1.0 INTRODUCTION

1.1 SCOPE OF WORK

This Final Technical Report (FTR) documents the methods, observations, and findings of various water resources (hydrology, geomorphology, and water quality) studies conducted to support the relicensing application for the PacifiCorp Klamath Hydroelectric Project (Project). This report describes the objectives, methods, and results of the water resources studies conducted through 2002 and early 2003.

These studies were conducted based on objectives and methods documented in study plans previously prepared by PacifiCorp in collaboration with stakeholders involved in the relicensing process. Drafts of the study plans for water resources studies were submitted for stakeholder review in fall 2001, winter 2001, and spring 2002 and were subsequently revised to address stakeholder comments. The discussion of objectives and methods contained in various chapters of this FTR reflect the finalized study plans.

The existing Project is located on the upper Klamath River in southern Oregon and northern California. The Project consists of seven mainstem hydroelectric facilities on the upper Klamath River and one tributary facility on Fall Creek. The Project is owned and operated by PacifiCorp under a single license (No. 2082) issued in 1956 by the Federal Energy Regulatory Commission (FERC). The existing FERC license expires March 1, 2006.

The information in this report provides the foundation for the development of Exhibit E (Environmental Report) of the FERC relicensing application. This FTR is not intended to assess the impacts of the Project or to recommend protection, mitigation, and enhancement (PM&E) measures. Its purpose is to serve as a reference to help agencies, tribes, and interested parties understand the status and results of studies as they relate to water resources.

1.2 OVERVIEW OF WATER RESOURCES STUDIES

Water resources (hydrology, geomorphology, and water quality) studies described in this FTR consist of the following:

- Section 2: Compilation and Assessment of Existing Water Quality (Study 1.1)
- Section 3: Monitoring of Water Temperature and Water Quality Conditions in the Project Area (Study 1.2)
- Section 4: Development of Water Quality Analysis and Modeling Framework (Study 1.3)
- Section 5: Analysis of Project Effects on Hydrology (Study 1.4)
- Section 6: Analysis of Project Effects on Sediment Transport and River Geomorphology (Study 1.5)
- Section 7: Water Quality Sampling During Routine Maintenance Activities (Study 1.6)
- Section 8: Fall 2002 Macroinvertebrate Monitoring (Study 1.11)

- Section 9: Determination of Sediment Oxygen Demand in Selected Project Reservoirs (Study 1.13)
- Section 10: Screening Level Determination of Chemical Contaminants in Fish Tissue in Selected Project Reservoirs (Study 1.14)
- Section 11: Investigation of Klamath River Freshwater Bivalves in the J.C. Boyle Peaking Reach and Downstream of Iron Gate Dam (Study 1.19)
- Section 12: Spring 2003 Macroinvertebrate Monitoring (Study 1.20)
- Section 13: Analysis of Potential Klamath Hydroelectric Project Effects on Water Quality Aesthetics (Study 1.22). This study has recently been approved by stakeholders. As of the publication date of this FTR, Study 1.22 has not been completed. The study will be completed and results reported to stakeholders (and FERC) by the end of April 2004.

The study plans are available on the Klamath Hydroelectric Project relicensing website: http://www.pacificorp.com/Article/Article1152.html.

2.0 COMPILATION AND ASSESSMENT OF EXISTING WATER QUALITY DATA

2.1 DESCRIPTION AND PURPOSE

An extensive body of water quality data and information exists for the Klamath Hydroelectric Project area, but it comes from multiple sources and is presented in differing forms. PacifiCorp collected the available data and assembled them in an electronic database. The data provide a basis against which to compare current water quality and identify general aspects of water quality in the Project.

The details of this study are contained in Study Plan 1.1, Compilation and Assessment of Existing Water Quality Data, approved by the Water Quality Working Group and Klamath Relicensing Plenary in August 2002. The study plan is available on the Klamath Hydroelectric Project Relicensing website, http://www.pacificorp.com/Article/Article1152.html.

2.2 OBJECTIVES

The objectives addressed by the data compilation study were as follows:

- Gather and organize existing data
- Identify spatial and temporal trends in water quality, if possible
- Identify data gaps to be filled by further study
- Provide information for use in planning additional water quality or related studies

2.3 RELICENSING RELEVANCE AND USE IN DECISIONMAKING

The database allows the existing data to be used to maximum advantage to meet the requirements of Oregon and California 401 certification and the FERC license application. The database assists in the assessment of water quality trends and helps to identify areas where water quality is of particular concern to relicensing. The database also helps to identify key water quality data gaps that may require additional sampling and fieldwork.

2.4 METHODS AND GEOGRAPHIC SCOPE

2.4.1 Database Development

PacifiCorp compiled relevant water quality data and information for the Project into a computerized database. Data were included in the database also according to the following criteria:

1. Data prior to 2001 available in digital form

2. Only sites with at least two samples

3. Sites with only one sample if the analytes consist of extensive organics, toxics screens, or other specialized analyses as may be available

4. Sites within 1 mile of the Klamath River on all tributaries

5. Sites on the Klamath River from Link River dam to the mouth of the Klamath River

6. Water quality data collected during the City of Klamath Falls proposed Salt Caves Hydroelectric Project studies

7. Not specifically including water-quality-related data for other media (e.g., sediment, phytoplankton, periphyton, macrophytes, macroinvertebrates, and fish tissue) in the database, but noting, flagging, or check-marking the availability of such data using the above rules.

Existing data collected before 2001 have been compiled and summarized. New data collected by PacifiCorp and cooperators since 2000 will be incorporated into a separate database, analyzed, and used to describe the existing water quality in the Project area and support water quality models (see Section 3.0).

2.4.2 Data Analysis

The analysis of data compiled in the database consisted primarily of nonparametric exploration of data trends, distributions, and site comparisons. The analysis produced summary graphs, plots, and tables of these trends, distributions, and site comparisons. Observations and interpretations from this analysis are described in the results portion of this section.

2.5 RELATIONSHIP TO REGULATORY REQUIREMENTS AND PLANS

The database, subsequent data gathering, data analysis, and reports are intended to help meet the requirements to show reasonable assurance that water quality standards will be met as outlined in Section 401 of the Clean Water Act.

2.6 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 was formed and meets approximately monthly or otherwise as needed to plan and discuss water quality studies and results, including this study.

2.7 RESULTS AND DISCUSSION

The water quality database is available on PacifiCorp's relicensing website at http://www.pacificorp.com/Article/Article579.html. The website link to the database opens a self-extracting zip file containing the database and accompanying information file. MicroSoft Access 2000® is required to open the database.

2.7.1 Review of Historical Data

Water quality data for the database were assembled from existing data available in electronic form. In addition, a limited amount of data was entered manually. Data were assembled from the U.S. Environmental Protection Agency STORET database, the Oregon Department of Environmental Quality (ODEQ) LASAR database, the U.S. Geological Survey (USGS) National Water Information System database, the Klamath Resource Information System, records of the

U.S. Bureau of Reclamation (USBR), and data submitted by other government and tribal resource agencies. The compiled database includes data from USEPA Headquarters, EPA Region 9, EPA Region 10, U.S. Forest Service, Oregon Water Resources Department, USBR, ODEQ, California Water Resources Control Board, USGS, City of Klamath Falls, and U.S. Bureau of Land Management (BLM).

The resulting database originally included more than 142,000 records. After removal of obvious duplicates, the database contained more than 86,000 records from 223 named sites covering a period from October 1950 through June 2001. Because data from many sites were duplicated in the different databases, but with slightly different site names or parameter descriptions, the revised database still included many duplicate measurements. Manual review of the records resulted in a final database of 57,378 records with measurements for 66 distinct constituents from 175 sites sampled on 2,180 different dates between October 12, 1950, and June 20, 2001. Figure 2.7-1 is a map of water quality sampling sites identified in the Klamath River basin.

Each sample location was given a unique identification code consisting of a two-letter designation for the water body (e.g., KR for Klamath River) and a five-digit designation for the river mile (RM) based on the PacifiCorp geographical information system (GIS) coverage for the Klamath River. RM zero is at the mouth of the Klamath River. Thus, site KR23490 is on the Klamath River at RM 234.90 (at the Highway 66 bridge near Keno, Oregon).

Not all sites were sampled equally. Of the 175 sites, only 87 were sampled more than five times during the 50-year period of record. Nor were all constituents measured with equal frequency. The most frequently sampled sites are listed in Table 2.7-1. The complete list of sites is provided in Appendix 2A. Ten of the 66 constituents account for more than 85 percent of the 57,378 measurements included in the database. The most frequently measured constituents are listed in Table 2.7-2. The complete list of constituents is available in Appendix 2B.

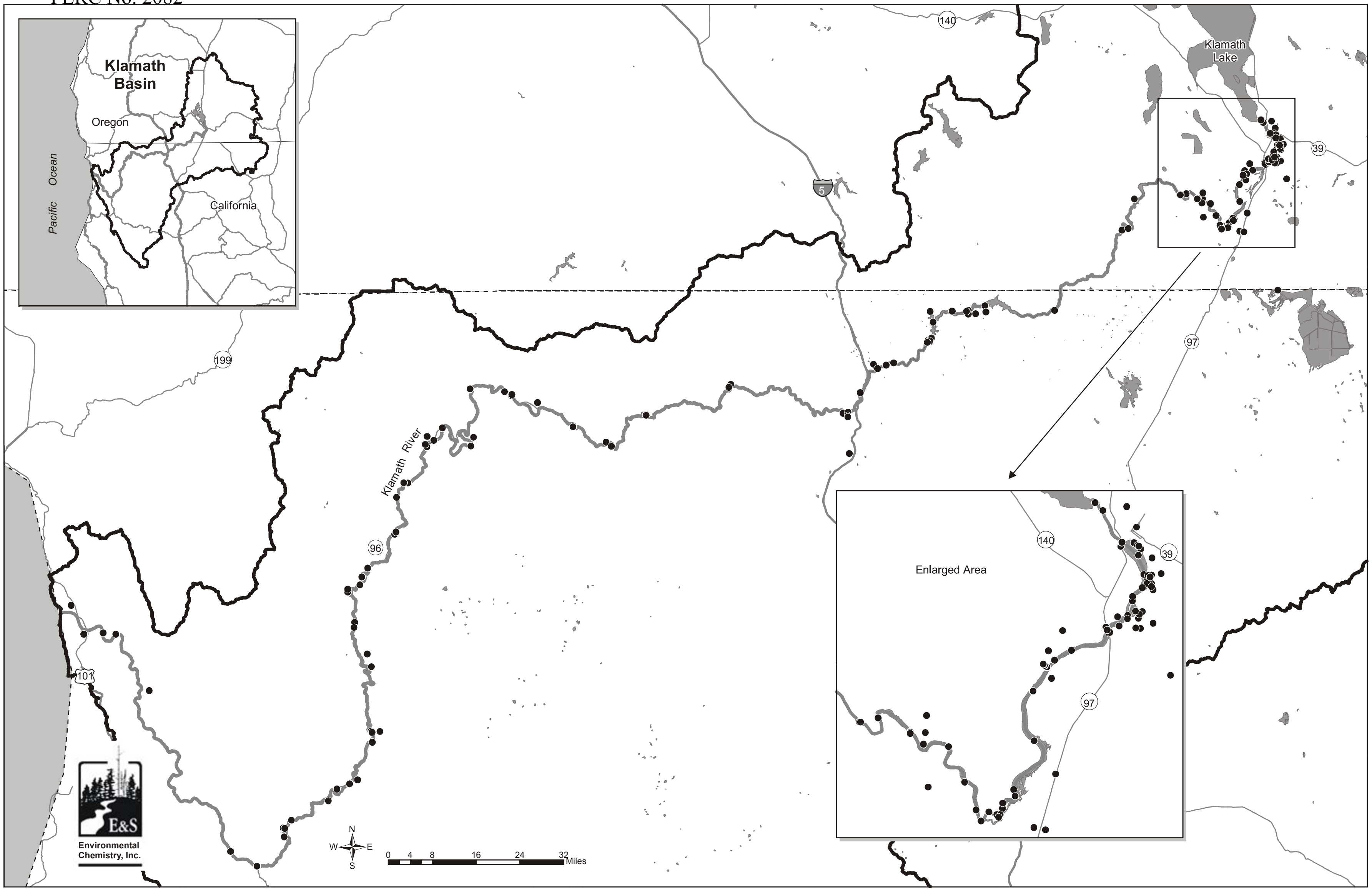

Figure 2.7-1. Distribution of water quality sampling sites identified in the Klamath River Basin from 1950-2001.

Table 2.7-1. The most frequently sampled sites in the Klamath River basin between 1950 and 2001.

Rank	Site ID	Site Name	Number of Days Sampled
1	KR00579	Klamath River at Klamath Glen	514
2	KR05912	Klamath River at Orleans	408
3	KR12855	Klamath River near Seiad Valley	349
4	KR18952	Klamath River below Iron Gate dam	338
5	KR23490	Klamath River at Keno Bridge (Hwy. 66)	321
6	SH00	Shasta River near Yreka	304
7	KR14906	Klamath River above Hamburg reservoir site	264
8	KS01	Klamath Straits Drain at Pumping Plant F	253
9	KR23193	Klamath River near Keno	245
10	KR24898	Klamath River at Hwy. 97 bridge	239
11	KR25312	Link River at mouth	234
12	KR23503	Klamath River below J.C. Boyle powerhouse	233
13	SA00	Salmon River at Somes Bar	149
14	KR00822	Klamath River near Klamath	146
15	KR19621	Klamath River below Fall Creek near Copco*	110
16	KR14900	Klamath River near Hamburg	92
17	KR06593	Klamath River below Salmon River	91
18	KR18334	Klamath River near Henley	82
19	KR25479	Link River at Fremont St. bridge	65
20	KR25344	Link River (421404121480101)	43
21	KR20642	Klamath River upstream of Shovel Creek	37
22	KR19645	Copco dam outflow	36
23	KR18973	Iron Gate dam outflow	36
24	KR17607	Klamath River downstream of Shasta River	35
25	KR18238	Klamath River upstream of Cottonwood Creek	35

*All samples from this site were collected prior to the construction of Iron Gate dam.

Table 2.7-2. Most frequently measured constituents in the Klamath River basin 1950-2001.

Rank	Code	Constituent Name	Total Analyses
1	pH	pH	7,985
2	DOPER	Dissolved oxygen percent saturation	7,336
3	DOCON	Dissolved oxygen concentration	7,249
4	SPC	Specific conductance	7,155
5	ALKT	Alkalinity, total	3,044
6	NO_3D	Nitrate nitrogen, dissolved	2,670
7	PT	Phosphorus, total	2,553
8	TURB	Turbidity	2,525
9	PO_4	Orthophosphate, dissolved	2,281
10	TKN	Total Kjeldahl nitrogen	2,084
11	NH_3T	Ammonia nitrogen, total	1,857
12	TEMP	Temperature, water	1,296
13	BOD	Biochemical oxygen demand	1,247
14	NO_3T	Nitrate nitrogen, total	1,166
15	Fecal	Fecal coliform	889
16	CHLA	Chlorophyll *a*	655
17	ALKF	Alkalinity, field	599
18	TOC	Total organic carbon	488
19	Cu_Dis	Copper, dissolved	274
20	Pb_Dis	Lead, dissolved	274
21	As_Dis	Arsenic, dissolved	272
22	Zn_Dis	Zinc, dissolved	244
23	TDS	Total dissolved solids	241
24	NH_3	Ammonia nitrogen	237
25	NH_3D	Ammonia nitrogen, dissolved	219

The number of samples collected in the basin varied through time. Figure 2.7-2 shows the year-to-year variation in the number of samples collected from the Klamath basin sites between 1950 and 2001.

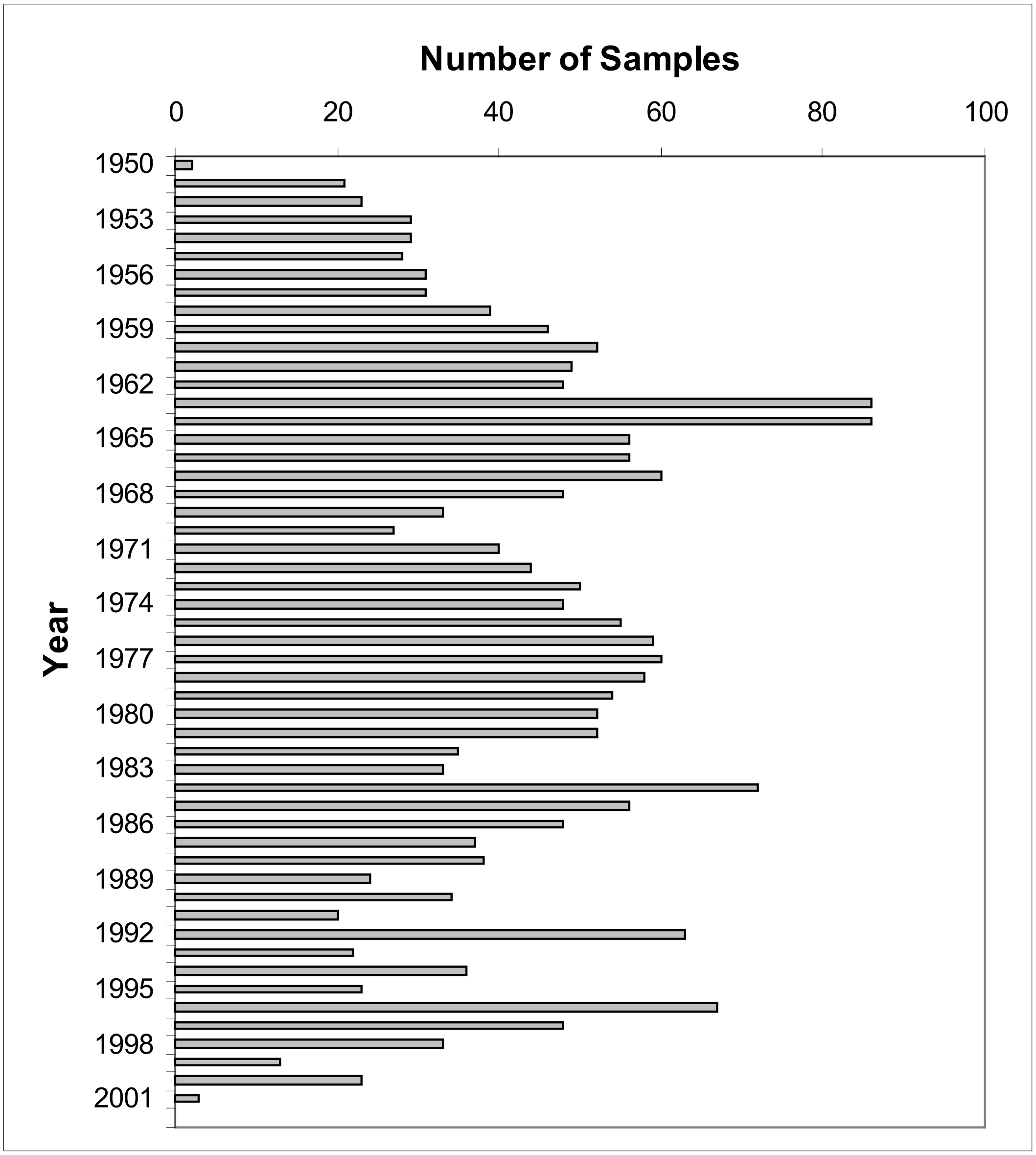

Figure 2.7-2. Number of water quality samples collected in the Klamath River basin below Upper Klamath Lake from 1950 to 2001.

