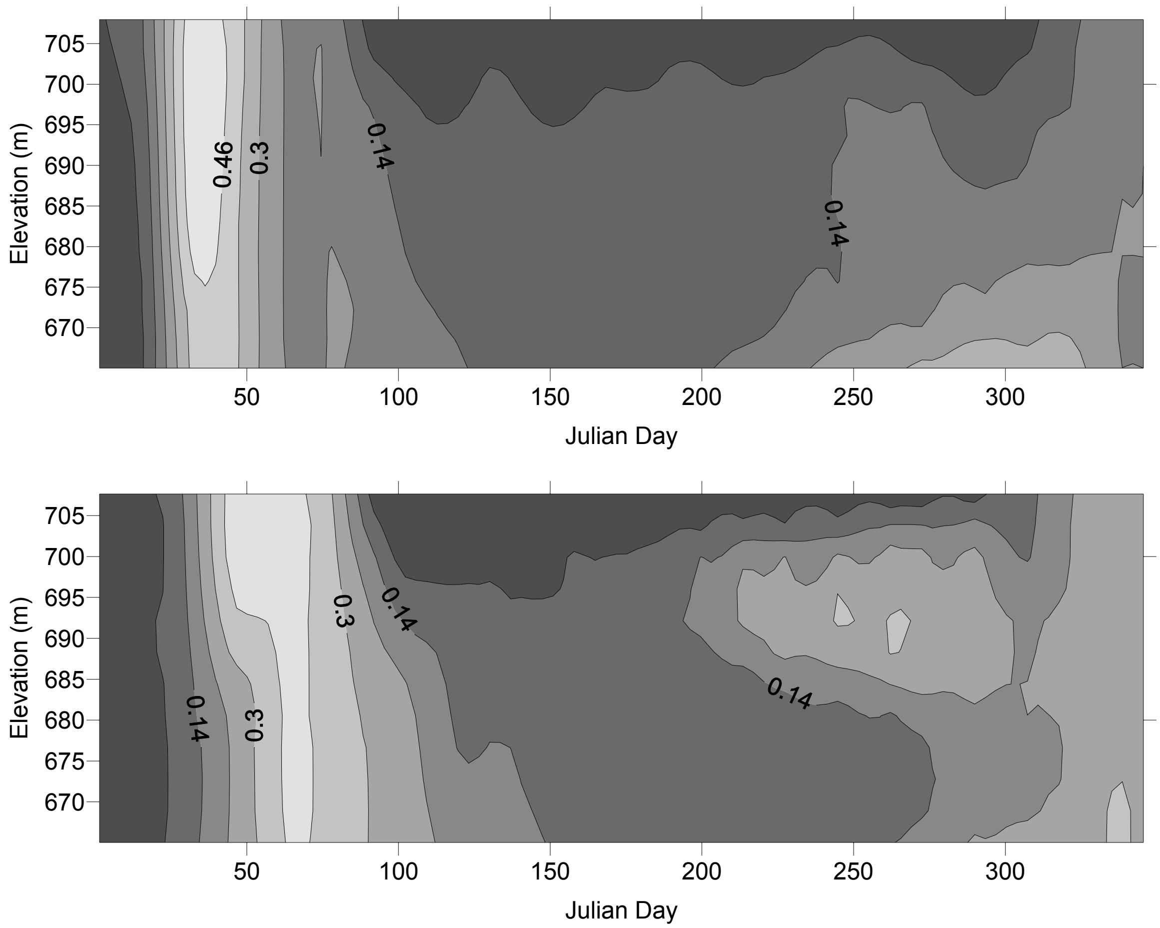


Figure 4.8-61. Iron Gate reservoir ammonia (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).

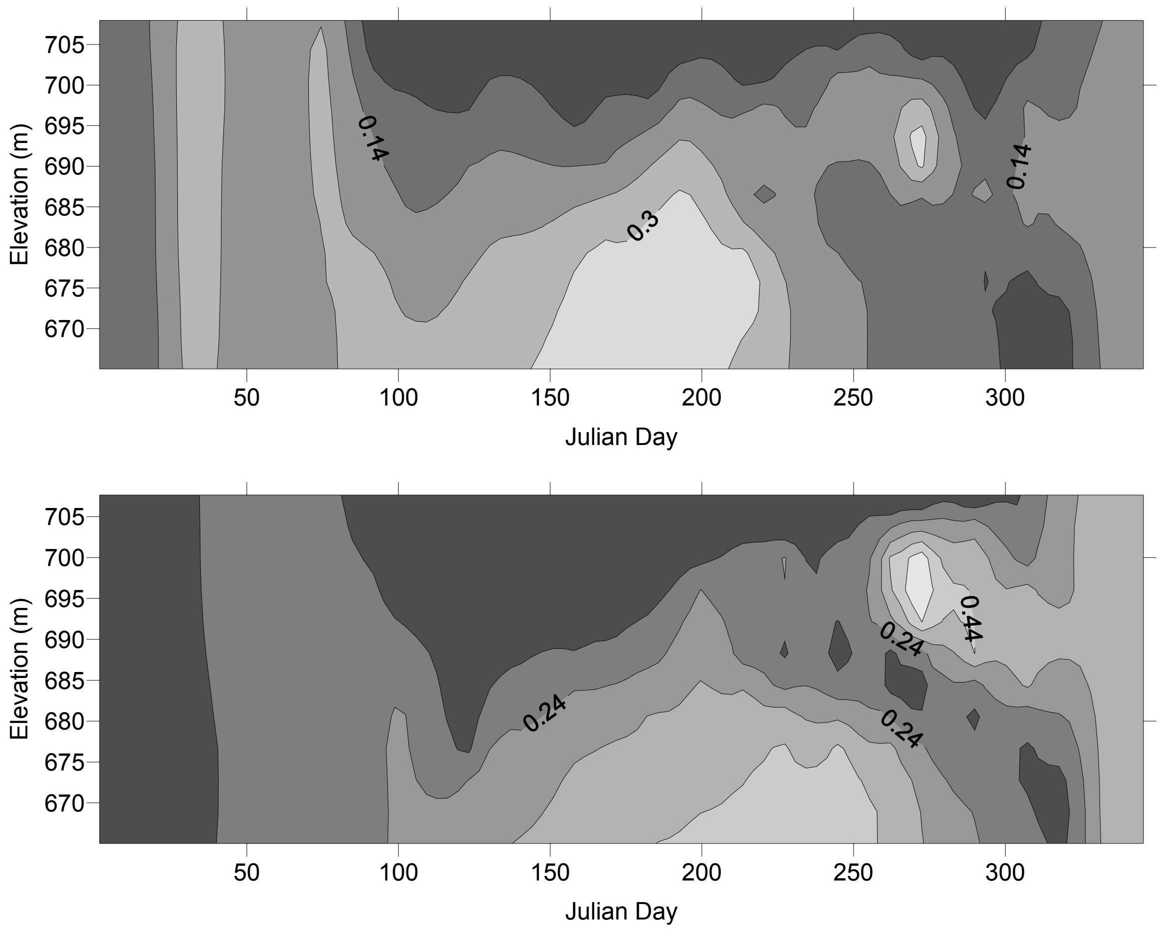


Figure 4.8-62. Iron Gate reservoir nitrate (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).