2.7.2 Spatial Trends in the Historical Data

The historical data provide the opportunity to compare water quality among sites along the Klamath River. However, not all constituents were measured frequently enough at enough sites to provide sufficient data for comparison. The constituents with enough data for comparison were specific conductance, alkalinity, dissolved oxygen, pH, nitrate nitrogen, ammonia nitrogen, biochemical oxygen demand, total Kjeldahl nitrogen, total phosphorus, orthophosphate phosphorus, turbidity, and chlorophyll *a*. For each constituent, the number of sites with sufficient data to make comparisons varied. In this analysis, all sites with ten or more observations for a particular constituent were included in the analysis. Those sites with sufficient data for most constituents to be used in this analysis are listed in Table 2.7-3.These sites and constituents cover most of the river and most of the constituents of water quality concern. The collected data span various flow conditions, basin activities, times of day, seasons, climatic conditions, sampling methodologies, and levels of quality assurance, which affects the accuracy and comparability of the data and makes it difficult to draw detailed conclusions. For the most part, the collected data do not allow for detailed site-by-site comparisons. Nevertheless, the pattern of differences among sites can provide some insight into the dynamics of water quality in the Klamath River.

Spatial trends in the data have been identified through nonparametric graphical analysis, primarily using box plots. Summary statistics and detailed box plots for each constituent are provided in Appendix 2C. Summary plots of median values are provided in the text. For ease of interpretation, station data have been plotted by river mile. Station identification and river miles are provided in Table 2.7-3.

Table 2.7-3. Frequently sampled sites in the Klamath River basin used for site comparisons.

RM	Site ID	Location
5	KR00579	Klamath River at Klamath Glen
8	KR00822	Klamath River south of Hoopa
59	KR05912	Klamath River at Orleans
65	KR06593	Klamath River below Salmon River
128	KR12855	Klamath River near Seiad Valley
142	KR14260	Klamath River downstream of Scott River
149	KR14900	Klamath River at Klamath River School near Hamburg
160	KR16075	Klamath River downstream of Beaver Creek
176	KR17607	Klamath River downstream of Shasta River
179	KR17923	Klamath River at Collier rest stop
182	KR18238	Klamath River upstream of Cottonwood Creek
183	KR18334	Klamath River near Henley
184	KR18417	Klamath River at Klamathon Bridge
189.5	KR18952	Klamath River below Iron Gate dam
189.7	KR18973	Iron Gate dam outflow
191	KR19000	Iron Gate reservoir
192	KR19198	Iron Gate reservoir
196[1]	KR19621	Klamath River below Fall Creek (pre-dam)
197	KR19645	Copco dam outflow
198	KR19856	Klamath River 0611A2 (below Copco No. 1 dam)
199	KR19874	Copco reservoir
203	KR20300	Copco inflow (angler access 2 above Copco reservoir)
206	KR20642	Klamath River upstream of Shovel Creek
209	KR20932	Klamath River near Stateline
217	KR21700	Salt Caves site
221	KR22127	Klamath River below J.C. Boyle power plant near Keno
222	KR22200	Canyon – C. (Klamath River in J.C. Boyle bypass reach)

Table 2.7-3. Frequently sampled sites in the Klamath River basin used for site comparisons.

RM	Site ID	Location
224	KR22400	Below J.C. Boyle dam
225	KR22505	J.C. Boyle reservoir at deepest point
228	KR22822	Klamath River above J.C. Boyle reservoir
231	KR23193	Klamath River near Keno
232	KR23200	Klamath River downstream of Keno dam
234	KR23490	Klamath River at Keno bridge (Hwy. 66)
235	KR23503	Klamath River below Big Bend power plant
236	KR23656	Klamath River at irrigation pumphouse
238	KR23828	Klamath River directly south of Hill 4315 (downstream of Klamath Straits Drain)
239	KR23932	Klamath River at powerline crossing (downstream of Klamath Straits Drain)
240	KR24013	Klamath River 1,000 feet downstream of Klamath Straits Drain
240.5[2]	KS01	Klamath Straits Drain 200 feet downstream of Pumping Plant F (South channel)
241	KR24077	Klamath River 1,000 feet upstream of Klamath Straits Drain
244	KR24408	Klamath River downstream of North canal (Midland)
245	KR24589	Klamath River at Miller Island boat ramp
247	KR24713	Klamath River at Weyerhaeuser Mill smokestack
248	KR24894	Klamath River at Hwy. 97 bridge, southeast
249	KR24901	Klamath River at Hwy. 97 bridge, northeast
250	KR25015	Klamath River at north end of Dog Pound Island
251	KR25127	Klamath River at KLAD radio tower
252	KR25200	Lake Ewauna between sewage treatment plants
253	KR25312	421404121480101 (Link River)
254	KR25479	Link River at Fremont St. bridge

[1] Site flooded by Iron Gate reservoir.

[2] Approximate river mile of confluence.

2.7.2.1 Specific Conductance and Alkalinity

Specific conductance is an indirect measure of the amount of dissolved solids in the water. Changes in specific conductance in a river can indicate a source of pollution (increase) or perhaps inputs from tributaries or groundwater (decrease or increase). The median values for specific conductance for the period of record at selected sites are shown in Figure 2.7-3.

The Klamath Straits Drain (RM 240.5) stands out because its specific conductance is much higher than other sites along the river. The median specific conductance of water entering Lake Ewauna (RM 253) is lower than the sites downstream. The influence of Klamath Straits Drain can be seen in the increase in median specific conductance in sites immediately downstream. The influence of springs below J.C. Boyle dam is reflected in lower specific conductance below RM 225. Specific conductance slightly increases in the Klamath River between the Shasta River (RM 176) and Seiad Valley (RM 128), and is somewhat lower nearer the mouth downstream of the Salmon River (RM 65). This may reflect the influence of tributary streams.

Alkalinity is a measure of the acid-neutralizing capacity of the water. It is also influenced by the amount of dissolved material in the water, and thus shows a pattern similar to specific conductance. Alkalinity is relatively low in Link River (RM 253) and increases in Lake Ewauna to a relatively constant value from Keno dam (RM 232) to below Iron Gate dam (RM 189). Sites near Hamburg (RM 149) and Seiad Valley (RM 128) have higher alkalinity, possibly a result of input from the Shasta River (Figure 2.7-4).

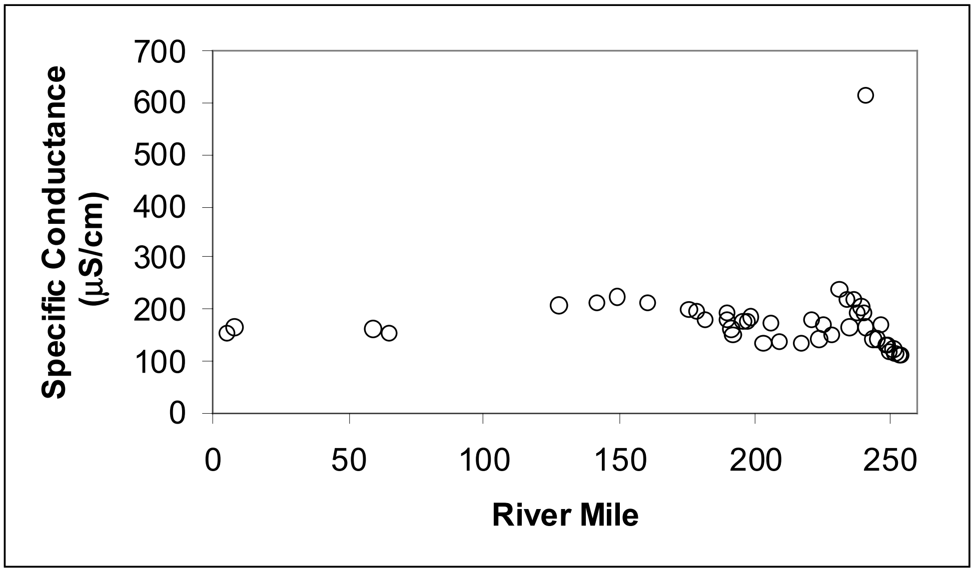

Figure 2.7-3. Median values for specific conductance (µS/cm) measured at various sites in the Klamath River between 1950 and 2001.

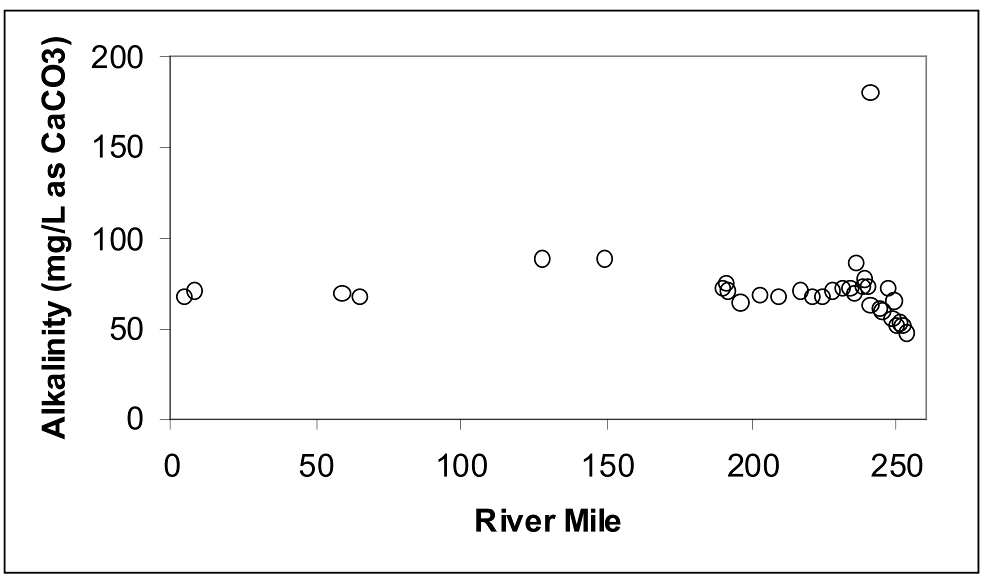

Figure 2.7-4. Median values for alkalinity (mg/L as $CaCO_3$) measured at various sites in the Klamath River between 1950 and 2001.

2.7.2.2 Dissolved Oxygen

Dissolved oxygen (DO), unlike specific conductance, is not a conservative constituent, but rather is influenced by local conditions of elevation and temperature. Photosynthesis by plants can increase DO, while respiration by bacteria, plants, and other organisms can decrease DO. For the elevations and temperatures encountered in the Klamath River, the saturation concentration of DO ranges between approximately 8 and 10.5 mg/L. As shown in Figure 2.7-5, median DO measured at many sites along the Klamath River generally fell in this range.

As is evident in Figure 2.7-5, however, a number of locations exhibit relatively low median DO. These sites are clustered in two areas: one, between RM 252 and RM 224, reflects the anoxic conditions that often exist in Lake Ewauna (Keno reservoir) during periods of the summer; the second, between RM 199 and RM 189, reflects measurements taken from the hypolimnion of Copco and Iron Gate reservoirs during stratification. Although median values of measurements collected over several years in different seasons and at different times of day cannot adequately describe the DO conditions at any particular site, the data assembled here suggest that DO is near saturation values in those regions of the Klamath River that are free-flowing.

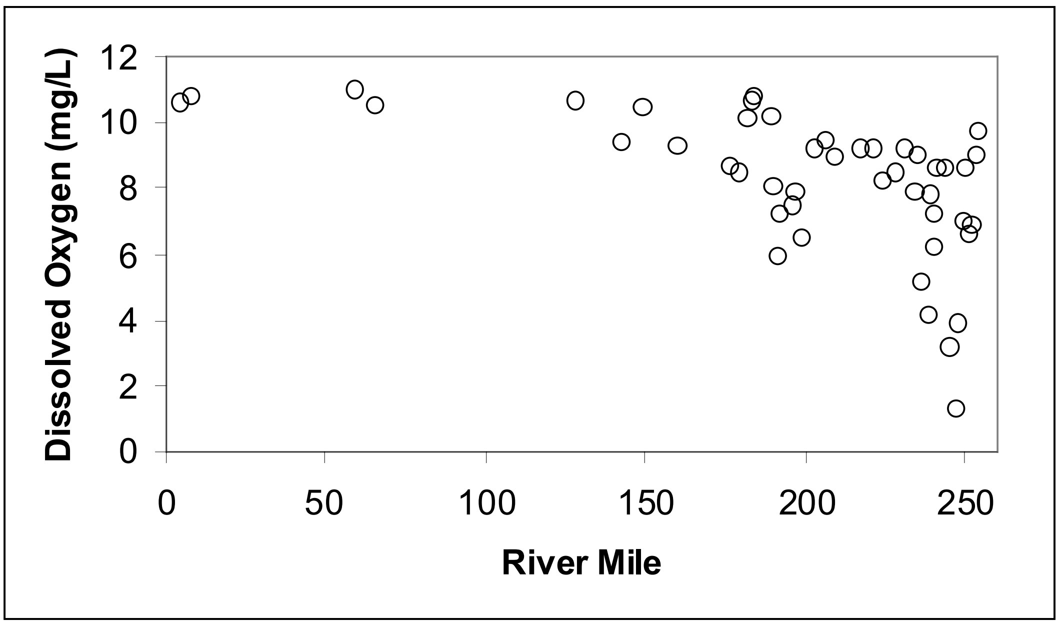

Figure 2.7-5. Median values for dissolved oxygen (mg/L) measured at various sites in the Klamath River between 1950 and 2001.

2.7.2.3 Nutrients

Nitrogen and phosphorus are important as major nutrients required by algae in the river system. Inputs of nutrients can lead to excessive algal growth, which in turn can have adverse water quality consequences, such as high pH and large diurnal swings in DO concentrations. The available historical data for nitrogen in the Klamath River show relatively low ammonia concentrations in Link River, but higher concentrations in Upper Klamath Lake, Lake Ewauna, and Keno reservoir. Median ammonia concentration is relatively low below Iron Gate dam

(Figure 2.7-6). The historical nitrate data indicate that nitrate concentrations were relatively low in the Klamath River above Iron Gate dam, but higher in the lower reaches of the river (Figure 2.7-7).

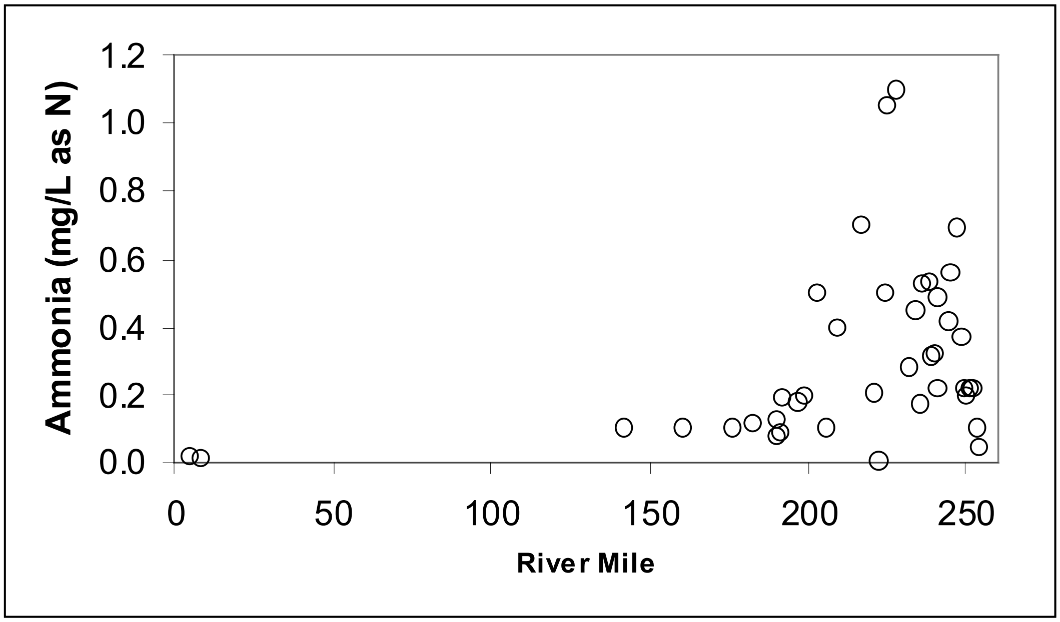

Figure 2.7-6. Median values for ammonia nitrogen (mg/L as N) measured at various sites in the Klamath River between 1950 and 2001.

The historical data for nitrate illustrate some of the difficulties encountered in interpreting historical data. Several high median values occur between RM 196 and RM 228. Inspection of the data reveal that all these data are from a single study (with the exception of RM 196, a pre-dam site below the mouth of Fall Creek) and are higher than median values of other sites in that river reach based on data from other sources. From the information available, it is not possible to determine whether the single-study data represent a real difference in river conditions or reflect a methodological difference.

Comparison of median nitrate data from two pairs of sites suggests the possibility of sources of nitrate pollution. Median nitrate concentration in the Klamath River near Keno (0.9 mg/L, RM 231) and several sites nearby downstream is substantially higher than in the Keno River immediately below Keno dam (0.1 mg/L, RM 232) and sites immediately upstream. Likewise, median nitrate concentration in the Klamath River near the USGS gauge (1.0 mg/L, RM 198.5) is substantially higher than median nitrate concentration in the Klamath River immediately below Iron Gate dam (0.19 mg/L, RM 189.7). There is no identified source of nitrate pollution at Keno, but the Iron Gate fish hatchery and the mouth of Bogus Creek are situated between the two sites below Iron Gate dam.

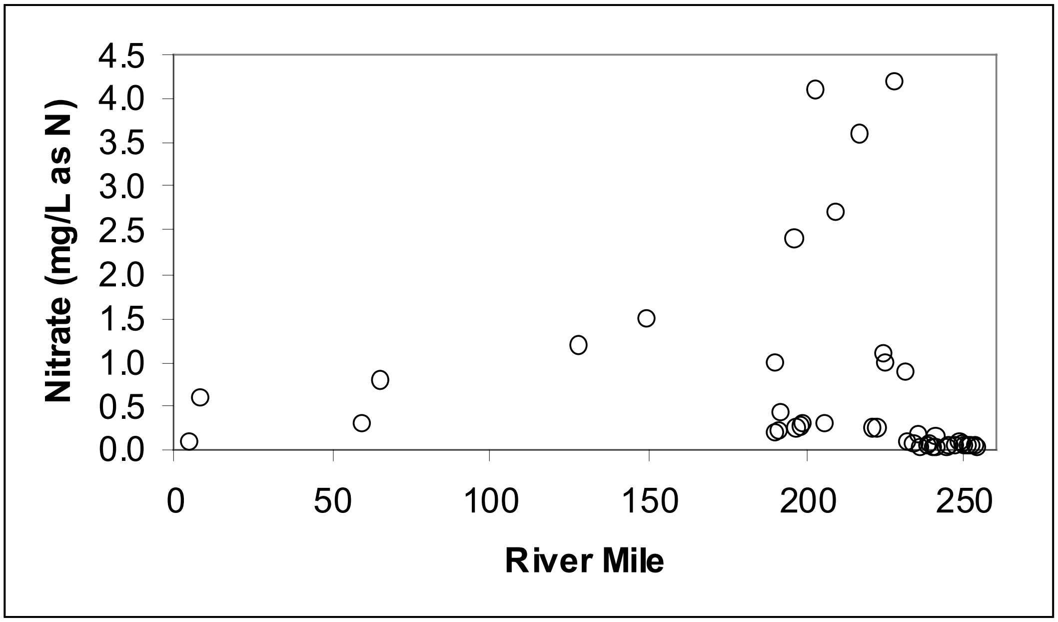

Figure 2.7-7. Median values for nitrate nitrogen (mg/L as N) measured at various sites in the Klamath River between 1950 and 2001.