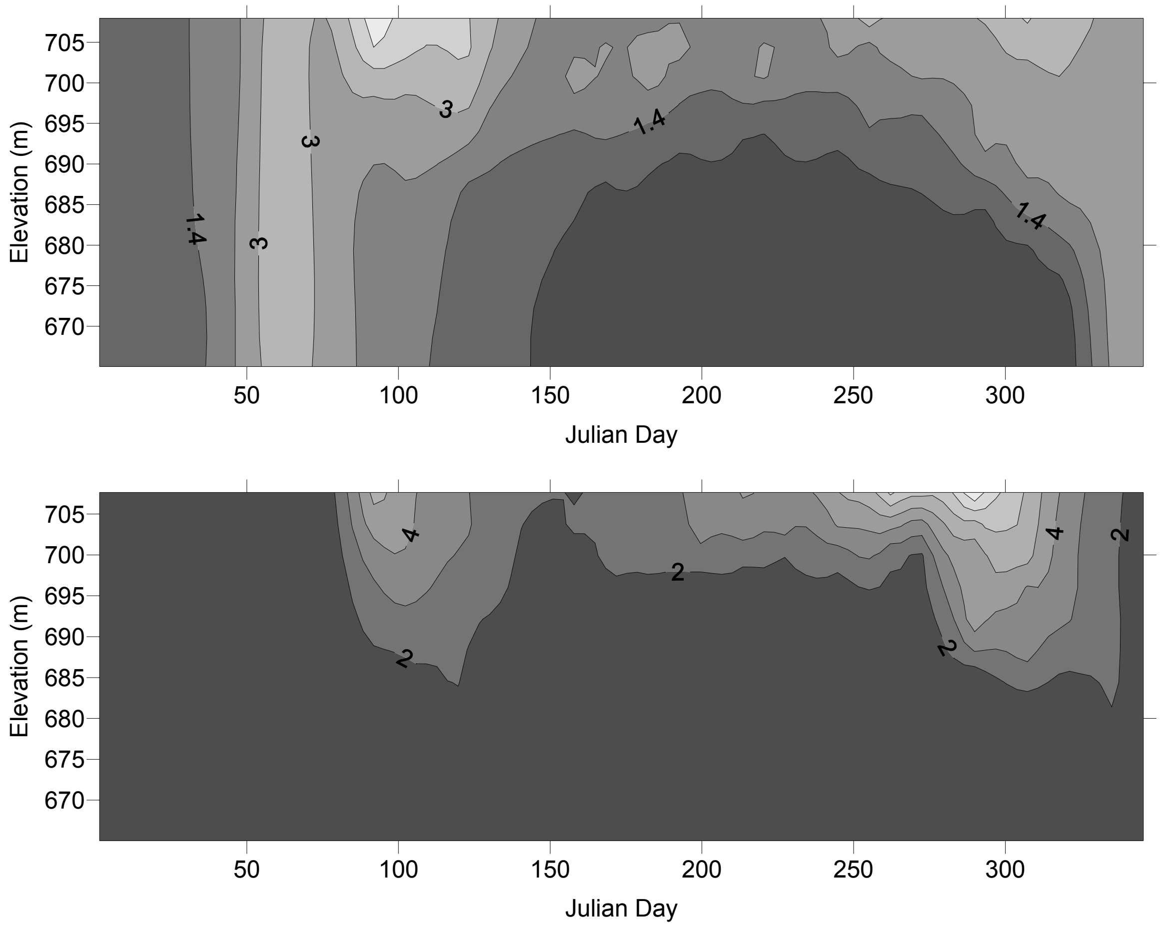


Figure 4.8-63. Iron Gate reservoir algae (mg/L) isopleths: EC for 2000 (top) and 2001 (bottom).

4.8.8 Iron Gate to Turwar

4.8.8.1 Flow

Model results for flow are discussed in Section 5.0 of this Water Resources FTR.

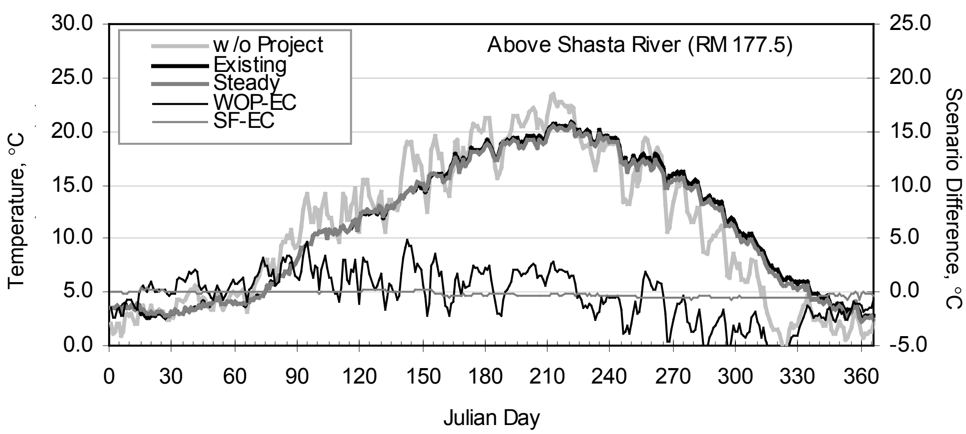
4.8.8.2 Temperature

- The EC and SF scenarios provide modest benefit in spring because Iron Gate reservoir (and Copco reservoir) acts to moderate the temperature of releases, particularly during short duration warm spells. The large volume of water in Copco and Iron Gate reservoirs (compared to the river, assuming reservoirs are absent) resists rapid changes in warming (during spring) and cooling (during late summer and fall). This creates the thermal lag in water temperature when compared with the WOP case (see Figure 4.8-57).

- The thermal lag effect is still evident in the Klamath River just above the Shasta River (RM 177.5) (Figure 4.8-64), but is greatly diminished by Seiad Valley (RM 129) (Figure 4.8-65) and generally absent by the Salmon River (RM 67) (Figure 4.8-66). The thermal lag cannot be removed with selective withdrawal because there is limited cold water supplies in Iron Gate and Copco reservoirs.

- The steady flow regime and relatively stable meteorological conditions, coupled with the moderated release temperature, create a signal that propogates down the river. These "nodes" of minimum temperature variation are evident at spacings of 1-day travel time. One-day travel time in the Klamath River under 2000 and 2001 summer flows occurred around RM 160, and at this location the maximum, minimum, and mean daily temperature traces converge. Offset from these nodes of minimum diurnal variation are points of maximum diurnal variation. These profiles are similar for the EC and SF scenarios (Figure 4.8-67), but differ for WOP (Figure 4.8-68).

- The upper Klamath River system is generally at or near equilibrium temperature throughout its length. Deviations from equilibrium occur below the springs in the J.C. Boyle reach where cool waters are introduced into the river, and below dams (i.e., Iron Gate) where deeper level releases act to moderate temperatures. The summer meteorological conditions are such that the river temperatures quickly rise towards equilibrium temperature. Many tributaries between Iron Gate dam and the Pacific Ocean have high elevation headwaters and provide appreciable snowmelt runoff that persists well into June in many years, but base flow quickly diminishes; contributions, although important to overall river quality, are modest during summer and fall months. The influent cold water, as spring flows, tributaries, or deep reservoir releases, is either insufficient in quantity or not significantly colder than river flows to have large scale (long distance) impacts during mid-summer months.



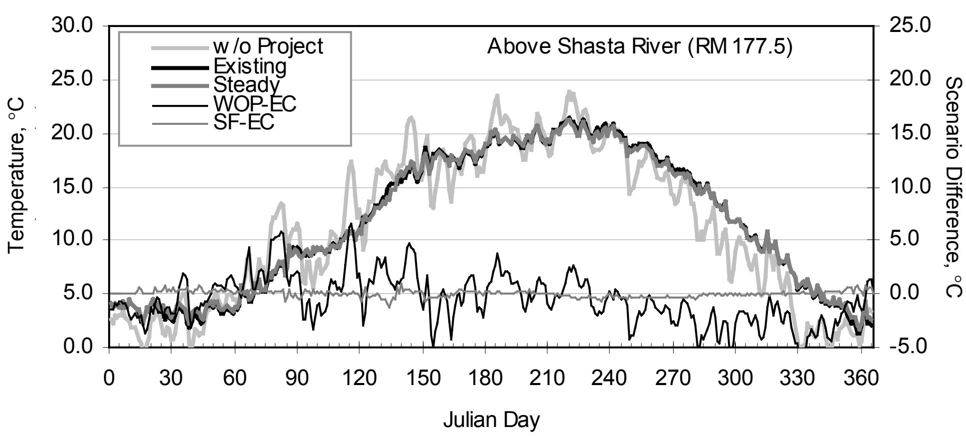


Figure 4.8-64. EC versus SF and WOP mean daily water temperature in the Klamath River above the Shasta River for 2000 (top) and 2001 (bottom).

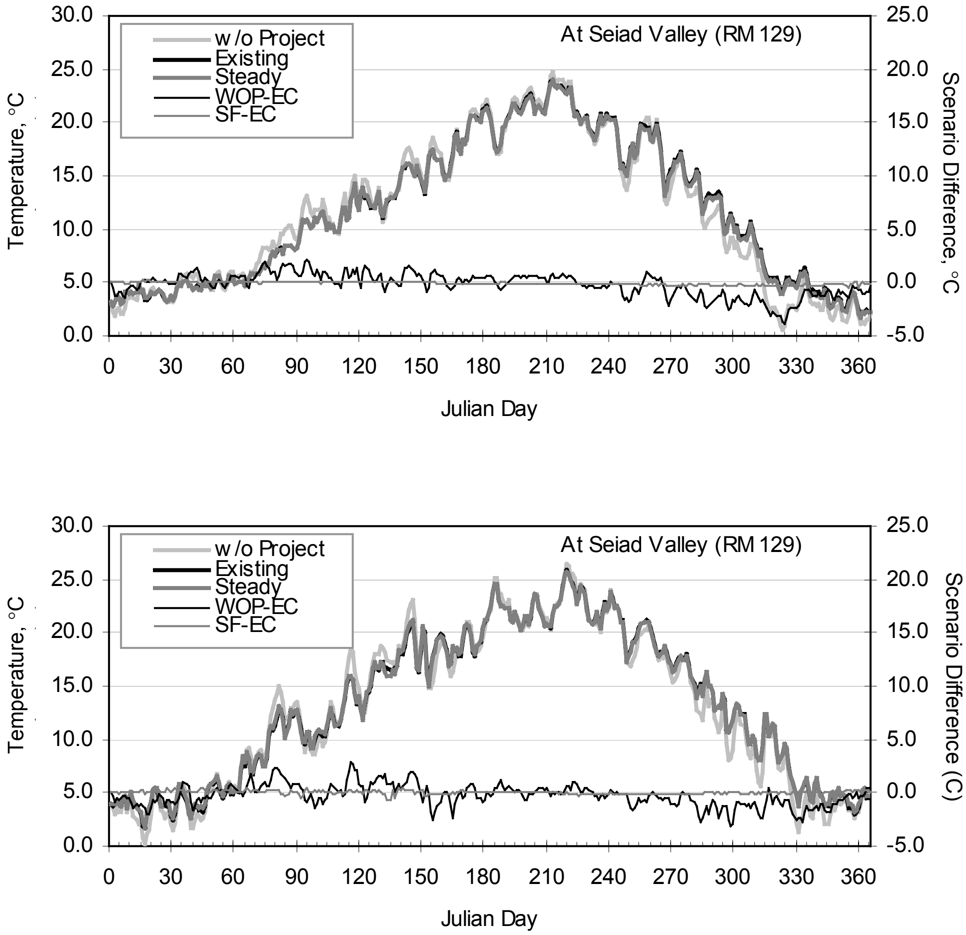
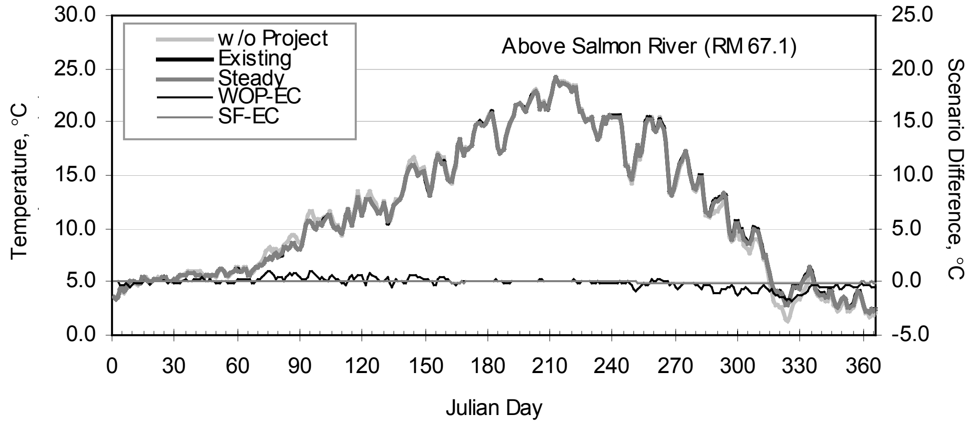


Figure 4.8-65. EC versus SF and WOP mean daily water temperature in the Klamath River at Seiad Valley for 2000 (top) and 2001 (bottom).



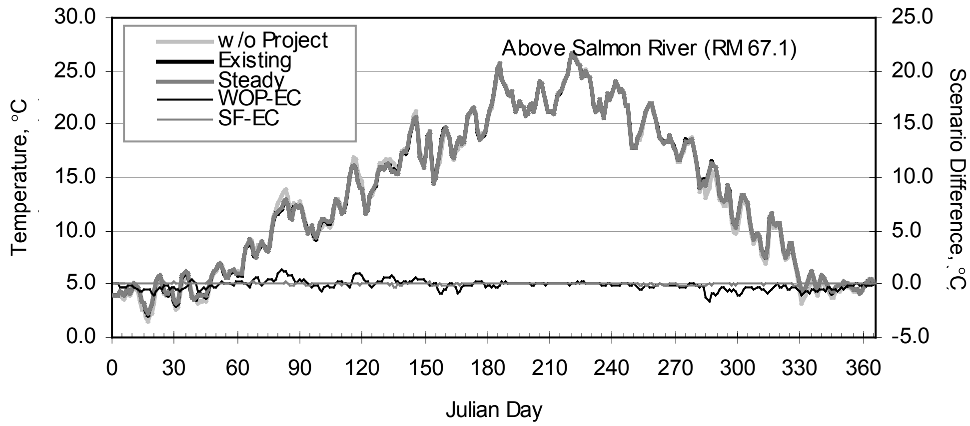


Figure 4.8-66. EC versus SF and WOP mean daily water temperature in the Klamath River above the Salmon River for 2000 (top) and 2001 (bottom).

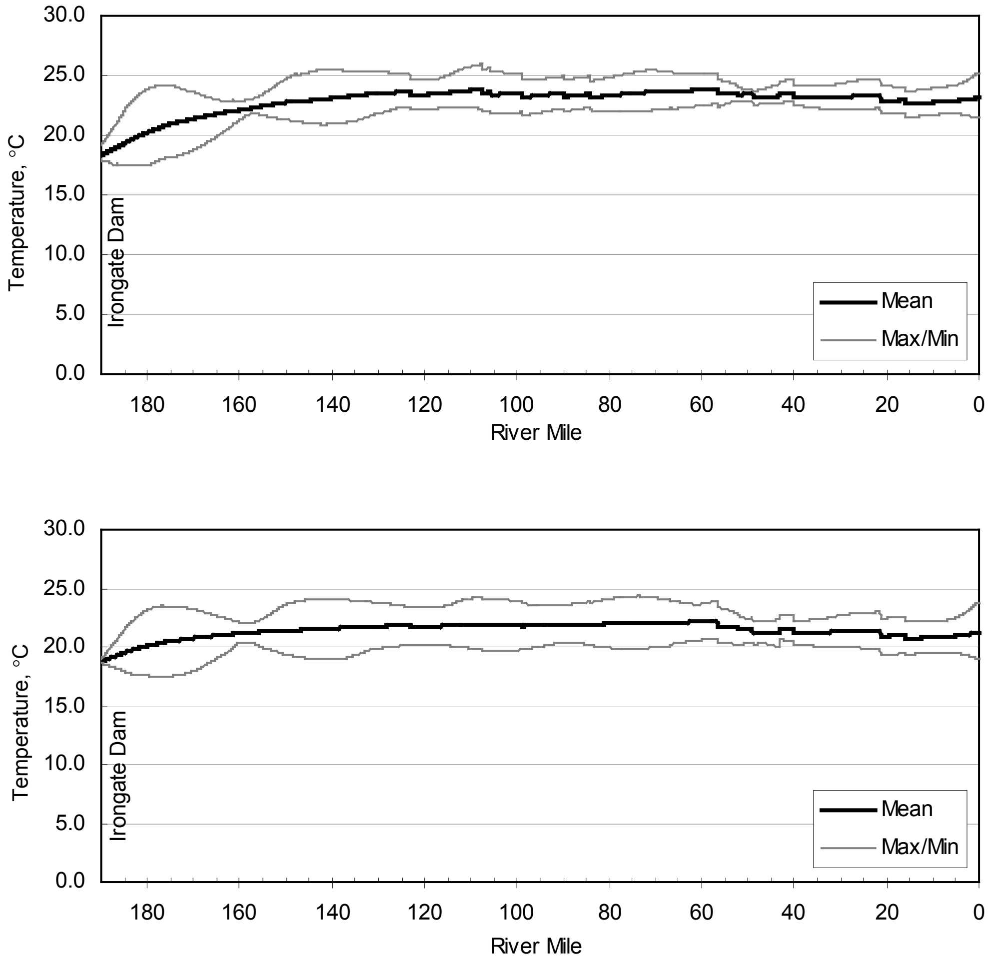


Figure 4.8-67. EC longitudinal profile of daily mean, maximum, and minimum water temperature in the Klamath River from Iron Gate dam to Turwar: August 1, 2000 (top) and August 1, 2001 (bottom).