The concentrations of orthophosphate phosphorus and total phosphorus measured historically at sites in the Klamath River are shown in Figures 2.7-8 and 2.7-9. Median values of orthophosphate phosphorus are relatively low in Upper Klamath Lake (RM 254) and Link River (RM 253), but they increase rapidly downstream in Keno reservoir. The input from Klamath Straits Drain is high in phosphorus and appears to influence orthophosphate concentrations at the sites downstream. Orthophosphate concentration decreases in the river below Iron Gate dam and reaches levels comparable to those in Upper Klamath Lake by RM 65. A cluster of high median orthophosphate concentrations at sites between RM 203 and RM 228 is from the same study that produced high nitrate concentrations. Median total phosphorus concentrations follow a pattern similar to that of orthophosphate phosphorus.

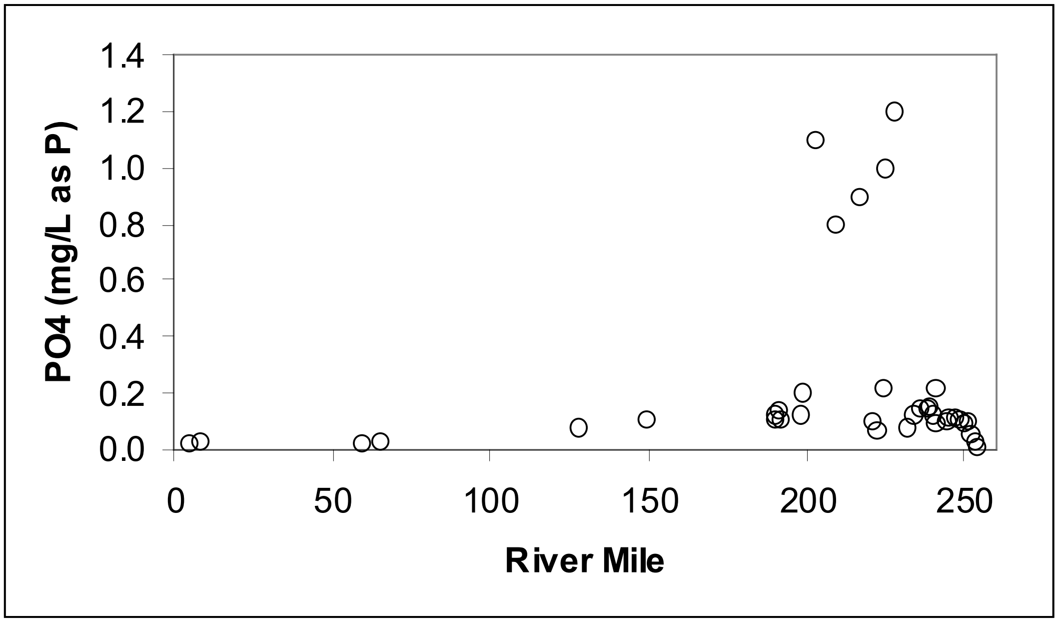

Figure 2.7-8. Median values for orthophosphate phosphorus (mg/L as P) measured at various sites in the Klamath River between 1950 and 2001.

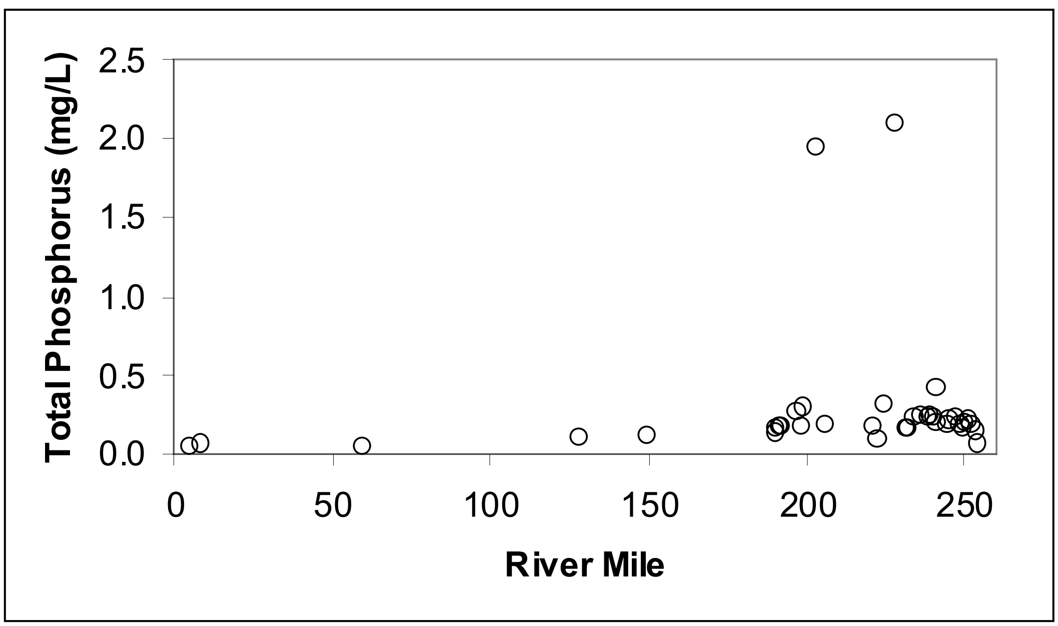

Figure 2.7-9. Median values for total phosphorus (mg/L) measured at various sites in the Klamath River between 1950 and 2001.

2.7.2.4 Organic Matter

Biochemical oxygen demand (BOD) is an indirect measure of the concentration of organic matter in water, and total Kjeldahl nitrogen (TKN) is a measure of organic nitrogen and ammonia. The waters of the Project area receive a considerable contribution of both BOD and TKN from Upper Klamath Lake. As water passes through the Project area, the organic matter is consumed or settles out and concentrations are reduced. This is reflected in the changes in BOD and TKN concentrations as illustrated in Figures 2.7-10 and 2.7-11. The low concentration of TKN at RM 222 (Figure 2.7-10) shows the influence of dilution by groundwater inputs in the J.C. Boyle bypass reach.

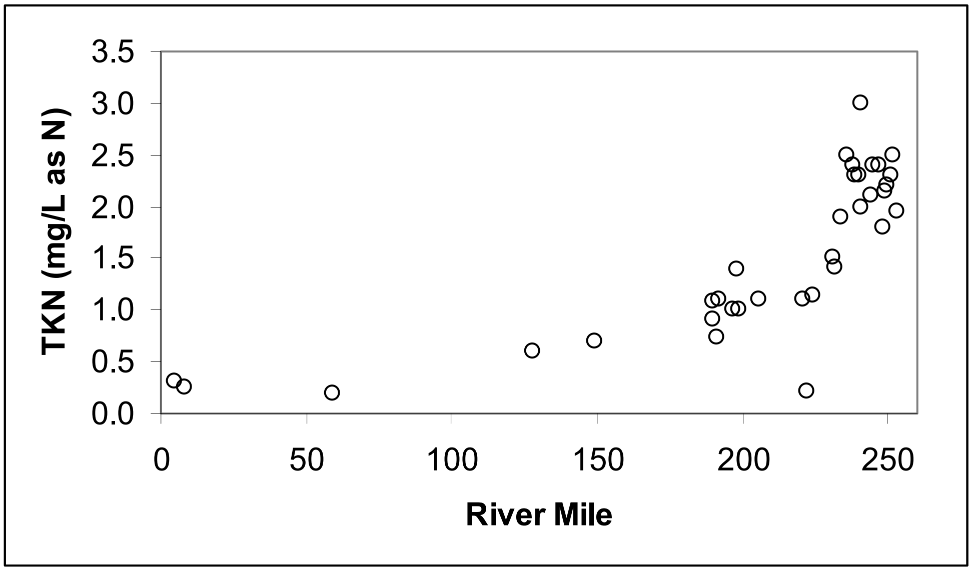

Figure 2.7-10. Median values for total Kjeldahl nitrogen (TKN, mg/L) measured at various sites in the Klamath River between 1950 and 2001.

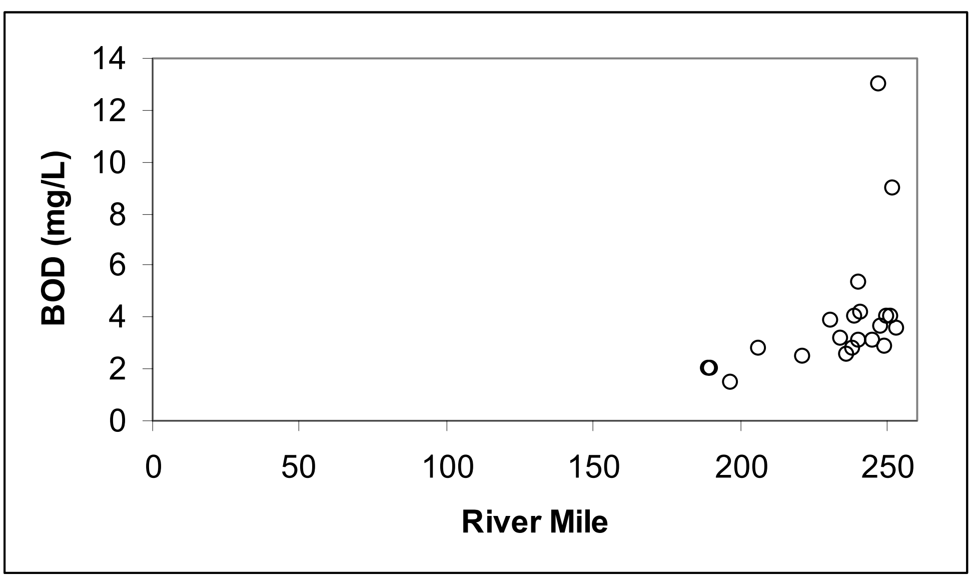

Figure 2.7-11. Median values for biochemical oxygen demand (BOD, mg/L) measured at various sites in the Klamath River between 1950 and 2001.

2.7.2.5 Turbidity

Turbidity is a measure of suspended material in the water (Figure 2.7-12). Inputs to Lake Ewauna (Link River, RM 253, and Klamath Straits Drain, RM 240.5) have high turbidity. This is reflected in the turbidity of Lake Ewauna (RM 252 to RM 248). Some settling appears to occur in Keno reservoir because sites between RM 247 and RM 234 have relatively lower turbidity. The trend in turbidity continues to decrease until near the mouth (RM 8), where median turbidity is noticeably higher than at nearby sites.

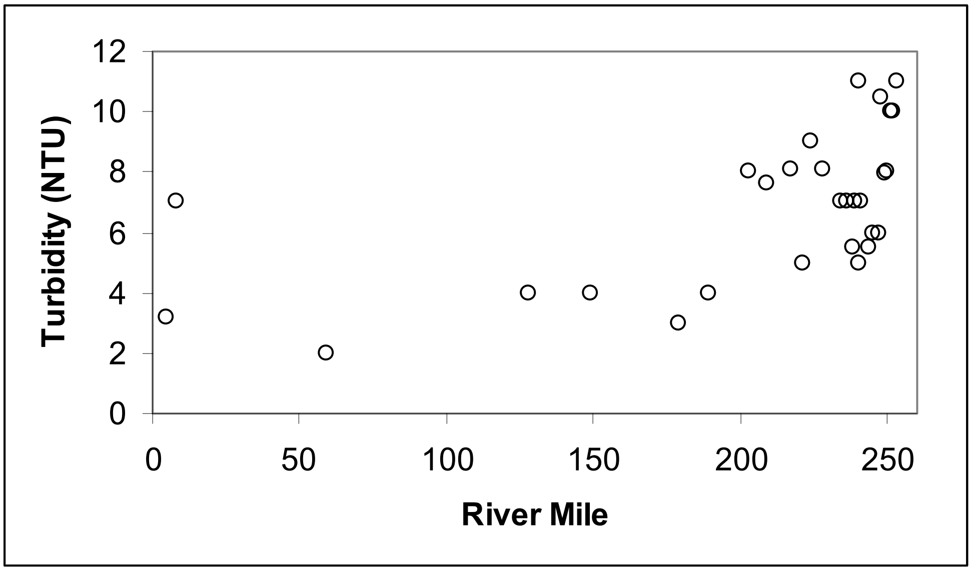

Figure 2.7-12. Median values for turbidity (NTU) measured at various sites in the Klamath River between 1950 and 2001.

2.7.2.6 Chlorophyll *a*

Relatively few sites along the length of the Klamath River were sampled for chlorophyll *a* (Figure 2.7-13). Most of the historical chlorophyll *a* measurements have been taken in the summer (Figure 2.7-14) so the median values are representative of summer conditions. However, the resolution of the collected data is not fine enough to discern shorter duration events, such as algal blooms. Chlorophyll *a* samples from Keno reservoir above Keno dam (RM 231 to RM253) tend to have high median chlorophyll *a* concentrations, greater than 15 micrograms per liter (µg/L). Below Keno dam, median chlorophyll *a* concentrations are considerably lower.

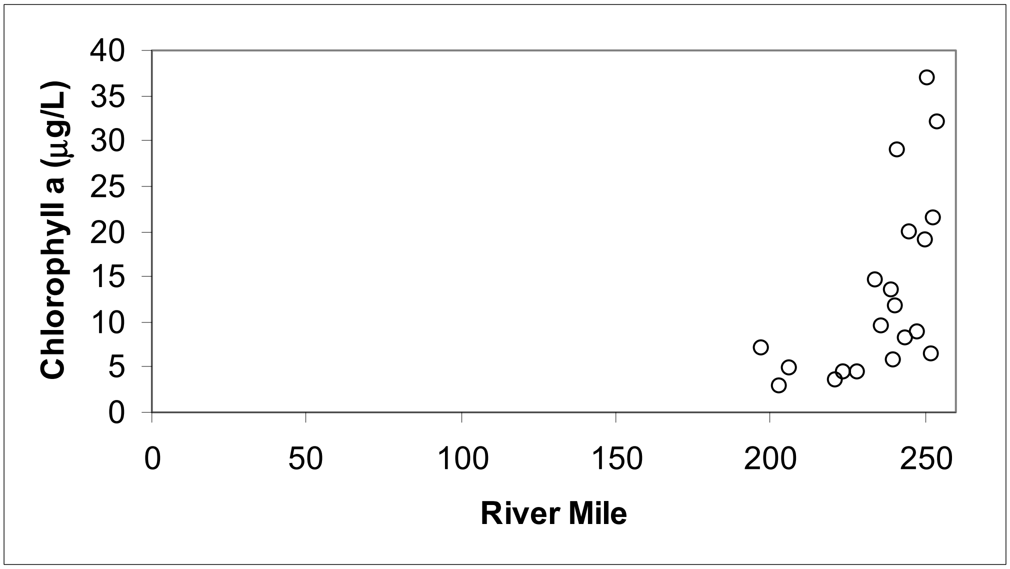

Figure 2.7-13. Median values for chlorophyll *a* (µg/L) measured at various sites in the Klamath River between 1950 and 2001.

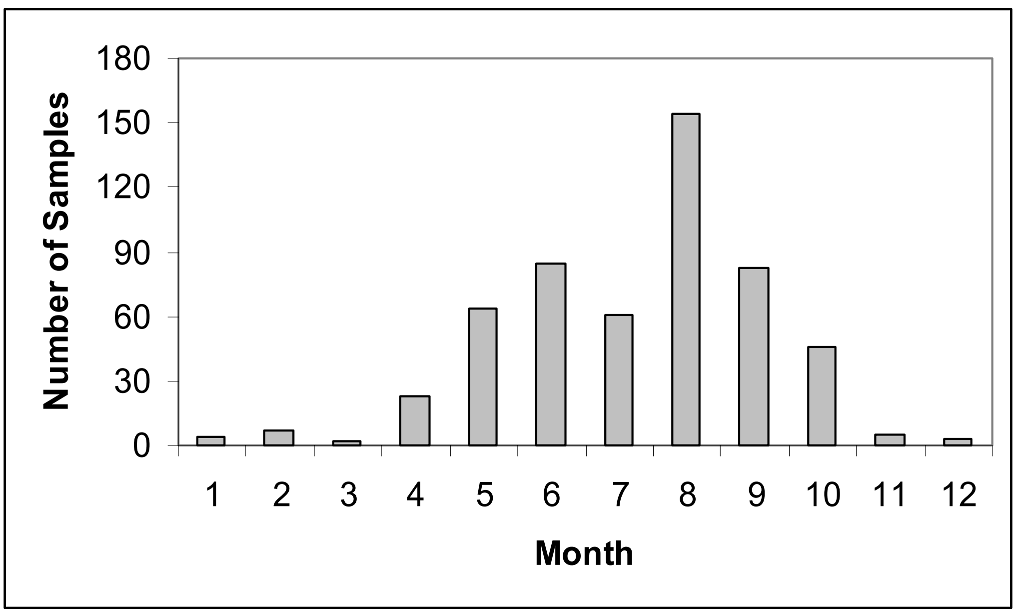

Figure 2.7-14. The distribution by month of the total number of chlorophyll *a* samples collected in the Klamath River, largely in Lake Ewauna (Keno reservoir), between 1950 and 2001.

2.7.2.7 pH

Aquatic organisms can affect pH through photosynthesis and respiration. During dense algal blooms, uptake of carbon dioxide during photosynthesis can raise the pH in a lake. Conversely, respiration by plants and other organisms can release carbon dioxide to the water and lower the pH. These effects can cause pH in a water body to vary considerably during a 24-hour cycle. Although the resolution of the historical data is not fine enough to demonstrate the daily cycle, the influence of biota on pH can be discerned in the data. Median pH values for sites with high median chlorophyll *a* concentration tend to be higher than at other sites (Figure 2.7-15).

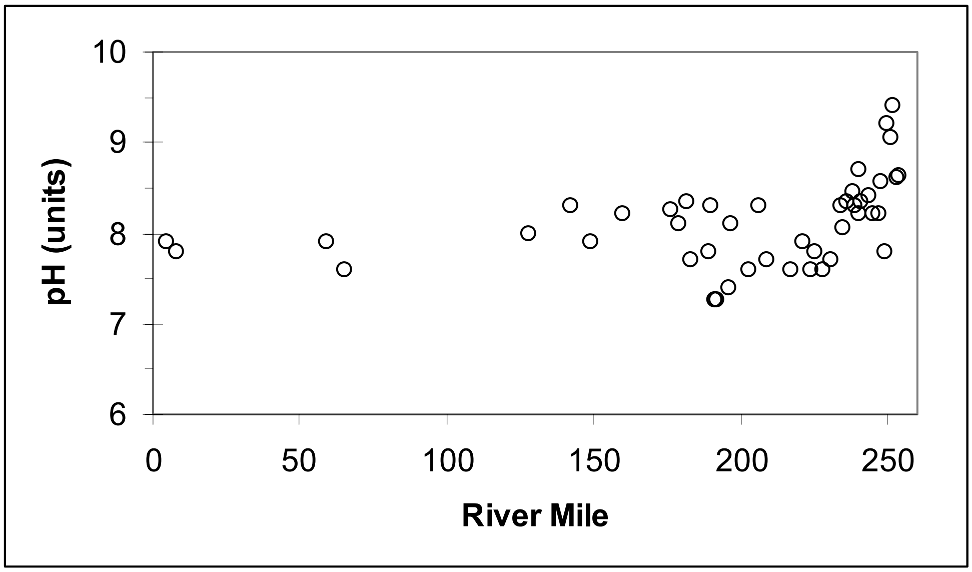

Figure 2.7-15. Median values for pH (units) measured at various sites in the Klamath River

2.7.2.8 Interpretation of Spatial Trends

Several factors affecting the collected historical data combine to make it difficult to undertake detailed comparisons between sites on the Klamath River for which data are available. The data were collected over many years, during which important changes occurred in the basin. The data from the different sites were often collected at different times, and large gaps in coverage occurred. There are seasonal aspects to the data, including variations in river discharge, that influence the comparability of calculated medians among the sites. Changes in sampling and analytical methodology have occurred during the time period when these historical data were collected, which may affect the accuracy and comparability of the data. Nevertheless, these data can provide an indication of the overall pattern of water quality in the basin.

The overall picture of the Klamath River that emerged from the historical data was one of higher production and organic matter in the upper reaches of the river (Lake Ewauna and Keno reservoir), changing to lower production and lesser organic matter in the lower reaches of the river. Based on the available historical data, Upper Klamath Lake and Klamath Straits Drain appear to be important sources of BOD, organic nitrogen, dissolved solids, turbidity (suspended solids), and phosphorus. Although there were insufficient data to characterize other tributaries to the Klamath River, comparison between sites on the river suggest locations where material inputs to the Klamath River occurred. For example, average nitrate nitrogen concentration was notably higher than at other sites in the Klamath River near Keno (RM 231), in the samples taken below Fall Creek prior to the construction of Iron Gate dam (RM 196), below the Iron Gate fish hatchery (RM 189.5), and in the Klamath River near Hamburg (RM 149).

The Scott River enters the Klamath River a short distance upstream from Hamburg, California, and could have been a source of nitrate loading to the river. Average nitrate nitrogen and ammonia nitrogen concentrations in the Iron Gate dam outflow (RM 189.7) were noticeably lower than the concentrations measured just downstream (RM 198.5), suggesting that a source of nitrogen occurred between the two sites. Both the Iron Gate fish hatchery discharge and the mouth of Bogus Creek are located in this short reach of river. The site on the Klamath River below Fall Creek before construction of Iron Gate dam (RM 196) was also downstream of the fish facility on Fall Creek. The high average concentration of nitrate nitrogen in the Klamath River near Keno (RM 231) relative to nearby upstream sites (RM 232, 233) may reflect nitrification of the abundant ammonia and organic nitrogen present in Lake Ewauna and Keno reservoir.

Median turbidity was higher in the Klamath River near Klamath (RM 8) than in other sites below Iron Gate dam, suggesting that there is a source of turbidity to the Klamath River downstream from Orleans.

2.7.3 Temporal Trends in the Historical Data

The aspects of the data mentioned above that cause difficulty for spatial analysis also apply to temporal analysis. Many of the constituents and sites for which data were collected did not have sufficient numbers of data points, or data were not collected frequently enough or for a long enough span of time to be useful for temporal analysis. However, several of the more commonly sampled constituents and sites did have sufficient data to make temporal analysis feasible. The constituents used for temporal analysis are alkalinity, ammonia nitrogen, chlorophyll *a,* DO, nitrate nitrogen, orthophosphorus, pH, TKN, and turbidity. The sites are listed in Table 2.7-4. Not every combination of site and constituent listed in Table 2.7-4 was suitable for use in the analysis.

Table 2.7-4. Sites used for temporal analysis of Klamath River historical data.

Site Location	Site Description
RM 5	Klamath River near Klamath Glen
RM 128	Klamath River near Seiad
RM 189.5	Klamath River below Iron Gate fish hatchery
RM 240.5	Klamath Straits Drain
RM 253	Link River near mouth

In general, the data are not amenable to standard time series analysis, which typically requires evenly spaced data. Likewise, the usual requirements for standard parametric analysis are typically not met. To overcome these impediments, the historical data were analyzed graphically. Each constituent under consideration was plotted against date and day of the year (Julian day) in order to detect both long-term trends and seasonal effects. A third-order polynomial was fit to the data for each graph, and the correlation coefficient of the fitted curve was determined. The results of the analysis are summarized in Table 2.7-5.

Table 2.7-5. Correlation coefficients (R^2) for third-order polynomial fit to Klamath River water quality data.

Parameter	**RM**	**R^2 Date**	**R^2 Julian Day**
Alkalinity	189.5	0.0626	0.0650
Ammonia Nitrogen	5	0.0219	0.0060
Ammonia Nitrogen	253	0.1353	**0.4282**
Chlorophyll *a*	240.5	0.1350	0.0088
Chlorophyll *a*	253	0.1310	**0.1533**
Dissolved Oxygen	240.5	0.0126	**0.4115**
Dissolved Oxygen	253	0.1363	**0.4733**
Nitrate Nitrogen	5	**0.2286**	0.0428
Nitrate Nitrogen	128	**0.2893**	**0.3233**
Nitrate Nitrogen	189.5	**0.3677**	**0.2507**
Nitrate Nitrogen	240.5	0.0594	0.1413
Nitrate Nitrogen	253	0.0047	**0.2517**
Orthophosphate	5	0.1124	0.0304
Orthophosphate	240.5	0.0879	**0.2514**
Orthophosphate	253	0.1095	0.0406
PH	5	**0.2080**	0.1218
PH	253	0.0863	**0.4808**
Total Kjeldahl Nitrogen	5	0.0513	0.1095
Total Kjeldahl Nitrogen	189.5	0.0424	**0.3058**
Total Kjeldahl Nitrogen	253	0.0422	**0.5863**
Turbidity	5	0.1148	**0.1608**
Turbidity	189.5	0.0305	**0.2563**
Turbidity	253	0.1287	0.1153

Note: Analysis was conducted to detect long-term trends (R^2 Date), and seasonal effects (R^2 Julian Day). Coefficients greater than 0.15, in bold, suggest that there is a temporal trend in the data.

2.7.3.1 Seasonal Trends

Ammonia nitrogen in Link River (RM 253), chlorophyll *a* in Link River, DO at several sites, nitrate nitrogen at Seiad (RM 128) and below the Klamath fish hatchery (RM 189.5), orthophosphate in Klamath Straits Drain (RM 240.5), TKN in Link River (RM 253) and below the fish hatchery (RM 189.5), and turbidity below the fish hatchery (RM 189.5) and near the mouth (RM 5) showed discernible seasonal trends (Figures 2.7-16 through 2.7-28).

Ammonia nitrogen in Link River and nitrate nitrogen below the fish hatchery and at Seaid exhibit a similar pattern of minimum concentration in June, July, and August, increasing to maximum concentration in December and January (Figures 2.7-16 to 18). In contrast, TKN entering Lake Ewauna from Link River is at a minimum during March and April, reaches a maximum in August and September, and then decreases through the winter (Figure 2.7-18). Although sampling for chlorophyll *a* has historically been limited to summer months, the seasonal pattern for chlorophyll at Link River, most likely a reflection of conditions in Upper Klamath Lake, is similar to that of TKN; minimum values occur in May and June, increasing to maximum values in August and September (Figure 2.7-20). Orthophosphate phosphorus in Klamath Straits Drain (RM 240.5) has relatively low values in winter that increase in spring to maximum values in June and July and then decrease through the fall (Figure 2.7-21).

DO follows a distinct seasonal pattern, reflecting the interaction of oxygen solubility and temperature. As water temperatures warm through the summer, DO concentration decreases, as indicated in Figure 2.7-22, where all sites are plotted. The many low values seen in Figure 2.7-22 are largely taken from sites in Lake Ewauna (Keno reservoir).

Turbidity in the Klamath River below the Iron Gate fish hatchery is generally quite low and relatively uniform, but it exhibits a seasonal pattern of higher values in December through March and minimum values in July through September (Figure 2.7-23). A similar pattern, although with considerably higher values and greater variability, can be seen in the Klamath River near Klamath Glen (RM 5) (Figure 2.7-24).

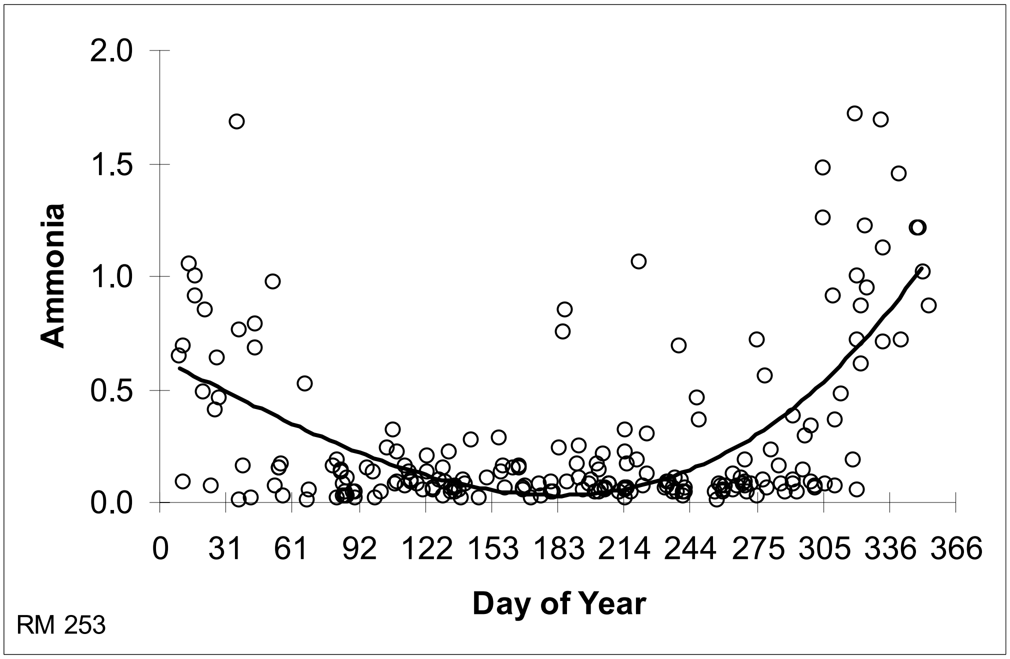

Figure 2.7-16. Ammonia nitrogen values (mg/L as N) measured in Link River near the mouth in 1950 through 2001. A third order polynomial curve is fitted to the data.

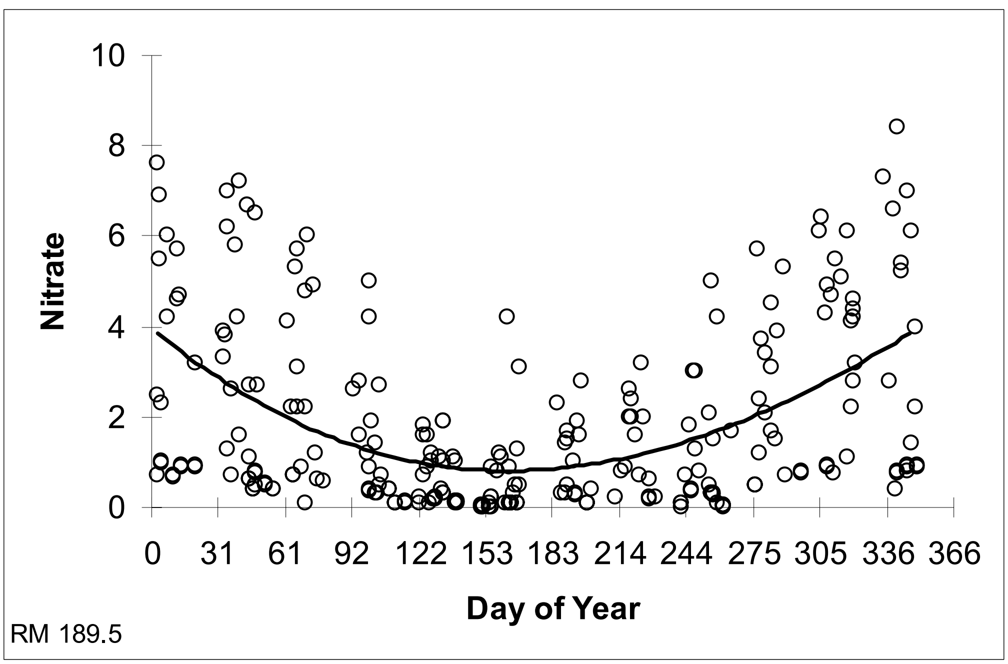

Figure 2.7-17. Nitrate nitrogen values (mg/L as N) measured in the Klamath River downstream of the Klamath River fish hatchery in 1950 through 2001. A third order polynomial curve is fitted to the data.

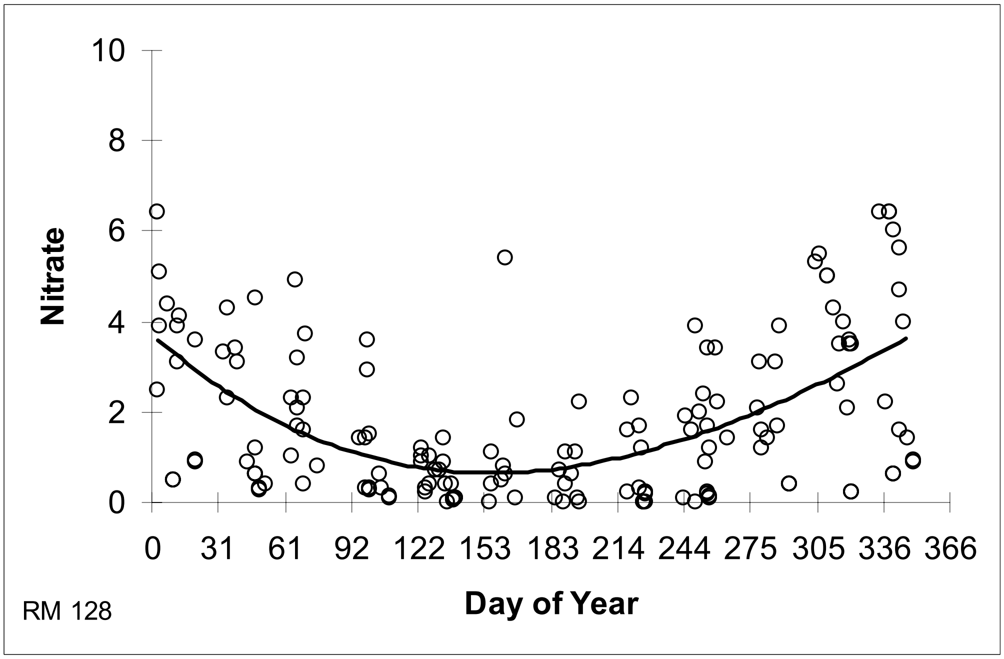

Figure 2.7-18. Nitrate nitrogen values (mg/L as N) measured in the Klamath River near Seiad in 1950 through 2001. A third order polynomial curve is fitted to the data

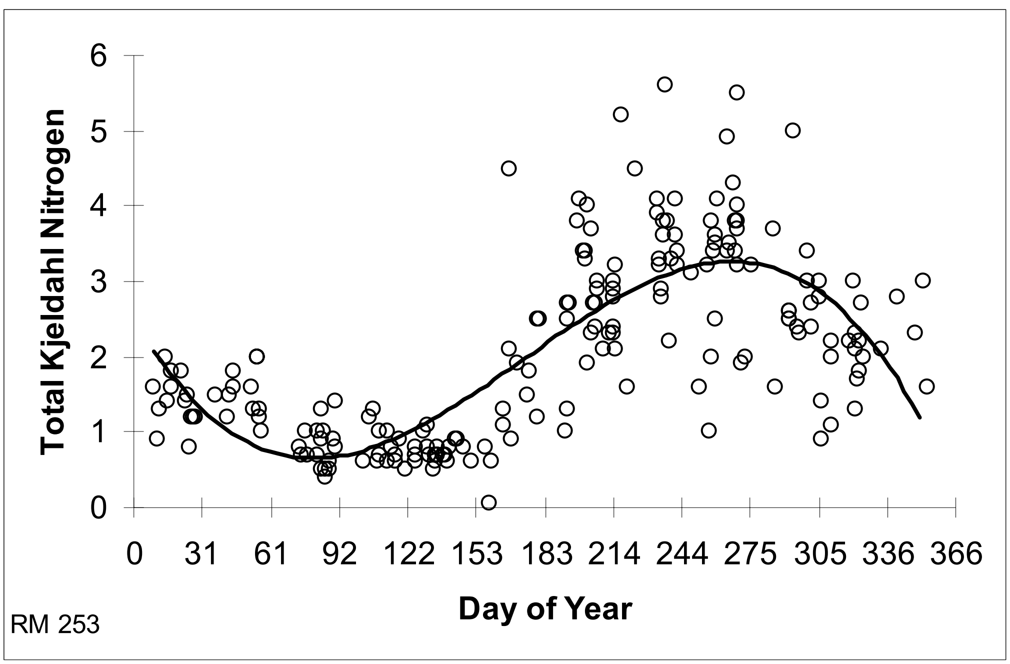

Figure 2.7-19. Total Kjeldahl nitrogen values (mg/L as N) measured in Link River near the mouth in 1950 through 2001. A third order polynomial curve is fitted to the data.

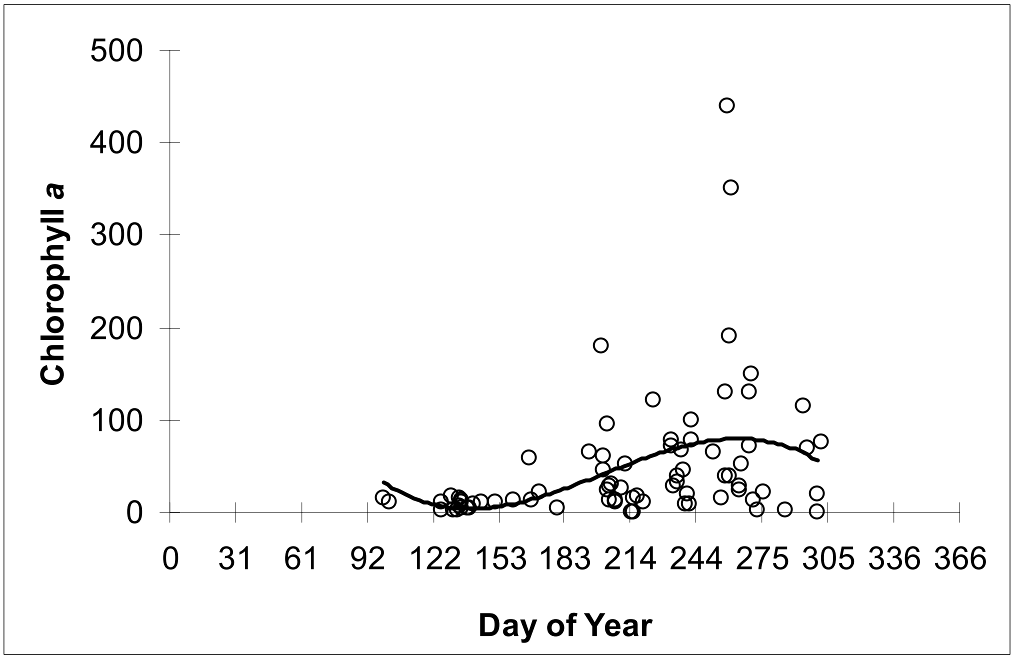

Figure 2.7-20. Chlorophyll *a* values (µg/L) measured in Link River near the mouth (RM 5) in 1950 through 2001. A third order polynomial curve is fitted to the data.