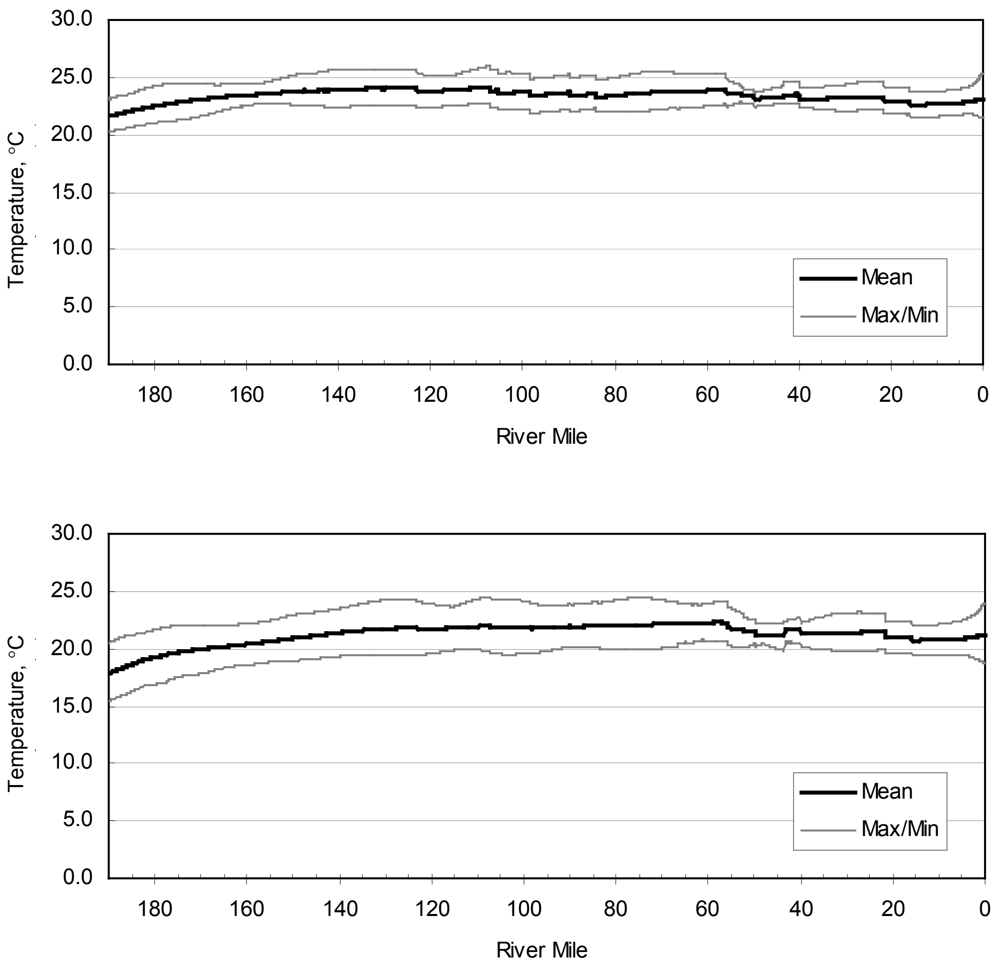


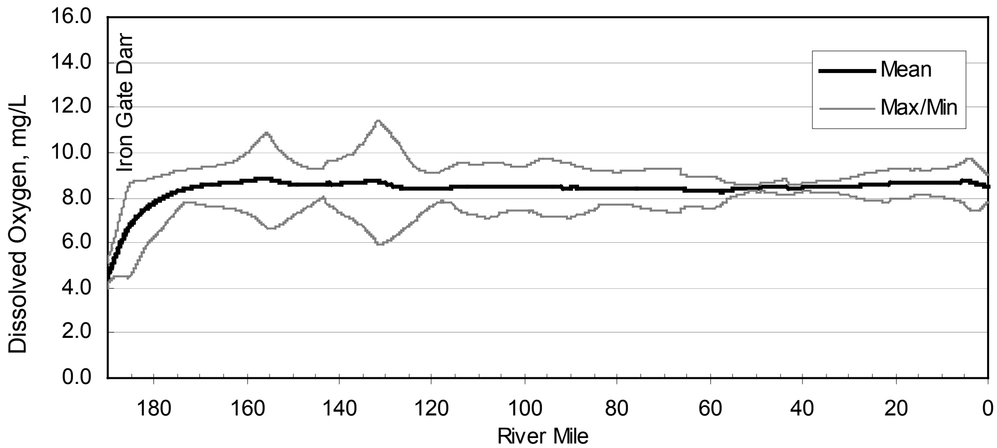
Figure 4.8-68. WOP longitudinal profile of daily mean, maximum, and minimum water temperature in the Klamath River from Iron Gate dam to Turwar: August 1, 2000 (top) and August 1, 2001 (bottom).

4.8.8.3 Dissolved Oxygen

- DO concentrations in waters released at Iron Gate dam under EC and SF scenarios return to near saturation values within the first 20 to 30 miles of river downstream, depending on the season (winter period DO concentrations are generally at or near equilibrium) (Figure 4.8-69).

- WOP simulations indicate that there is the potential for appreciable algal dynamics in the middle Klamath River (in the vicinity of Iron Gate dam and immediate downstream reaches), resulting in concomitant DO conditions that are quite variable (Figure 4.8-70). Transport of organic matter and nutrients under WOP conditions takes 2 to 3 days from Link dam to this reach during summer periods, compared with 6 to 8 weeks under EC. With the EC scenario, extended transit times allow sufficient time for nutrient transformations to occur and particulate matter (a predominant form of organic matter from Upper Klamath Lake) tends to settle in the reservoirs. Under WOP conditions, however, transit times are sufficiently short so that large organic and nutrient loads are transported to the vicinity of Iron Gate dam site in only a few days, resulting in increased algal growth (Figure 4.8-71).

- DO effects at Iron Gate are still evident in the Klamath River just above the Shasta River (RM 177.5) (Figure 4.8-72), but greatly diminished by Seiad Valley (RM 129) (Figure 4.8-73) and generally absent by the Salmon River (RM 67) (Figure 4.8-74).



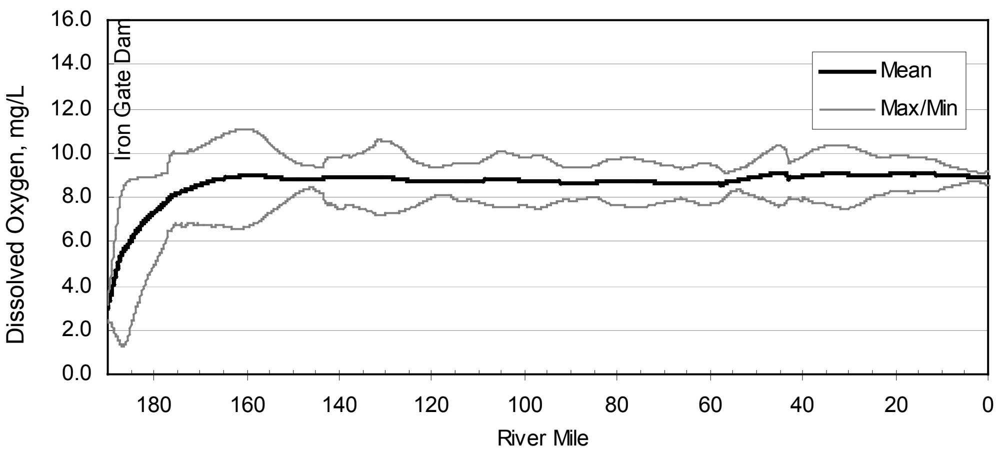
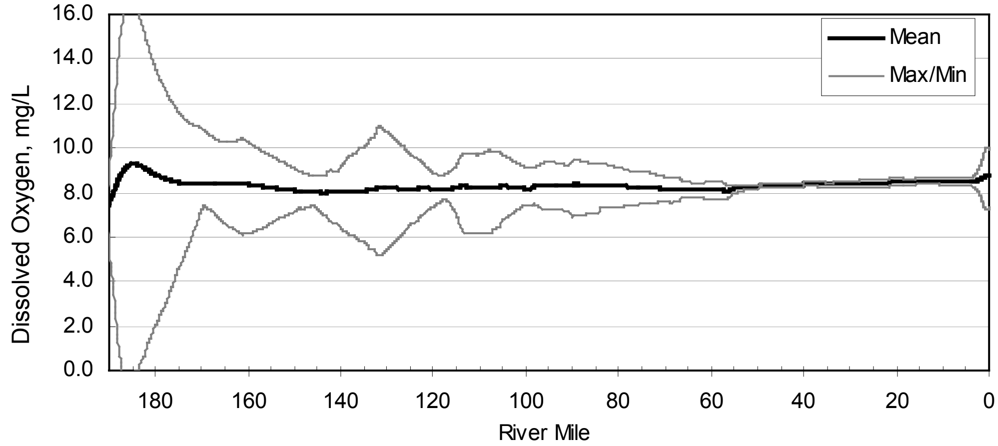


Figure 4.8-69. EC longitudinal profile of daily mean, maximum, and minimum dissolved oxygen in the Klamath River from Iron Gate dam to Turwar: August 1, 2000 (top) and August 1, 2001 (bottom).