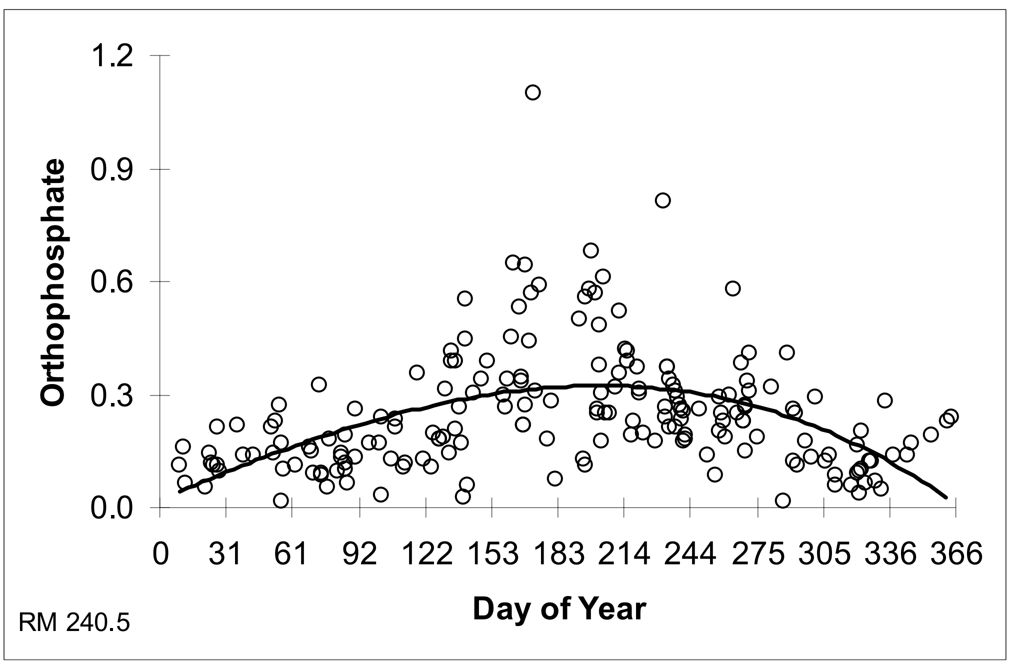

Figure 2.7-21. Orthophosphate phosphorus values (mg/L as P) measured in the Klamath Straits Drain in 1950 through 2001. A third order polynomial curve is fitted to the data.

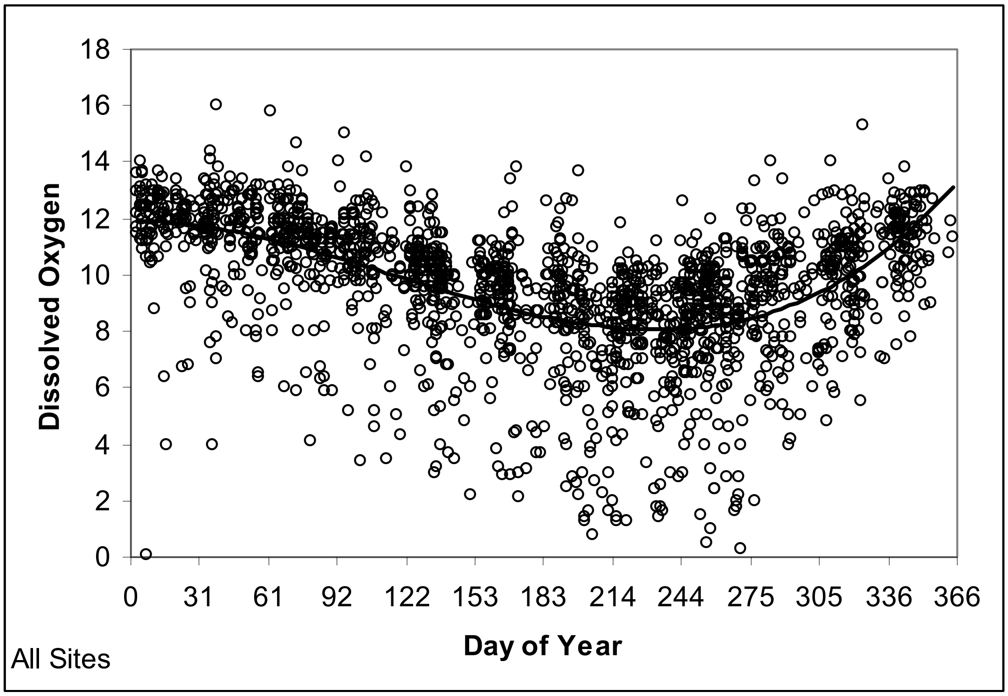

Figure 2.7-22. Dissolved oxygen values (mg/L) measured at various sites in the Klamath River in 1950 through 2001. A third order polynomial curve is fitted to the data.

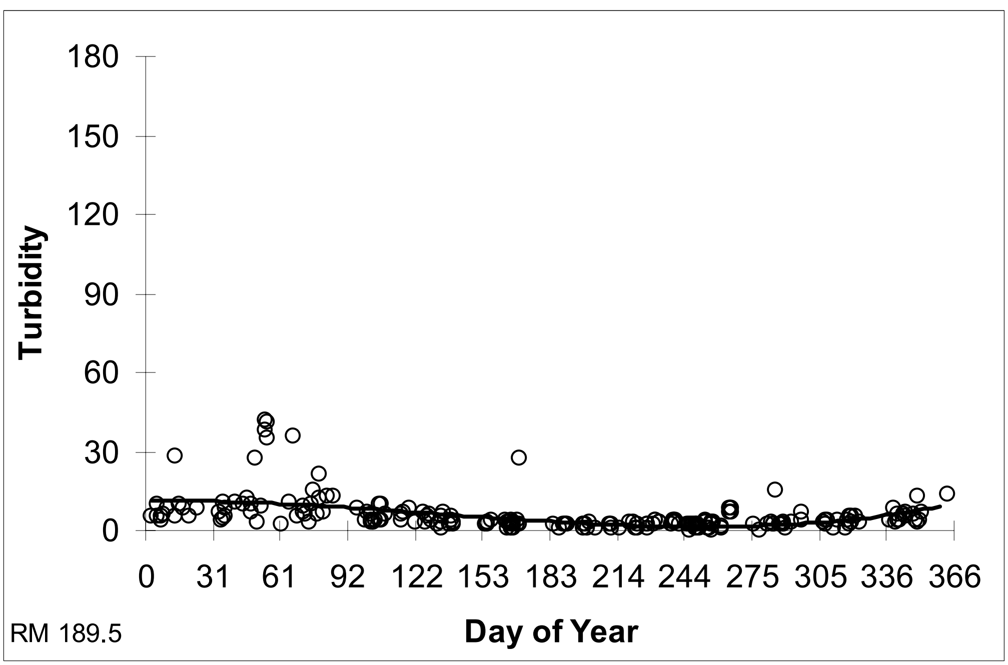

Figure 2.7-23. Turbidity values (NTU) measured in the Klamath River downstream of the Klamath River fish hatchery in 1950 through 2001. A third order polynomial curve is fitted to the data.

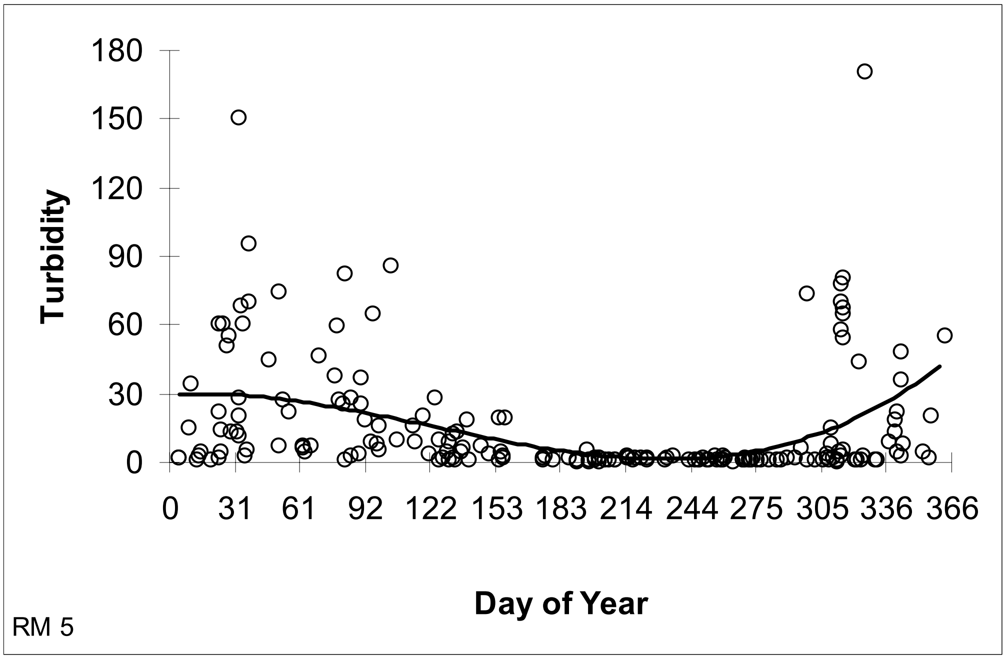

Figure 2.7-24. Turbidity values (NTU) measured in the Klamath River near the mouth in 1950 through 2001. A third order polynomial curve is fitted to the data

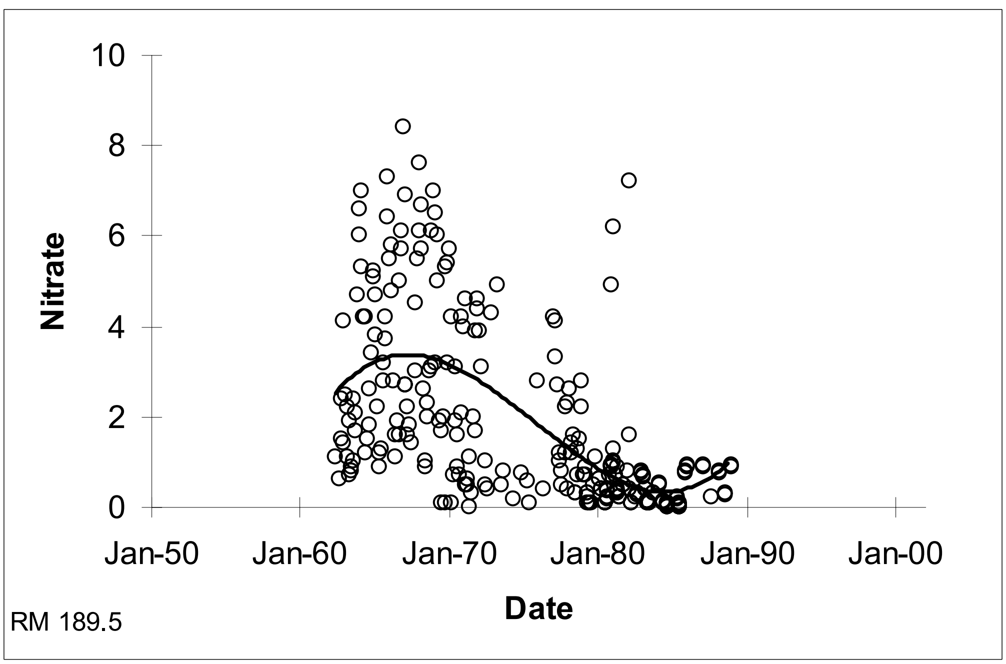

Figure 2.7-25. Nitrate nitrogen values (mg/L as N) measured in the Klamath River downstream of the Klamath River fish hatchery in 1950 through 2001. A third order polynomial curve is fitted to the data.

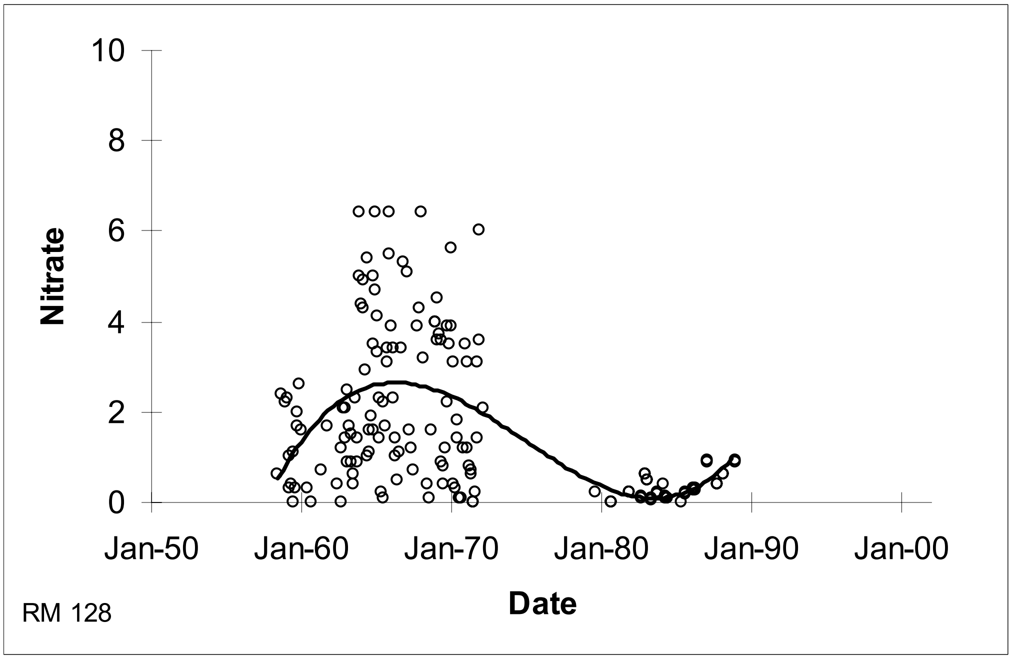

Figure 2.7-26. Nitrate nitrogen values (mg/L as N) measured in the Klamath River near Seiad in 1950 through 2001. A third order polynomial curve is fitted to the data

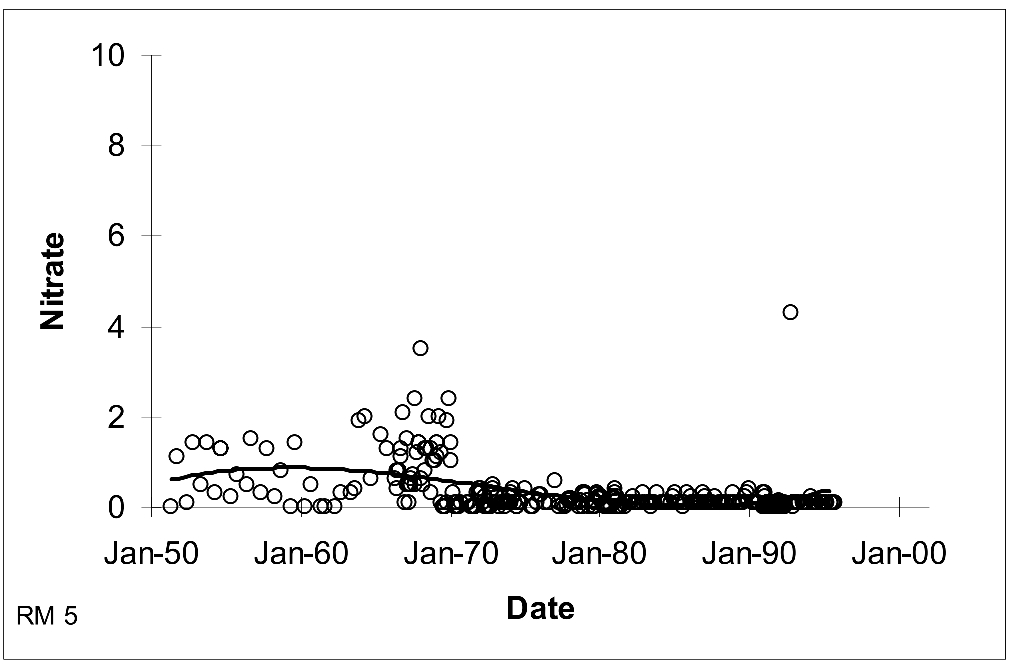

Figure 2.7-27. Nitrate nitrogen values (mg/L as N) measured in the Klamath River near the mouth in 1950 through 2001. A third order polynomial curve is fitted to the data.

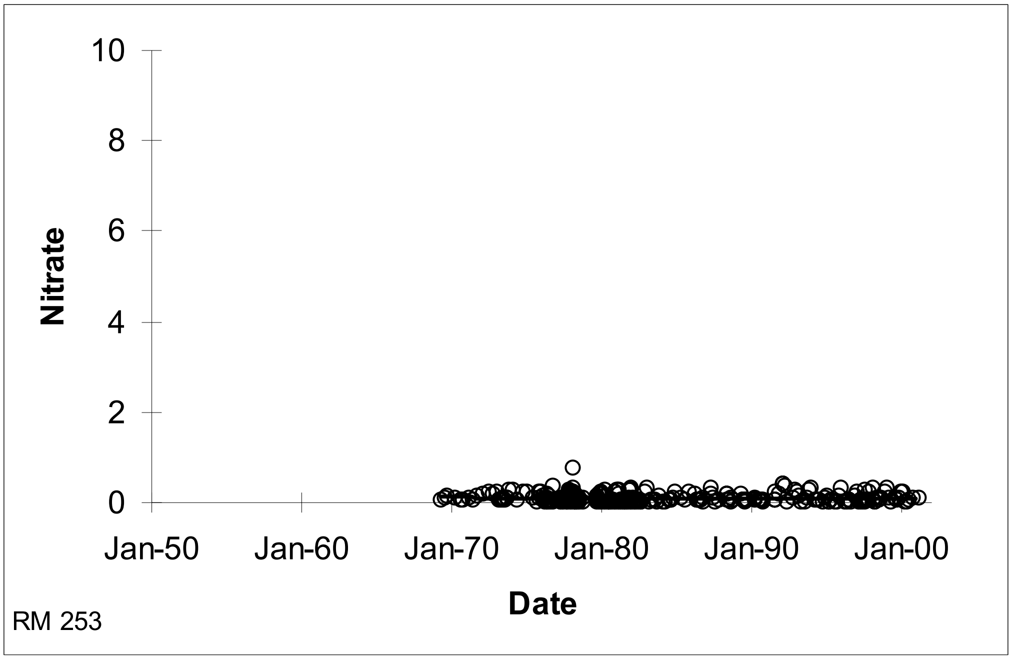

Figure 2.7-28. Nitrate nitrogen values (mg/L as N) measured in Link River near the mouth in 1950 through 2001. A third order polynomial curve is fitted to the data

2.7.3.2 Long-Term Trends

Few long-term trends were evident in the historical data. The exceptions were nitrate nitrogen at several sites, TKN in the Klamath River below the fish hatchery, and pH in the Klamath River near the mouth. A distinctive pattern occurs in the abundance of nitrate nitrogen at three sites; relatively high and variable values occur prior to approximately 1980, and lower and less variable values occur after 1980. The pattern is similar below the fish hatchery (RM 189.5), at Seiad (RM 128), and near Klamath Glen (RM 5), although the absolute value of nitrate concentration and the magnitude of the change decrease with distance downstream (Figures 2.7-25 to 2.7-28). A similar change does not occur in Link River (Figure 2.7-29). The polynomial fit to TKN data at RM 189.5 indicates that a trend may exist, but inspection of the plot suggests that the trend is an artifact. A linear fit to the data indicates that no trend exists ($R^2 = 0.0032$). An increasing trend in pH is evident in measurements made near the mouth of the Klamath River (RM 5) (Figure 2.7-30).