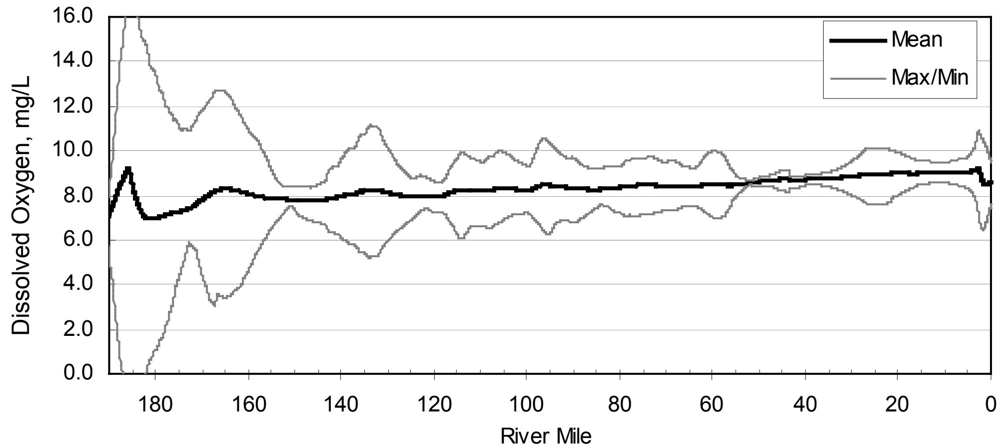
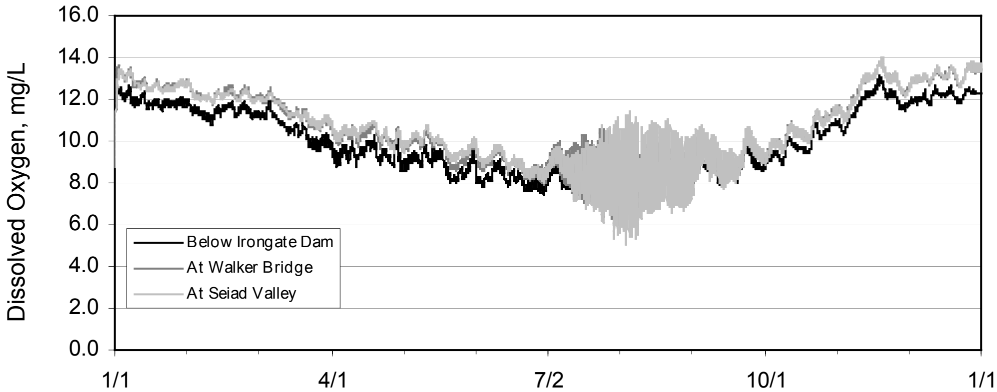


Figure 4.8-70. WOP longitudinal profile of daily mean, maximum, and minimum dissolved oxygen in the Klamath River from Iron Gate dam to Turwar: August 1, 2000 (top) and August 1, 2001 (bottom).



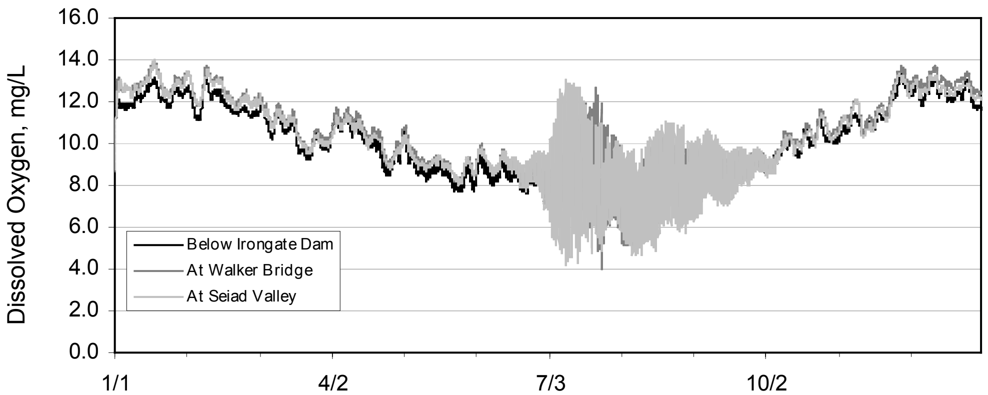


Figure 4.8-71. Simulated hourly dissolved oxygen in Klamath River below Iron Gate dam: WOP 2000 (top) and 2001 (bottom).

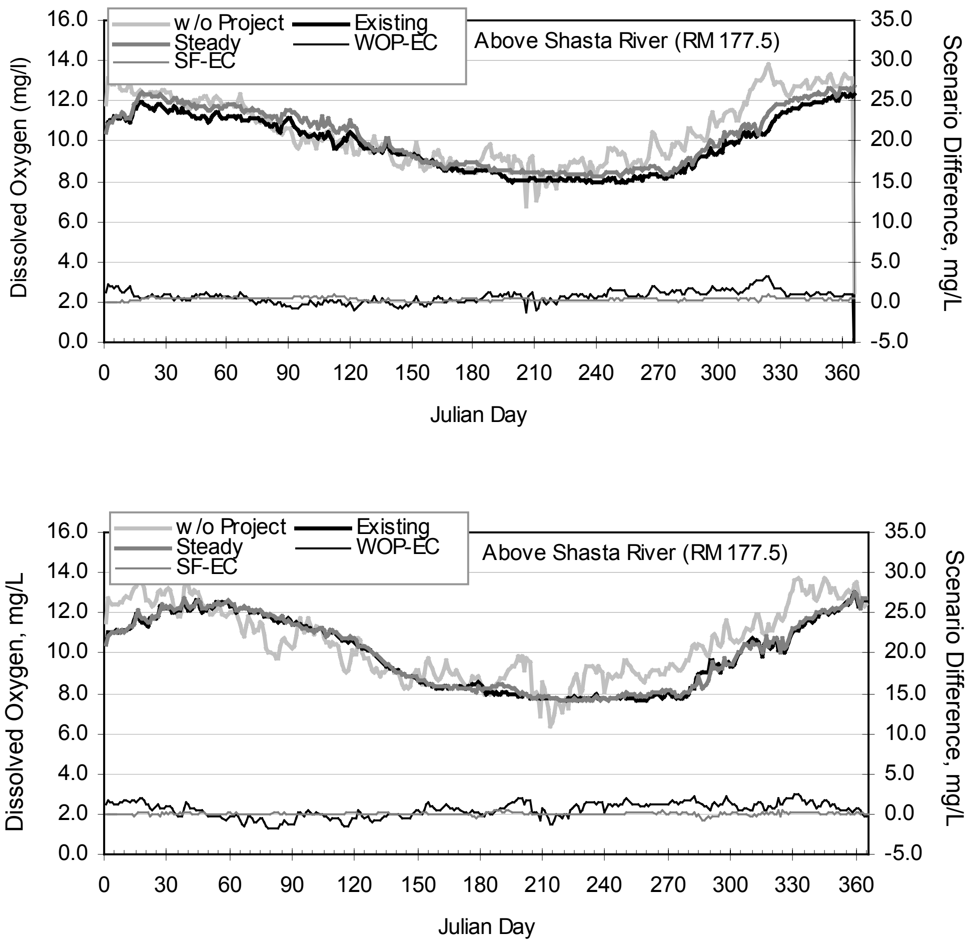
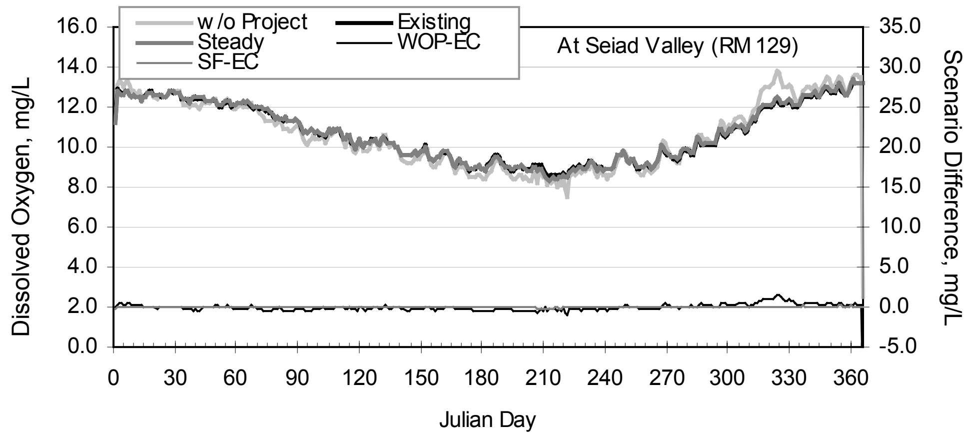