2.0 COMPILATION AND ASSESSMENT OF EXISTING WATER QUALITY DATA

2.1 DESCRIPTION AND PURPOSE

An extensive body of water quality data and information exists for the Klamath Hydroelectric Project area, but it comes from multiple sources and is presented in differing forms. PacifiCorp collected the available data and assembled them in an electronic database. The data provide a basis against which to compare current water quality and identify general aspects of water quality in the Project.

The details of this study are contained in Study Plan 1.1, Compilation and Assessment of Existing Water Quality Data, approved by the Water Quality Working Group and Klamath Relicensing Plenary in August 2002. The study plan is available on the Klamath Hydroelectric Project Relicensing website, http://www.pacificorp.com/Article/Article1152.html.

2.2 OBJECTIVES

The objectives addressed by the data compilation study were as follows:

- Gather and organize existing data
- Identify spatial and temporal trends in water quality, if possible
- Identify data gaps to be filled by further study
- Provide information for use in planning additional water quality or related studies

2.3 RELICENSING RELEVANCE AND USE IN DECISIONMAKING

The database allows the existing data to be used to maximum advantage to meet the requirements of Oregon and California 401 certification and the FERC license application. The database assists in the assessment of water quality trends and helps to identify areas where water quality is of particular concern to relicensing. The database also helps to identify key water quality data gaps that may require additional sampling and fieldwork.

2.4 METHODS AND GEOGRAPHIC SCOPE

2.4.1 Database Development

PacifiCorp compiled relevant water quality data and information for the Project into a computerized database. Data were included in the database also according to the following criteria:

1. Data prior to 2001 available in digital form

2. Only sites with at least two samples

3. Sites with only one sample if the analytes consist of extensive organics, toxics screens, or other specialized analyses as may be available

4. Sites within 1 mile of the Klamath River on all tributaries

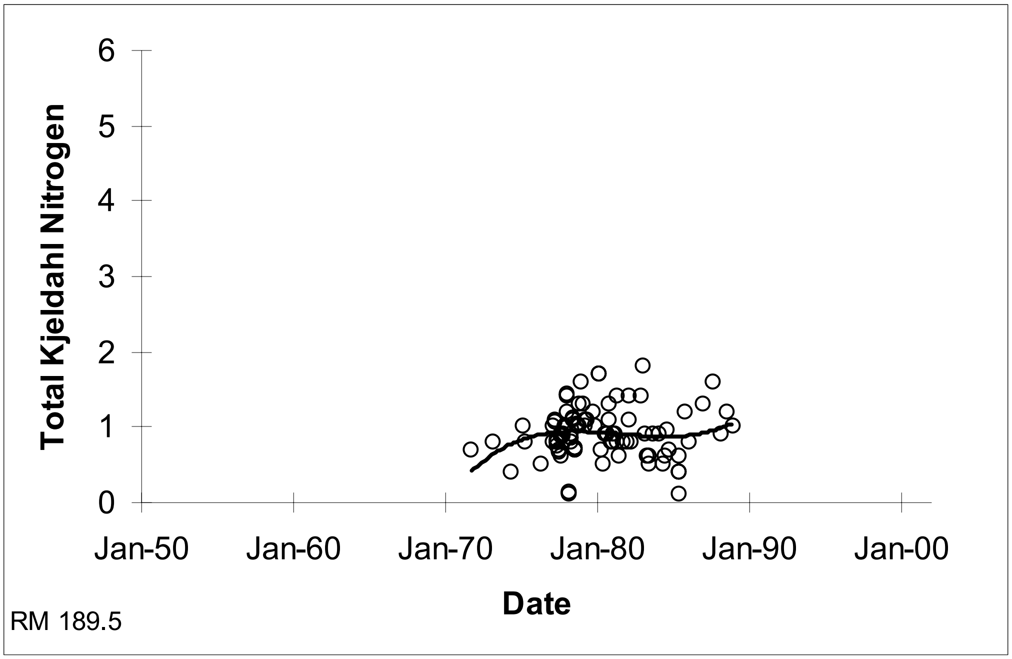

Figure 2.7-29. Total Kjeldahl nitrogen values (mg/L as N) measured in the Klamath River downstream of the Klamath River fish hatchery in 1950 through 2001. A third order polynomial curve is fitted to the data

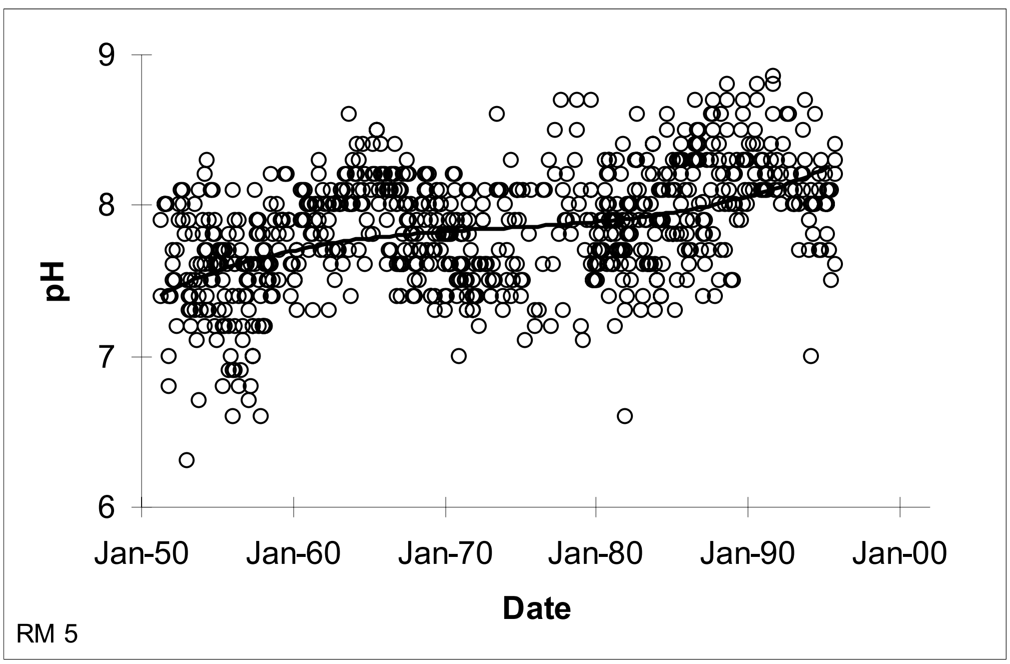

Figure 2.7-30. pH (units) measured in the Klamath River near the mouth in 1950 through 2001. A third order polynomial curve is fitted to the data.

3.0 CURRENT WATER QUALITY CONDITIONS IN THE PROJECT AREA

3.1 DESCRIPTION AND PURPOSE

Study Plan 1.2, Monitoring of Water Temperature and Water Quality Conditions in the Project Area, describes the water quality sampling effort planned for 2002. The study plan was prepared and presented to the Water Quality Working Group in March 2002, and approved by the plenary in October 2002. The purpose of Study Plan 1.2 was to obtain data to support modeling and assessment of the Project's potential effects on water quality and to characterize current water quality conditions within and downstream of the Project area. In addition to this work, PacifiCorp also collected water quality data in 2000 and 2001, and conducted additional water quality monitoring, in response to the requirements of the modeling effort in 2003. In addition, USBR made available to PacifiCorp water quality data it had collected in 2000 and 2002, and BLM provided temperature data collected in 2002. Study Plan 1.2 is included in Appendix 3A.

The water quality monitoring conducted during 2000 through 2003 and its application to current water quality conditions in the Project area are described in this section. In Section 4.0 of this document the results of water quality modeling are used to determine the effects of the Project on water quality and the potential effects of PM&E measures related to water quality.

3.2 OBJECTIVES

The objective of this study was to collect water quality data in 2002 that, combined with the data collected by PacifiCorp in 2000, 2001, and 2003 and the data provided by other agencies, would be used to address the following questions:

- What are the water quality conditions in key river, reservoir, and tributary areas within and downstream of the Project area?
- What are the potential factors driving water quality conditions in key river, reservoir, and tributary locations within and downstream of the Project area?
- Are Oregon and California water quality standards and objectives being met? Where and when?

The first two objectives are dealt with in this section. The third objective will be considered in Exhibit E of the FERC License Application and in applications to the water quality control agencies of Oregon and Washington for 401c water quality certification. In addition, the data from this study are being used to support modeling and assessment of the Project's potential effects on water quality and possible PM&E measures where necessary (as described in Section 4.0.

3.3 RELICENSING RELEVANCE AND USE IN DECISIONMAKING

The information obtained through Study Plan 1.2 and from water quality monitoring conducted by PacifiCorp and others helps to determine the factors that contribute to current water quality conditions and the way in which Project operations may influence those conditions. Study emphasis is focused on water temperature, DO, and nutrient conditions because the Klamath River, from Upper Klamath Lake to the mouth, is listed as water-quality-limited by both Oregon and California under Section 303(d) of the federal Clean Water Act. One or more sections of the Klamath River in Oregon are 303(d)-listed for water temperature (summer), pH (summer), chlorophyll *a* (summer), DO (April 1-November 30), and ammonia toxicity (summer and winter). The Klamath River in California is 303(d)-listed for water temperature, nutrients, organic enrichment, and DO. Warm water temperatures and enriched nutrient conditions, particularly during summer, are the primary focus of water quality management planning in the basin by Oregon and California water quality agencies.[1]

Relicensing of the Project will require certifications from California and Oregon water quality agencies that the Project complies with Section 401requirements of the federal Clean Water Act. PacifiCorp is using information from Study Plan 1.2 and additional studies to document water quality conditions and identify potential Project effects as they relate to water quality objectives and standards promulgated by these agencies.

3.4 METHODS AND GEOGRAPHIC SCOPE

In 2000 and 2001, PacifiCorp sampled sites in the reservoirs of the Project area. In 2000, USBR sampled sites in the Klamath River between Link dam and Keno dam, as well as below Iron Gate dam. In 2002, PacifiCorp expanded its monitoring to include sites in the Klamath River from Link River (RM 254.8) to the Shasta River (RM 176). USBR also conducted water quality sampling in 2002 at various sites between Link River dam and Keno dam and made the results available to PacifiCorp. The combined efforts of PacifiCorp and USBR in 2002 constituted the work conducted under Study Plan 1.2. In 2003, PacifiCorp continued collecting water quality data at a number of sites between the mouth of Link River and the outflow from Iron Gate dam to fill in data gaps needed for calibration and validation of the water quality models.

The methods and results of the 2000 and 2001 USBR sampling program are described in a recent technical report titled Klamath River Water Quality 2000 Monitoring Program: Project Report (Watercourse Engineering, January 2003). This section describes current water quality conditions in the Klamath River in the Project area between Link River dam and the Shasta River based on data collected in 2000 through 2003.

3.4.1 Study Sites

Sampling sites were chosen to provide information suitable for calibration and validation of water quality models being developed by PacifiCorp as part of the Project relicensing process. The goal was (1) to characterize the boundary conditions for the project reaches identified in the Klamath River Reach Water Quality Summaries,[2] and (2) to describe the vertical variability in the Project reservoirs.

Thirty-three sites on the Klamath River between Upper Klamath Lake and the mouth of the Shasta River were sampled for water quality constituents in 2000 through 2003. In general,

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[1] The Klamath River in Oregon is scheduled to have development of total maximum daily load (TMDL) limits and implementation plans by December 31, 2004, and with TMDL implementation plans established by December 31, 20054.

[2] Available at: http://www.pacificorp.com/Article/Article16141.html

PacifiCorp sampled reservoir and river sites monthly during March through November in 2000 through 2003. USBR sampled sites in Lake Ewauna and Keno reservoir, plus additional sites on the Klamath River, biweekly during May through October in 2000 and 2002. USBR has shared its data with PacifiCorp for consideration in this report. Not every site was sampled for the entire time. Sampling sites are shown in Figure 3.4-1. The number of samples collected by site and by year is presented in Table 3.4-1.

PacifiCorp installed temperature data loggers (Onset TidBits®) at 26 additional sites in the Klamath River to gather hourly temperature data. The sites and dates recorded are listed in Table 3.4-2. In addition, vertical arrays of temperature data loggers collecting hourly temperature data have been placed near the dams in the main Project reservoirs from 2000 through 2003.

On three occasions during 2002 (May, July, and September), a 3-day synoptic sampling event was conducted. The purpose of this 3-day effort was to collect data representing smaller scale variations in time and space than were obtained during the regular monthly sampling. The synoptic sample events had several components:

- Multiple sampling teams visited 25 monthly sampling sites plus five additional sample sites on the same day. This provided a snapshot of conditions throughout the Project on a single day.

- Additional daily samples were collected at five sites on the day before and the day after the monthly samples were taken. The additional days provided information on the shorter term variability in the reservoirs and at a few other sites that would be missed with only monthly sampling.

- Four multiparameter data loggers were deployed to augment the instruments deployed by USBR. This sub-daily information was necessary to adequately represent the dynamic conditions for developing the computer models of the system.

- Multiple measurements were made in Copco and Iron Gate reservoirs to document diurnal changes in water quality. These measurements were intended to characterize diurnal variation in water quality, especially pH and DO, in the epilimnion of the reservoirs.

3.4.2 Cooperative Water Quality Monitoring during 2000 and 2001

A cooperative water quality monitoring program conducted by USBR in 2000 and 2001 provided data on the Klamath River from Link River dam (RM 253) to Seiad Valley (RM 128.9) (Watercourse Engineering, Inc., 2003). The program consisted of six related tasks:

- Semimonthly grab samples
- Reservoir water quality surveys
- Water temperature monitoring
- Continuous water quality probe (hydrolab data-sonde) deployment
- Synoptic water quality surveys
- Attached algae sampling

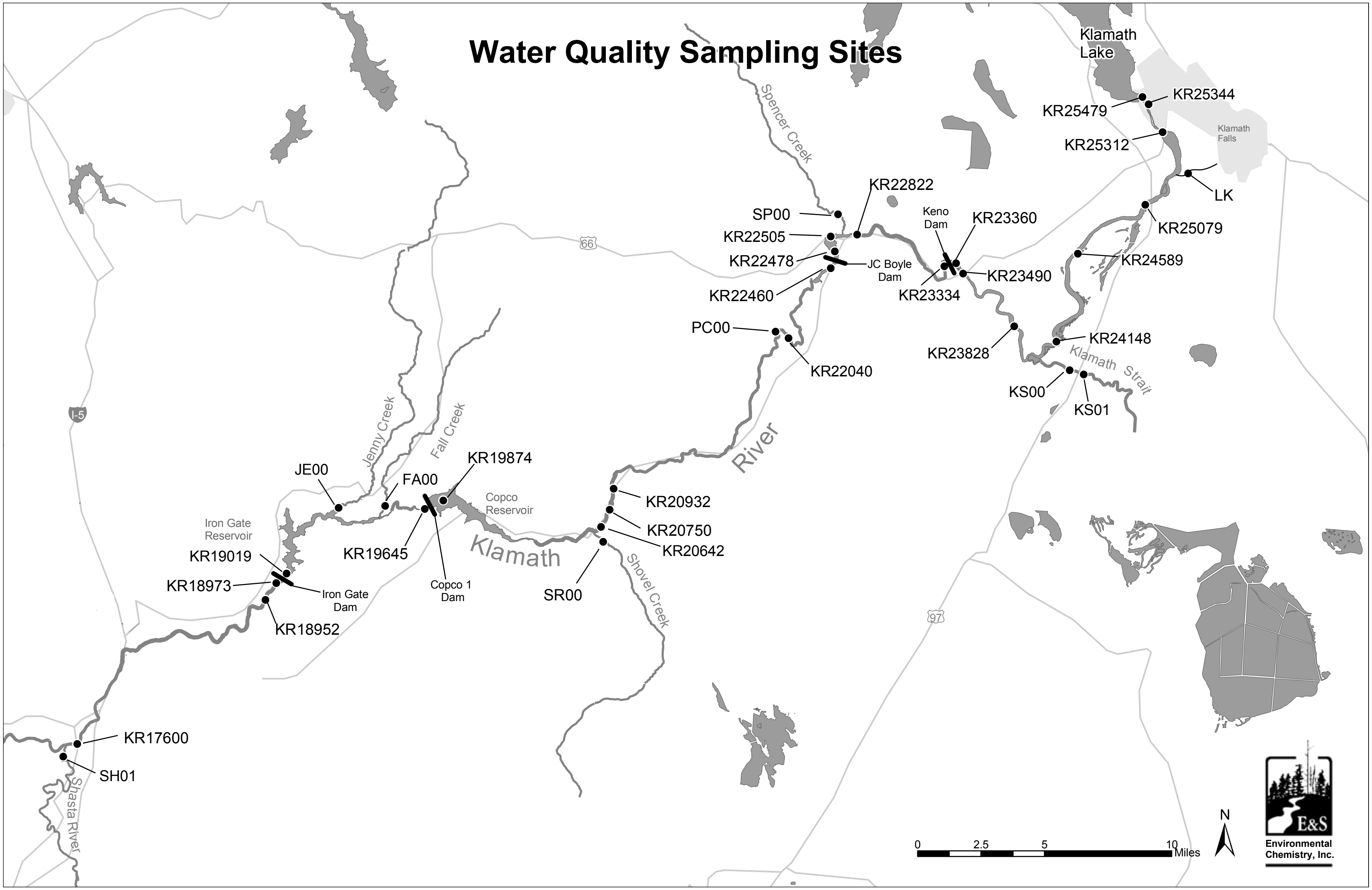


Figure 3.4-1. PacifiCorp and USBR water quality sampling sites in the Klamath River, 2000-2002.

Table 3.4-1. Sample site locations and number of dates sampled for water quality data in the Project area.

Site ID*	Site Name	2000	2001	2002	2003
KR25479	Upper Klamath Lake at Fremont St. Bridge			8	1
KR25344	Link River near powerhouse			13	
KR25312	Link River at mouth			20	9
LK	Lost River diversion canal at Klamath River			3	
KR25079	Klamath River at South-Side Bypass Bridge			14	
KR24589	Klamath River at Miller Island boat ramp	13		14	
KR24148	Klamath River upstream of Klamath Straits Drain	1		13	
KS01	Klamath Straits Drain pumping plant F	14		14	
KS00	Klamath Straits Drain 200 feet downstream of pumping plant F	1		7	
KR23828	Klamath River directly south of Hill 4315			14	
KR23490	Klamath River at Keno Bridge (Hwy. 66)	14		14	9
KR23360	Keno reservoir at log boom		8		
KR23334	Klamath River below Keno dam			15	9
KR22822	Klamath River above J.C. Boyle reservoir			16	9
SP00	Spencer Creek		1	10	1
KR22505	J.C. Boyle reservoir at deepest point			8	
KR22478	J.C. Boyle reservoir at log boom	8	6	15	8
KR22460	Klamath River below J.C. Boyle dam			15	9
KR22040	J.C. Boyle bypass (bottom)			16	9
PC00	J.C. Boyle powerplant tailrace	1		13	1
KR20932	Klamath River near Stateline			10	
KR20750	Klamath River above Copco			11	
KR20642	Klamath River upstream of Shovel Creek	13	8	9	9
SR00	Shovel Creek			11	1
KR19874	Copco Lake near Copco	8	9	14	9
KR19645	Copco dam outflow			9	9
FA00	Fall Creek near the mouth	1		9	1
JE00	Jenny Creek near the mouth			9	1
KR19019	Iron Gate reservoir near Hornbrook	8	9	14	9
KR18973	Iron Gate dam outflow	13	9	9	9
KR17600	Klamath River upstream of Shasta River			7	
SH01	Shasta River at mouth	12		11	

*Site ID codes are based on river mile. A two-letter code identifies the water body, and a two- or five-number numeric code identifies the river mile, measured from the mouth. Thus, KR22460 identifies a site on the Klamath River at RM 224.60 (below J.C. Boyle dam). River miles on the Klamath River are based on GIS river coverage, while river miles for tributaries are estimates to the nearest mile.