Figure 4.8-72. EC versus SF and WOP mean daily dissolved oxygen in the Klamath River just above the Shasta River for 2000 (top) and 2001 (bottom).



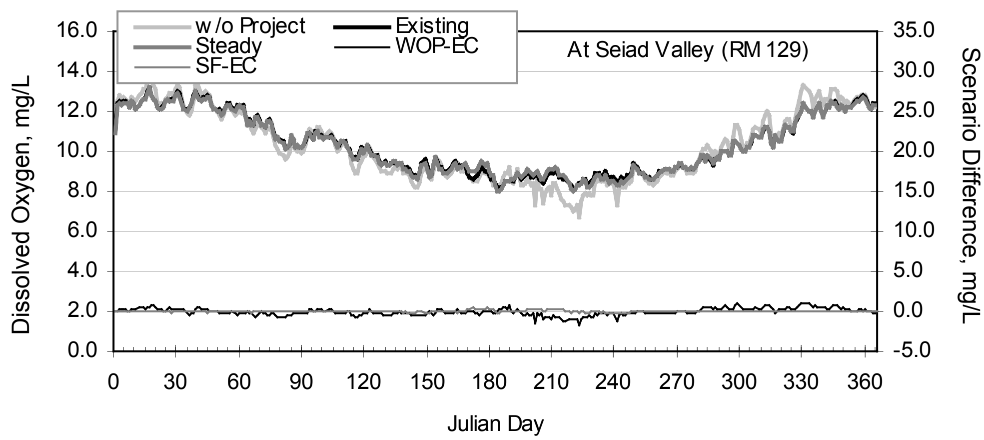


Figure 4.8-73. EC versus SF and WOP mean daily dissolved oxygen in the Klamath River at Seiad Valley for 2000 (top) and 2001 (bottom).

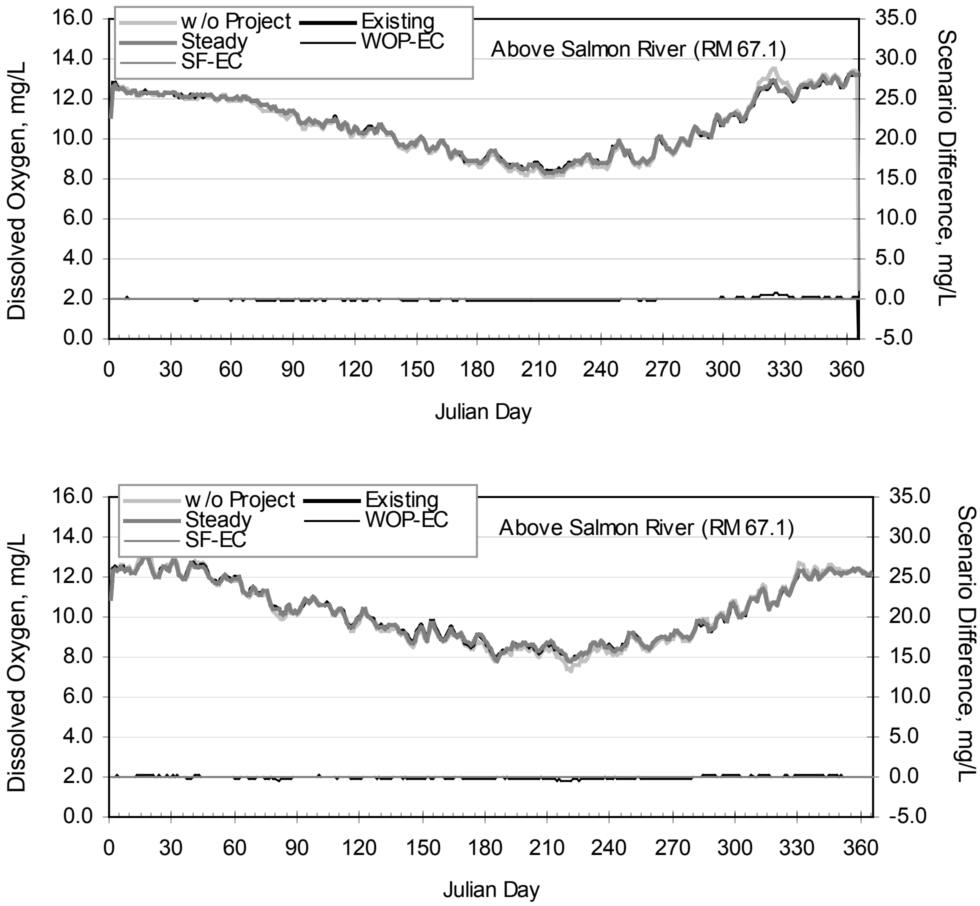


Figure 4.8-74. EC versus SF and WOP mean daily dissolved oxygen in the Klamath River just above the Salmon River for 2000 (top) and 2001 (bottom).

4.8.8.4 Nutrients, Algae, and Organic Matter

- EC nutrients are generally stable or declining through the Klamath River between Iron Gate dam and Turwar during the spring and summer months (Figure 4.8-75). Algal growth plays a predominant role in sequestering nutrients from the water column. As such, algal biomass diminished in the downstream direction. SF model simulations of nutrients were similar.

- A comparison of EC to WOP scenarios indicates that even as far down as Seiad Valley there are elevated nutrient concentrations in the WOP scenario compared with EC (Figures 4.8-76 and 4.8-77). Because WOP transit times from Link dam to Iron Gate dam are significantly faster than EC or SF, nutrients and organic matter borne out of Upper Klamath Lake and anthropogenic sources in the upper basin (e.g., agricultural returns) travel well into the middle Klamath River in a few days (versus weeks and impoundment in mainstem reservoirs under EC and SF).

- Simulations of algal growth indicate similar findings with respect to simulations of algal growth. A comparison of EC to WOP scenarios indicates that even as far down as Seiad

Valley there are elevated algal concentrations in the WOP scenario compared with EC (Figures 4.8-78 and 4.8-79).