Table 3.4-2. Location and dates of temperature data collection at sites in the Project area.

Location	2001	2002	2003
Link Fish Ladder	05/11-10/04		04/30-11/23
Link Bottom Upstream of East Side Powerhouse	07/17-12/31	01/01-10/23	05/07-11/23
East Side Powerhouse Tailrace	05/11-12/31	01/01-05/05	
Keno Fish Ladder	05/11-12/31	01/01-05/02	05/07-11/23
Keno Reach at USGS Gauge	05/14-12/31	01/01-05/05	
Keno Reach Bottom at Gun Club	05/11-07/17	05/07-10/23	05/07-11/23
Spencer Creek	05/11-12/31	01/01-10/24	04/30-11/23
J.C. Boyle Bypass Top (at condemned bridge)	05/11-12-31	01/01-10/24	05/07-11/23
J.C. Boyle Bypass halfway from Diversion to Powerhouse	07/17-09/20		
J.C. Boyle Bypass Bottom above Powerhouse	07/24-12/31	01/01-10/23	05/07-11/23
J.C. Boyle Powerhouse Tailrace	05/11-12/31	01/01-10/23	05/07-11/23
J.C. Boyle Peaking at USGS Gauge	07/17-12-31	01/01-05/27	
J.C. Boyle Peaking at Stateline Recreation Site	07/18-10/15		
J.C. Boyle Peaking Upstream from Shovel Creek (at angler bridge)	07/24-10/15	05/05-10/24	04/30-11/23
Shovel Creek	05/10-12-31	01/01-10/24	05/06-11/23
Copco No. 2 Reservoir Upstream of Dam	10/15-12/31	01/01-05/06	
Top of Copco No. 2 Bypass Reach	10/15-12/31	01/01-05/06	
Copco No. 2 Bypass Reach Bottom	05/10-12/31	01/01-05/06	
Copco No. 2 Powerhouse			04/30-11/23
Klamath River above Iron Gate Reservoir			04/30-11/23
Jenny Creek	05/10-12/31	01/01-10/24	04/30-11/23
Fall Creek above Diversion	05/10-12/31	01/01-05/06	
Fall Creek Bottom of Bypass	10/15-12/31	01/01-05/06	
Fall Creek below Copco Access Road		05/05-06/17	04/30-11/23
Fall Creek Powerhouse Tailrace	07/18-12/31	01/01-05/06	
Iron Gate Dam at Powerhouse	05/10-12/31	01/01-12/31	

Data from the semimonthly grab samples and the reservoir water quality surveys (conducted by PacifiCorp) have been provided to PacifiCorp for consideration in this FTR. Additional cooperation occurred with the Yurok Tribe in conducting continuous water quality monitoring at two sites in the lower Klamath River: (1) above the Trinity River confluence (RM 43.5), and (2) at Martin’s Ferry downstream of the Trinity River confluence. Data from the continuous water quality probes have been used for calibration and validation of the water quality models, as described in Section 4.0 (Appendix 4A).

3.4.3 Methods

The monitoring program followed the standardized sampling protocols and procedures developed by ODEQ and other state and federal agencies. In general, sampling equipment and procedures were as defined in the ODEQ Laboratory Field Sampling Reference Guide (1998) and the Oregon Plan Water Quality Monitoring Guidebook (1999). Pre- and postdeployment accuracy checks of temperature loggers were conducted using the protocol outlined in the Oregon Plan Water Quality Monitoring Guidebook (1999, Chapter 6). Field audits were conducted at least three times during the sampling period, including immediately after deployment and immediately before retrieval.

Routine inspection and preventive maintenance of field equipment, and calibration of sampling instruments, were done according to the procedures and protocols outlined in the ODEQ Laboratory Field Sampling Reference Guide (1998) and the Oregon Plan Water Quality Monitoring Guidebook (1999, Chapter Six). Instruments were maintained and calibrated according to the standards outlined in the Oregon Plan Water Quality Monitoring Guidebook or the manufacturers' specifications. All sample collection and analysis were governed by written standard operating procedures (SOP) and a formal Quality Assurance Project Plan, included in Appendix 3A.

All water samples were collected using the grab-sample method. Samples were collected using a clean sample bottle, churn splitter, Van Dorn sampler, or a submersible pump, as appropriate to the site. The SOP describes how the monitoring and sampling were performed as well as associated procedures for documenting the field activities. A multiprobe instrument (i.e., Hydrolab Series 4 Datasonde, Hydrolab Series 4a Minisonde, or YSI 600) was used to measure the physical parameters of the ambient water (pH, specific conductance, DO, water temperature, and oxidation-reduction potential [ORP]).

The analyses selected were based on previous analyses of basin water and requirements for water quality models. Basic Laboratory Incorporated in Redding, California, analyzed water samples for total dissolved solids (TDS), TKN, ammonia, nitrate + nitrite as N, total phosphorus, orthophosphate, and BOD in 2000 through 2002. In 2003, those analyses were completed by CH2M HILL Applied Sciences Laboratory in Corvallis, Oregon, and North Creek Analytical Laboratory (TKN samples) in Beaverton, Oregon. Chlorophyll *a* and algal species were analyzed by Aquatic Analysts of Wilsonville, Oregon. The following methods were used to determine the concentrations of these constituents in the water samples.

Constituents	**Standard Methods**
Ammonia	4500 NH_3
Total Kjeldahl nitrogen	4500 NORG
Nitrate + nitrite, as N	4500 NO_3
Orthophosphate	4500 P
Total phosphorus	4500 P
Total alkalinity	2320
Total dissolved solids	2540
Biochemical oxygen demand	5210
Chlorophyll *a*	10200H

3.5 RELATIONSHIP TO REGULATORY REQUIREMENTS AND PLANS

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

Relicensing of the Project requires certifications from relevant agencies that the Project complies with requirements of Section 401 of the federal Clean Water Act. This study provides information to help assess potential Project effects as they relate to water quality objectives and standards promulgated by these agencies.

Together with other hydrology and water quality studies conducted by PacifiCorp (described elsewhere in this FTR), this study provides information to help address compliance with management objectives from various resource agencies, tribes, and other stakeholders that relate to water quality.

3.6 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 was formed and met approximately monthly or otherwise as needed to plan and discuss water quality studies and results, including this study.

3.7 RESULTS

Pacificorp wishes to acknowledge and thank USBR and BLM for their assistance and cooperation during the 2000 through 2003 water quality data collection. USBR provided assistance during sampling and collected nearly all the data used in this report relating to Lake Ewauna and Keno reservoir. BLM provided hourly temperature data collected during 2002 between J.C. Boyle dam and Copco reservoir. Their assistance has been invaluable to the success of this effort.

The discussion of results presented below is based on grab sample data collected by PacifiCorp from 2000 through 2003, grab sample data provided to PacifiCorp by USBR for that same period, hourly temperature data collected by Pacificorp from 2000 through 2003, and hourly temperature data provided to PacifiCorp by BLM. The database includes data collected by PacifiCorp between Klamath Lake (Fremont Bridge) and the mouth of the Shasta River during 2000 through 2003, as well as data collected by USBR between Klamath Lake and Keno dam. It does not include hourly water quality data-sonde data collected by USBR or data collected by USBR in 2000 outside the geographic limits mentioned above. Hourly data-sonde data are considered in more detail in Section 4.0 (Appendix 4A).

Many of the results in this chapter are presented as box plots. A box plot is a chart that indicates the central tendency of a set of values, their variability, the symmetry of the distribution, the presence of outliers (values very different from the others), and the range of the distribution. Box plots are often used to compare several sets of data. Box plots in this section use the following format:

- The lower edge of the box represents the first quartile Q1.
- A black line through the box represents the median Q2.
- The upper edge of the box represents the third quartile Q3.
- Vertical lines indicate the range of typical values.
- Individual points indicate extreme values.

The limits of the box define the interquartile range (IQR) and enclose the central 50 percent of the distribution. The vertical lines (whiskers) at the top and the bottom of the box indicate the range of "typical" data values. Whiskers extend to the largest or smallest data point that is within one and one-half times the IQR from the limits of the box. Any values beyond one and one-half times the IQR (possible outliers) are represented individually by asterisks if they are within three times the IQR, and by open circles if they are beyond three times the IQR (probable outliers).

3.7.1 Water Temperature

Water temperature data were collected by two methods. Instantaneous (grab sample) water temperature was recorded by hand-held instruments (YSI or Hydrolab multiparameter probe) at each site and for vertical profiles in the reservoirs at the time of sample collection. Grab samples were typically collected between 8:00 a.m. and 6:00 p.m. In addition, water temperature data recorders (Onset TidBits®) were installed at various stream locations and as vertical arrays in the Project reservoirs (as listed in Table 3.4-2). Summary statistics for water temperatures measured at all sampling sites are presented in Appendix 3B. More complete statistics are presented in Appendix 3C.

Grab sample water temperature measured in the Project area ranged from 3 to 27°C. The river sites underwent an annual cycle of water temperature, with minimums during the winter warming to a maximum in late July or early August and then cooling through the fall (Figure 3.7-1). Superimposed on this annual cycle were short-term fluctuations in response to changes in ambient air temperature and daily fluctuations of up to 12°C.

Water temperatures measured in the reservoirs (vertical profiles near the dams) show a similar annual cycle but also have a component that does not change greatly during the year (Figure 3.7-2). This is a consequence of the density stratification of the reservoirs in response to warming at the surface combined with incomplete mixing that allows the deeper water to remain cool throughout the year. This cycle of stratification is illustrated by isopleth diagrams for each reservoir (Figure 3.7-3). Copco and Iron Gate reservoirs exhibit stable temperature-driven density stratification during the summer months. A vertical water temperature gradient begins to develop typically in early March, and it persists until late October (Copco) or late November (Iron Gate). J.C. Boyle reservoir may develop a short-lived vertical water temperature gradient at times during the summer but does not exhibit stable seasonal stratification.

Data from the water temperature data recorders at river sites between Keno reservoir and Copco reservoir are presented in Figure 3.7-4 as daily averages of the hourly data. The annual cycle and short-term response to ambient conditions are clearly evident in this figure. Daily average water temperature below Keno dam (KR23334) has the most extreme annual range of the sites measured, being considerably warmer during the summer and cooler during the winter. The close correspondence in water temperature between sites below Keno dam and below J.C. Boyle dam (KR22460), combined with the short-term fluctuations in water temperature, suggest that these sites are at thermal equilibrium and responding to ambient conditions. Water temperatures at site KR22040, the downstream limit of the J.C. Boyle bypass reach, are less variable, both annually and short term, compared with upstream sites. This difference is most likely the result of the approximately 220 cfs of groundwater input to this reach. The cooling effect of the groundwater entering the Klamath River in the bypass reach appears to persist for quite a distance downstream. Average daily water temperature in the Klamath River just upstream from the mouth of Shovel Creek (KR20642) is consistently lower than it is below Keno dam or J.C. Boyle dam.

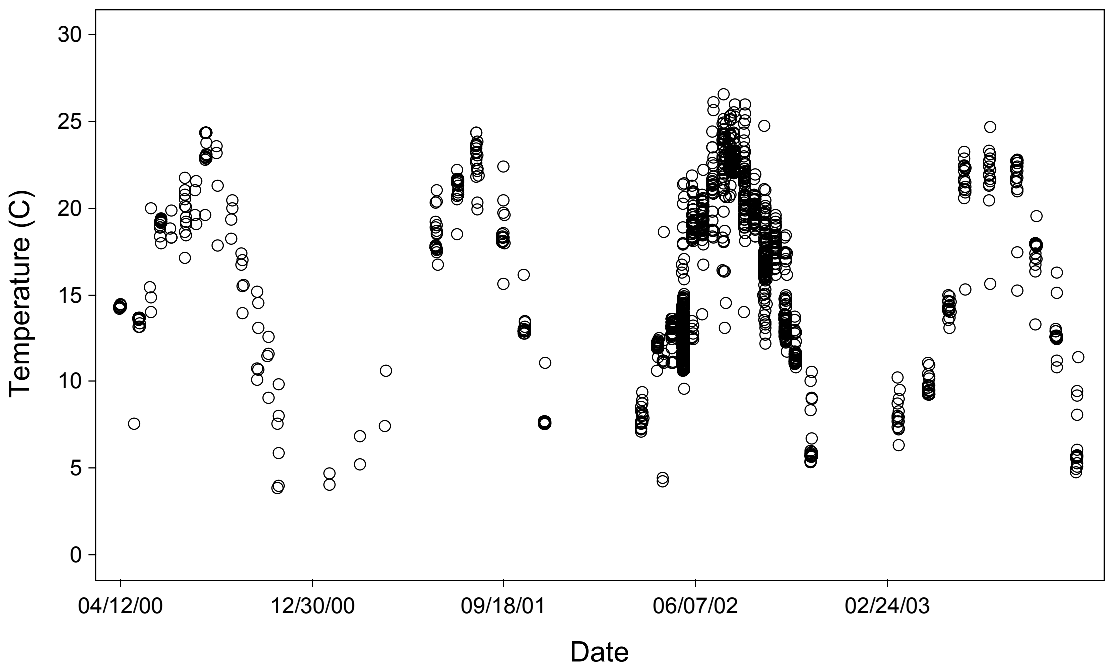


Figure 3.7-1. Water temperatures measured during regular sampling visits at river sites in the Project area during 2000-2003.

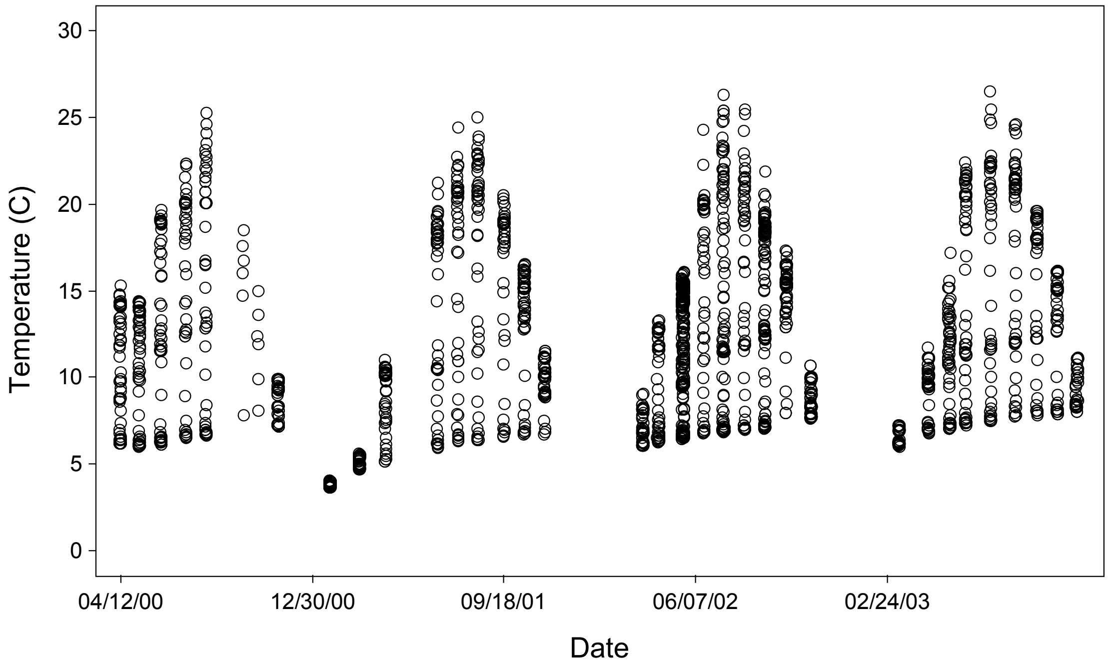


Figure 3.7-2. Water temperatures measured during regular sampling visits at reservoir sites in the Project area during 2000-2003.

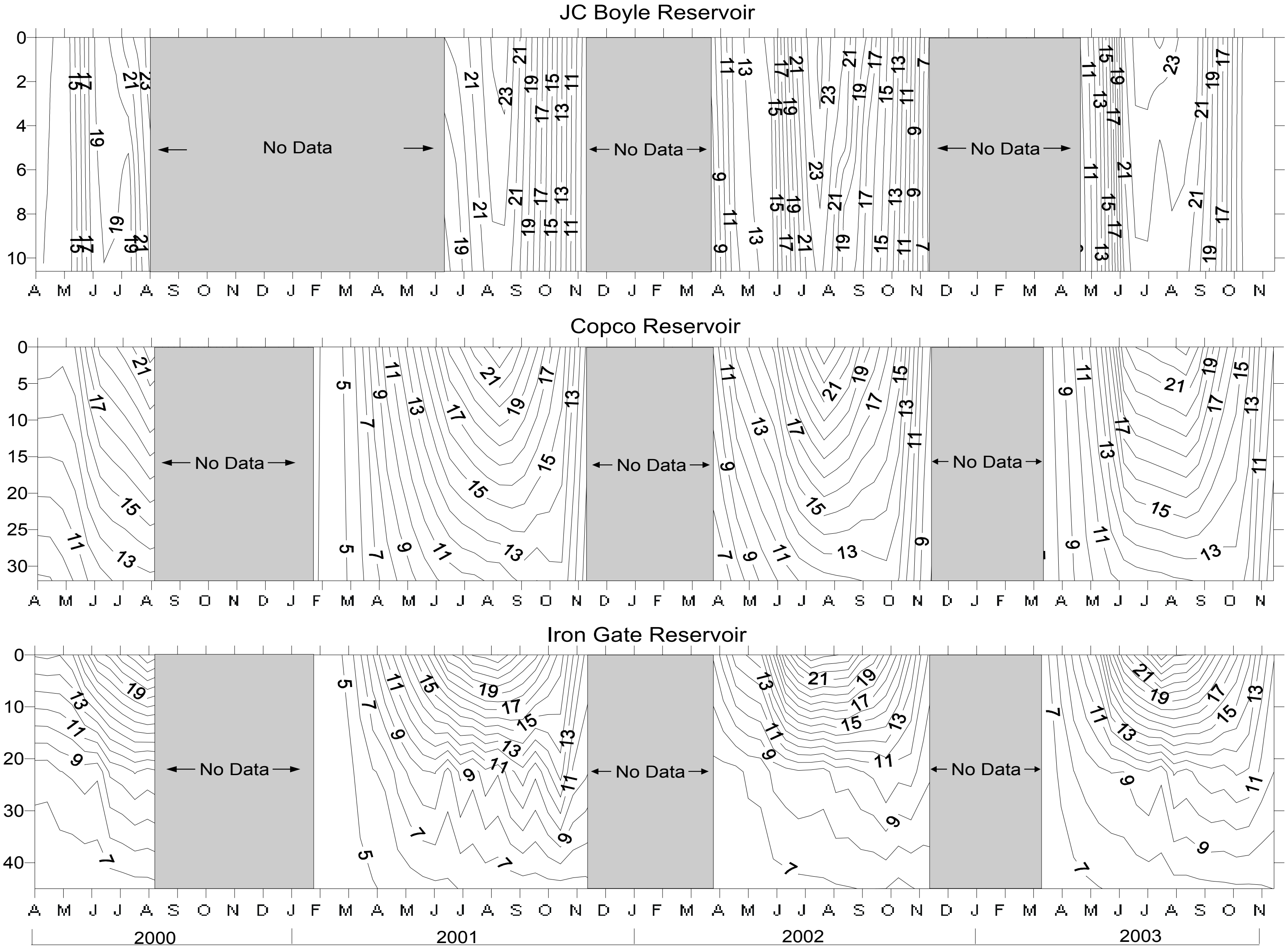


Figure 3.7-3. Isopleth diagram of water temperature for J.C. Boyle, Copco, and Iron Gate reservoirs for 2000 through 2003, illustrating seasonal stratification.