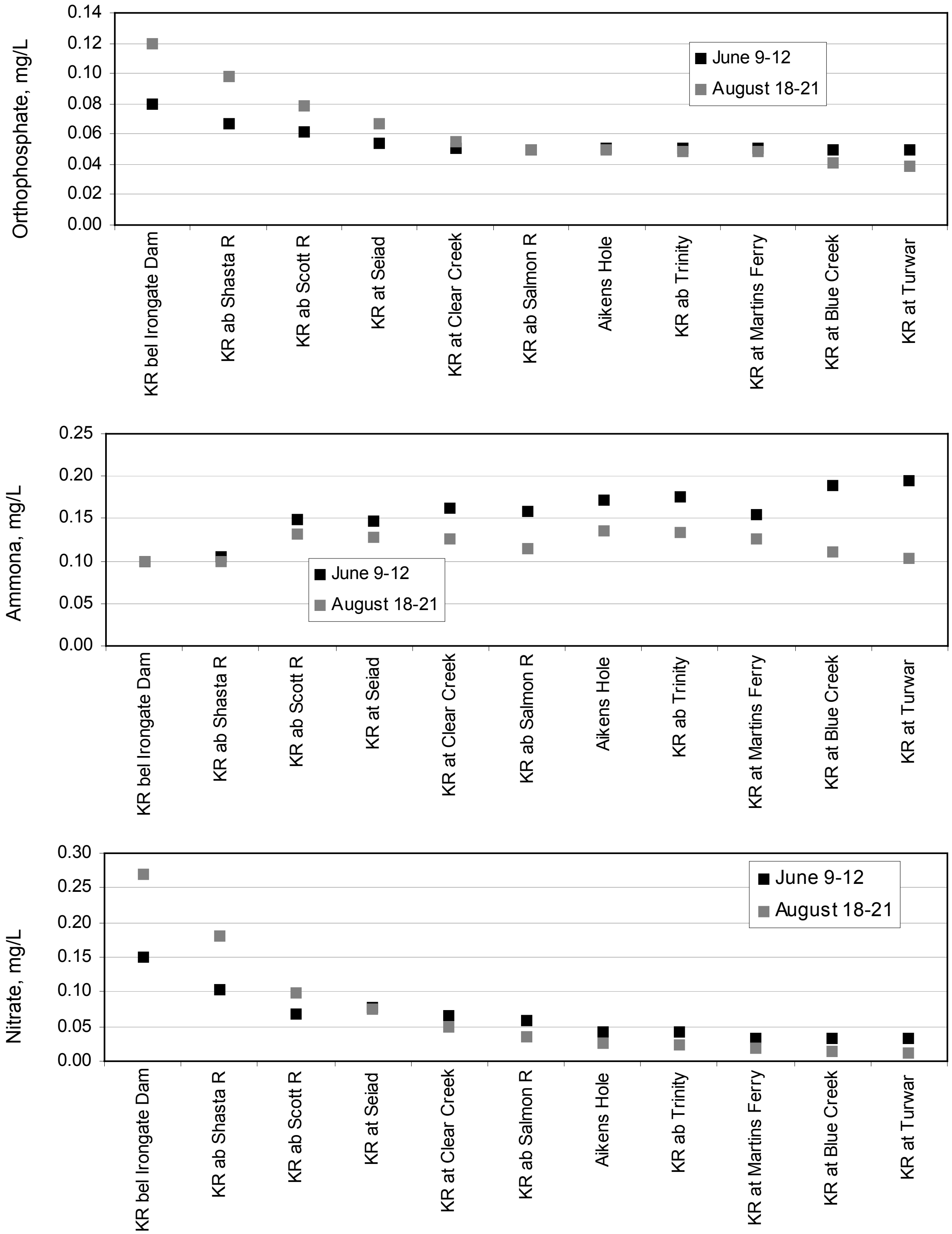


Figure 4.8-75. EC simulated nutrient concentrations in the Klamath River between Iron Gate dam and Turwar, June and August 2003: orthophosphate (top), ammonia (middle), and nitrate (bottom).

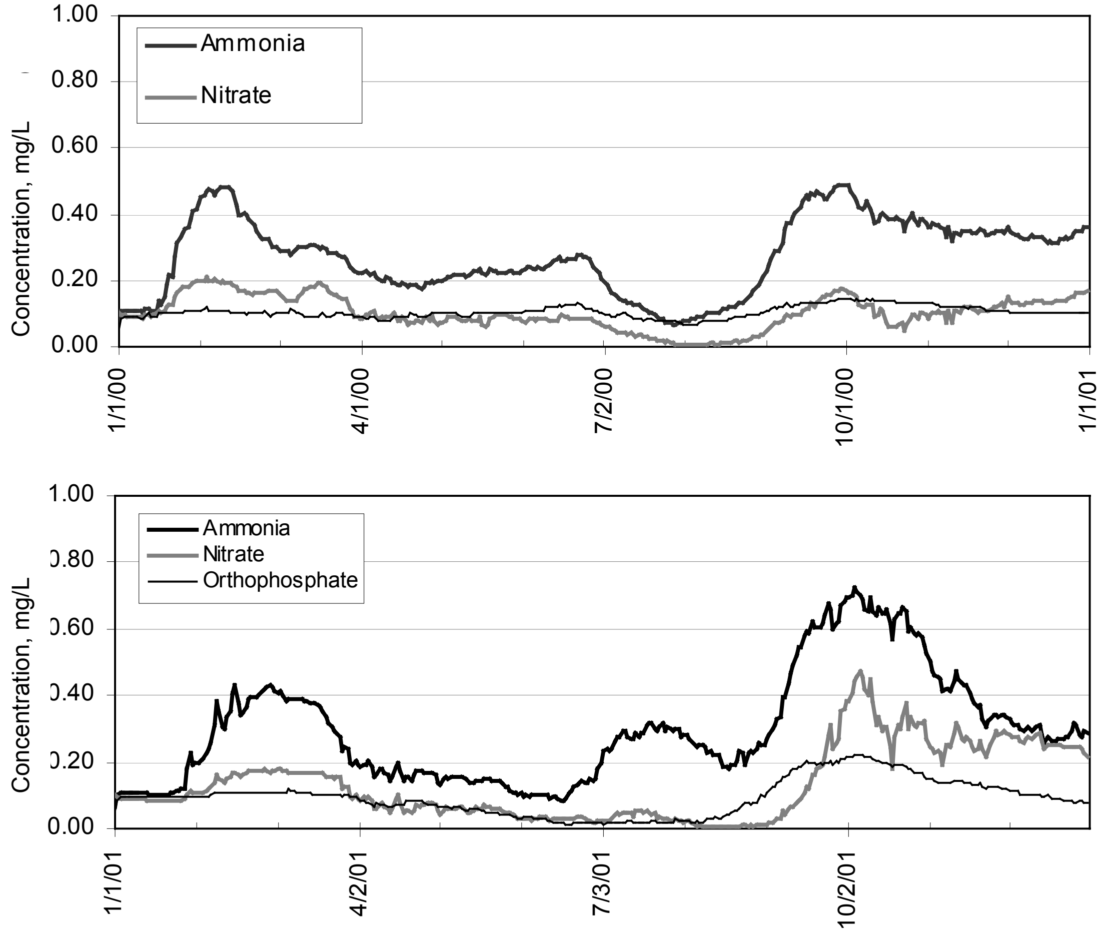


Figure 4.8-76. EC simulated ammonia, nitrate, and orthophosphate concentrations in the Klamath River at Seiad Valley: 2000 (top) and 2001 (bottom).

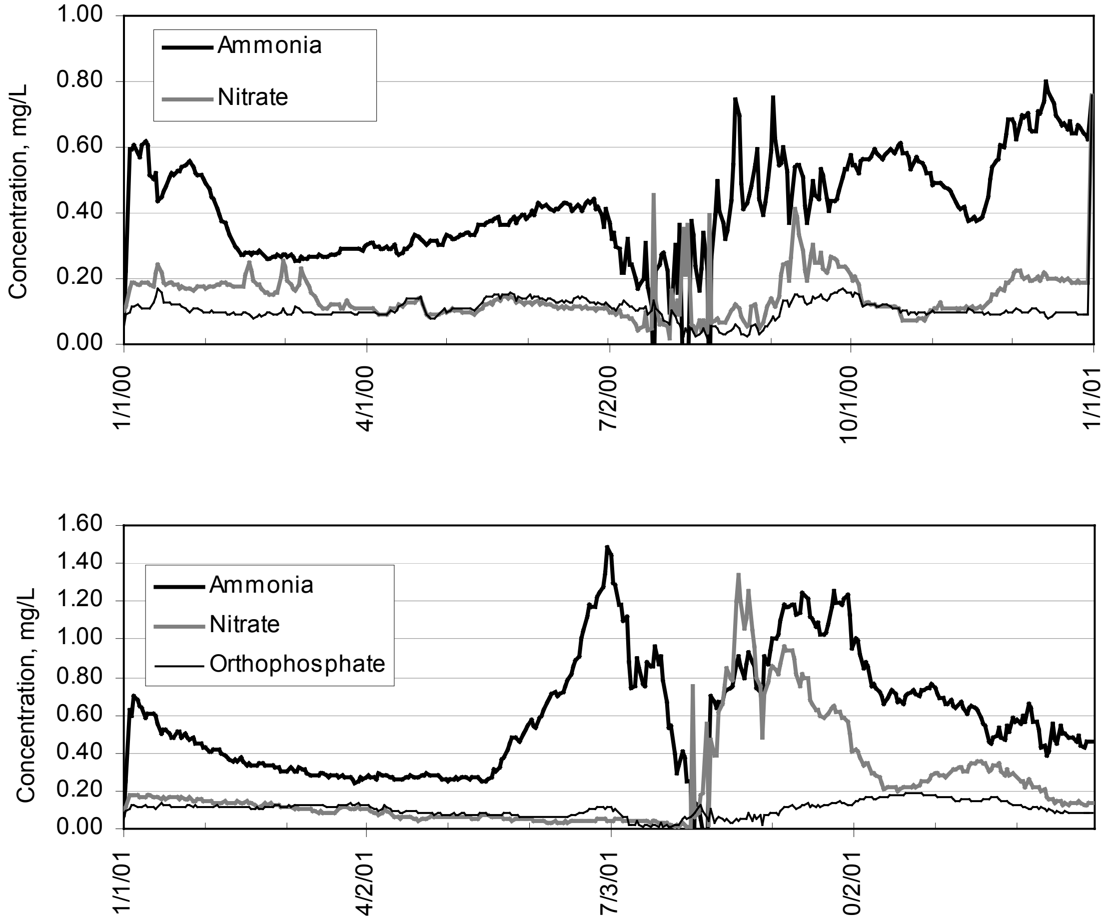


Figure 4.8-77. WOP simulated ammonia, nitrate, and orthophosphate concentrations in the Klamath River at Seiad Valley: 2000 (top) and 2001 (bottom).

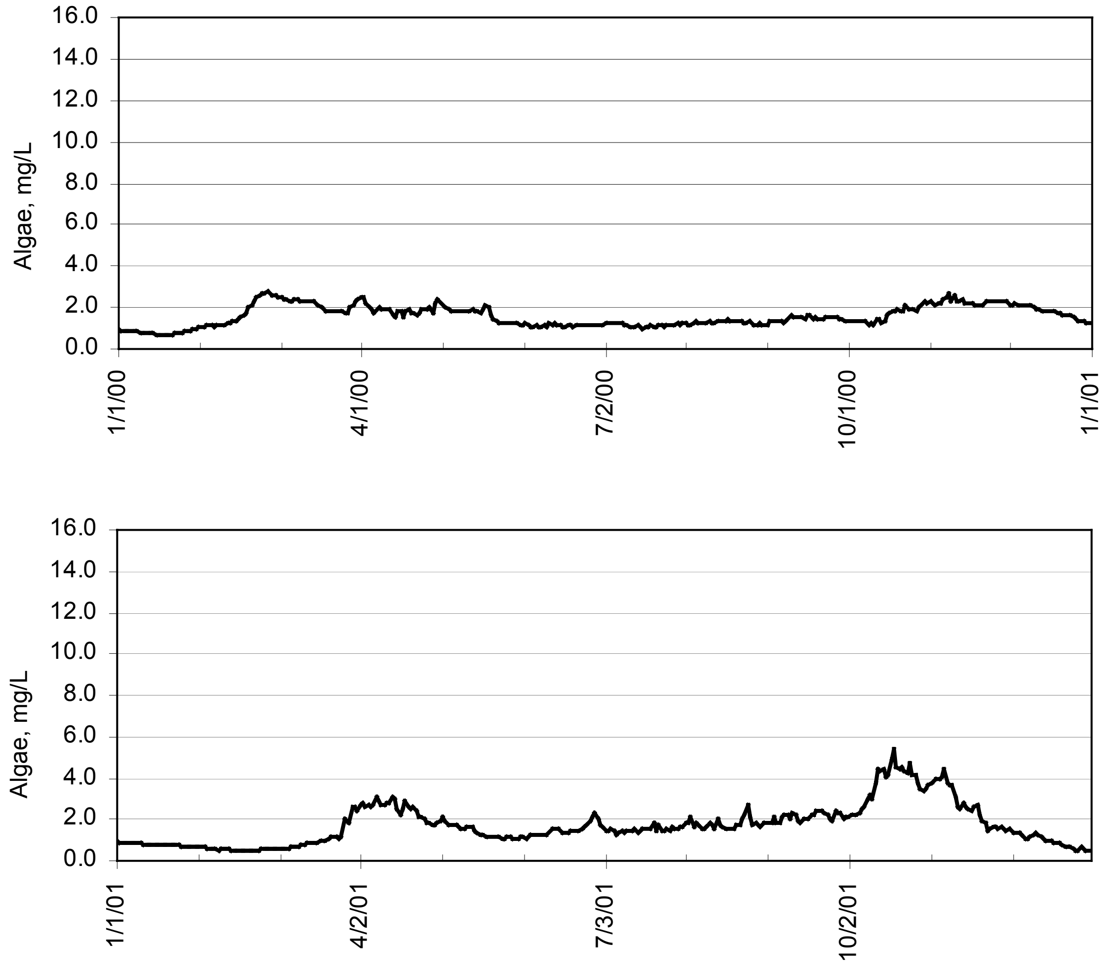


Figure 4.8-78. EC simulated algae concentrations in the Klamath River at Seiad Valley: 2000 (top) and 2001 (bottom).

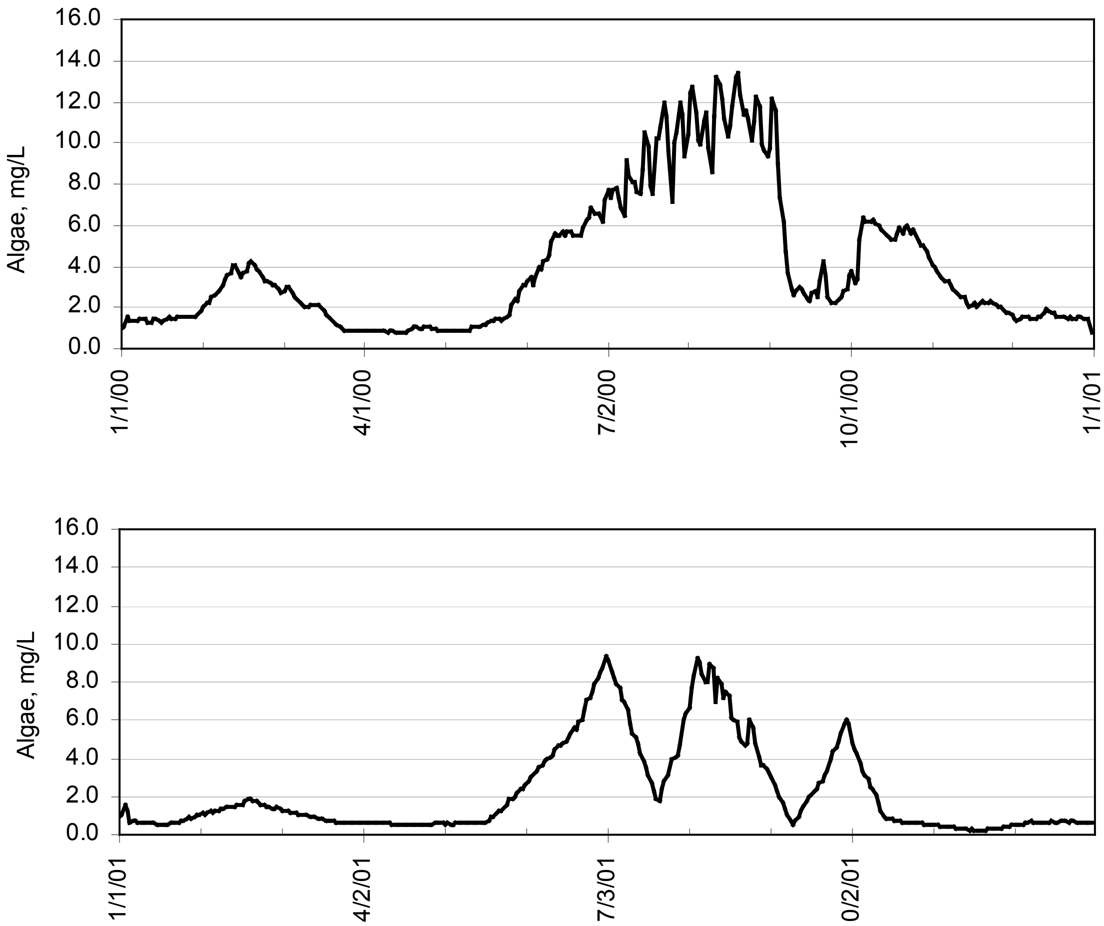


Figure 4.8-79. WOP simulated algae concentrations in the Klamath River at Seiad Valley: 2000 (top) and 2001 (bottom).