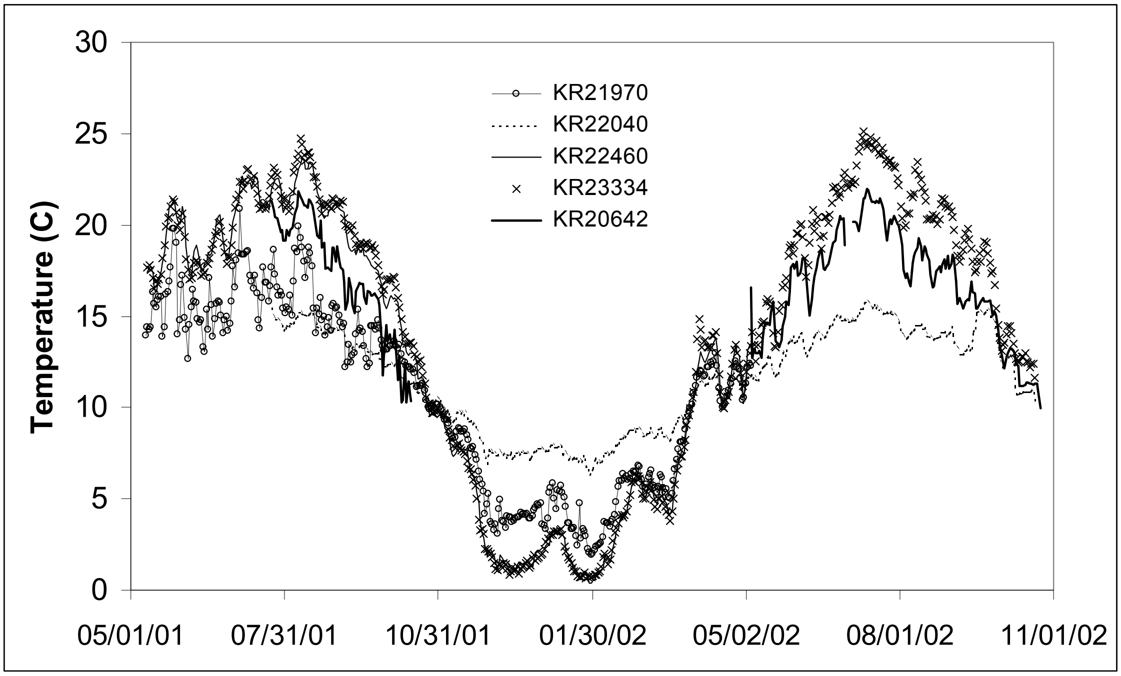


Figure 3.7-4. Daily average stream temperature measured at various sites in the Project area. KR20640 – Klamath River upstream of Shovel Creek, KR21970 – Klamath River at the USGS gauge below J.C. Boyle dam, KR22040 – Klamath River at bottom of J.C. Boyle bypass reach, KR22460 – Klamath River below J.C. Boyle dam, KR23334 – Klamath River below Keno Dam.

It is possible to highlight spatial trends in the water temperature data by calculating a temperature "residual"—i.e., the daily average water temperature at a site for a given day minus the mean of all sites for that day. The results of this calculation are presented in Figure 3.7-5. It is clear from this figure that water temperature at the downstream end of the J.C. Boyle bypass reach (KR22040) and in the Klamath River above Shovel Creek (KR20642) is consistently cooler than at other sites.

J.C. Boyle dam is operated in peaking mode, with large daily fluctuations in discharge. September and October 2002, however, J.C. Boyle dam was shut down for modifications, resulting in relatively constant daily discharge. Figure 3.7-6 shows daily discharge measured at the USGS gauge below J.C. Boyle powerhouse for representative periods of peaking and nonpeaking operation. The relatively cold water flowing in the bypass reach, combined with the fluctuation in discharge from the J.C. Boyle powerhouse during normal operation, has an effect on the water temperature regime in the Klamath River below the powerhouse (peaking reach). The diurnal pattern of water temperature variation is similar to sites not affected by peaking operation, but the range of variation is larger (Figure 3.7-7a). The range of daily water temperature variation below the powerhouse is greatly reduced, relative to unaffected sites, under conditions of constant daily discharge (Figure 3.7-7b). This reduction in range is largely the result of warmer minimum daily water temperatures because the influence of cool groundwater is reduced.

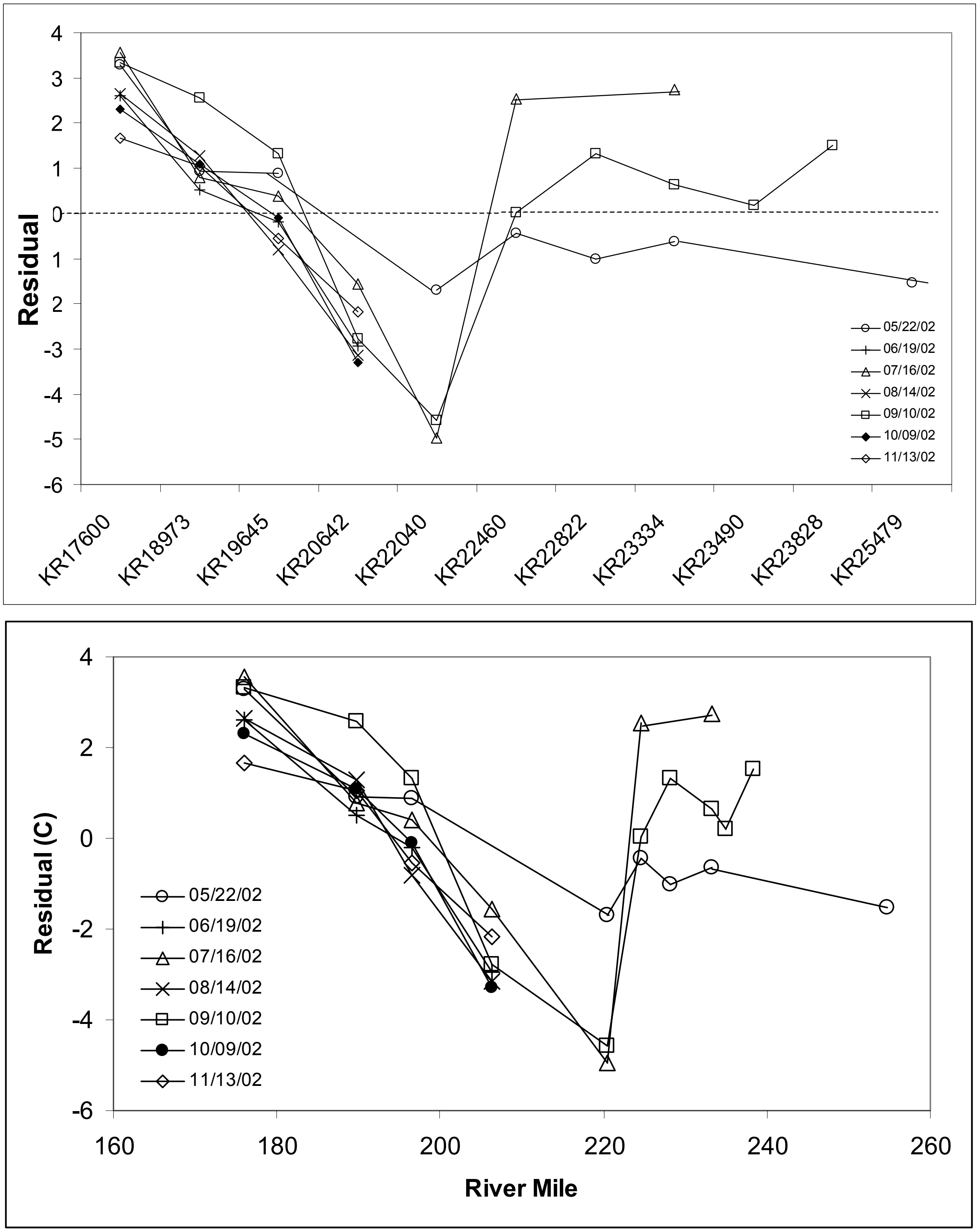
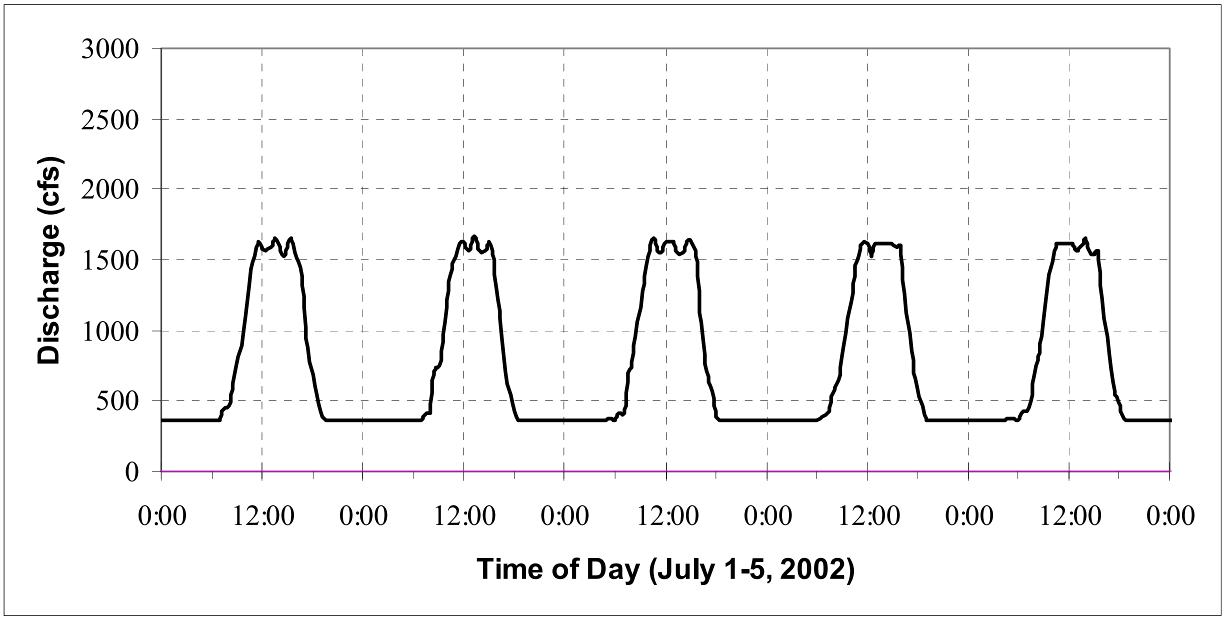


Figure 3.7-5. Spatial trends in water temperature residual in the Klamath River between Link Dam and the Shasta River. The residual = Tx – T, where Tx is the temperature at site x on a particular day and T is the mean temperature of all sites for that day. Sites are shown in upstream order from left to right in the plot.



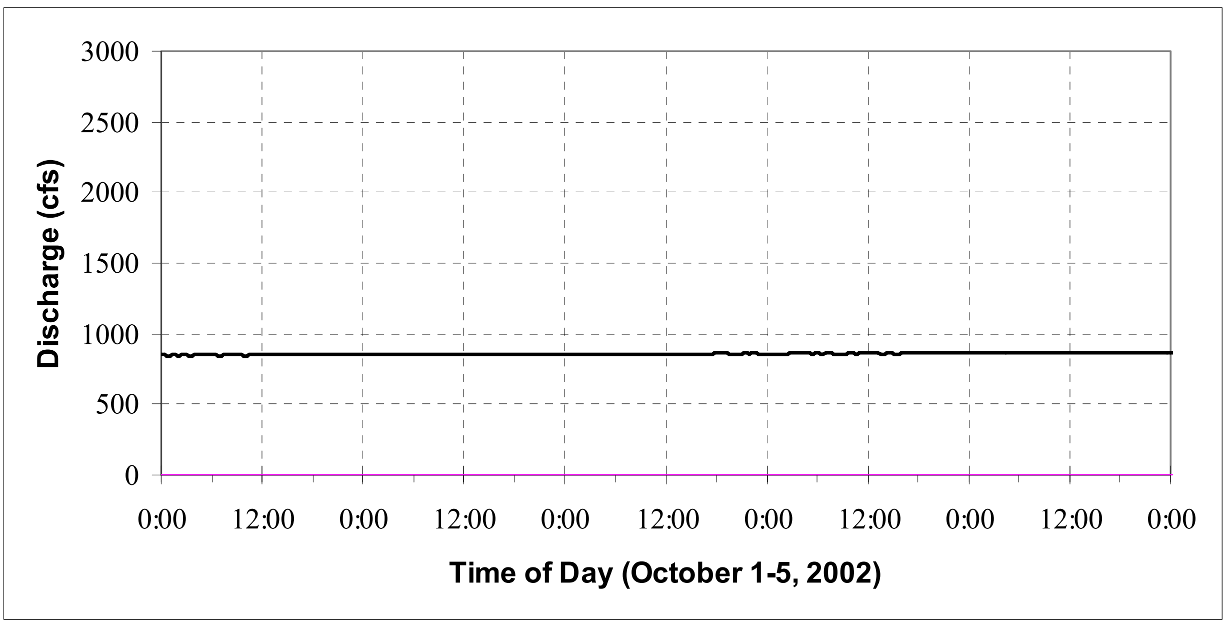
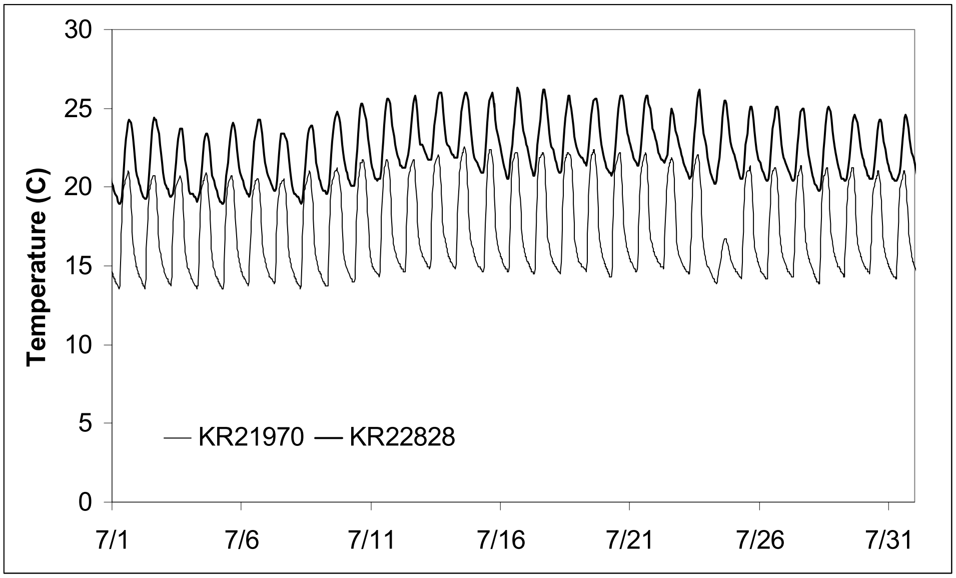


Figure 3.7-6. Discharge measured at the USGS gauge below the J. C. Boyle powerhouse in 2002 during peaking operation (top) and during nonpeaking flow (bottom).



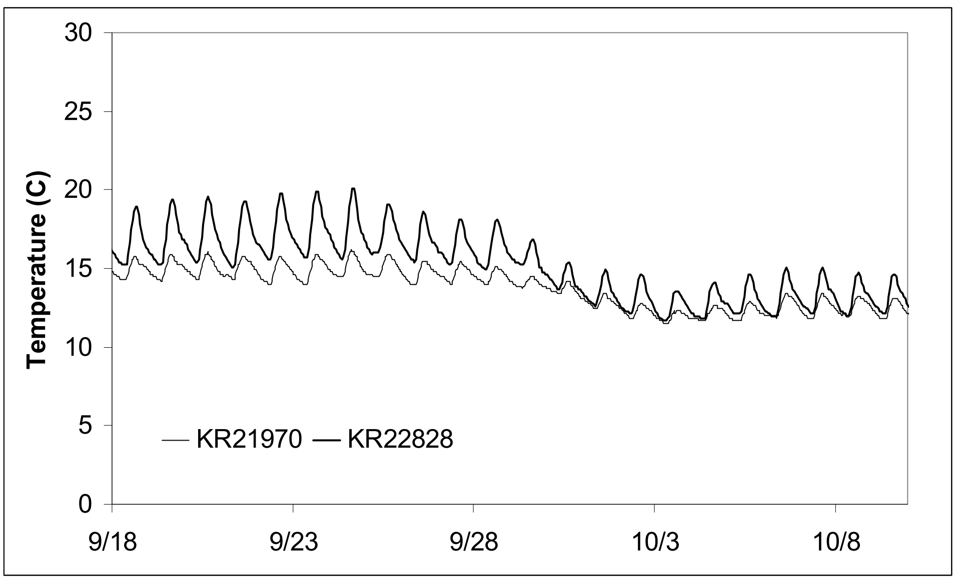


Figure 3.7-7a and 3.7-7b. Water temperatures measured above and below the J.C. Boyle powerhouse during peaking operation (top) and during nonpeaking flow (bottom) in 2002. KR22828 (upper curve in both plots) – Klamath River above J. C. Boyle reservoir, KR21970 (lower curve) – Klamath River at the USGS gauge below J.C. Boyle dam. (Source: USBR – 2002 data)

The interaction of varying discharge and travel time has an effect on the diurnal water temperature pattern at the downstream end of the J.C. Boyle peaking reach. Figure 3.7-8 shows the diurnal water temperature cycle measured in the peaking reach just upstream from Copco reservoir (KR20300, angler access 2) during peaking operation (July 1-5) and during constant daily discharge (October 1-5). The "notch" in the July curve between approximately 1:00 p.m. and 6:00 p.m. marks the arrival at the site of cooler water leaving the J.C. Boyle bypass reach when flow through the power turbines is shut off. That pattern is absent from the site during constant discharge operations in October. However, by October, temperatures in the river are similar to those in the bypass reach, which may make such a pattern more difficult to discern.

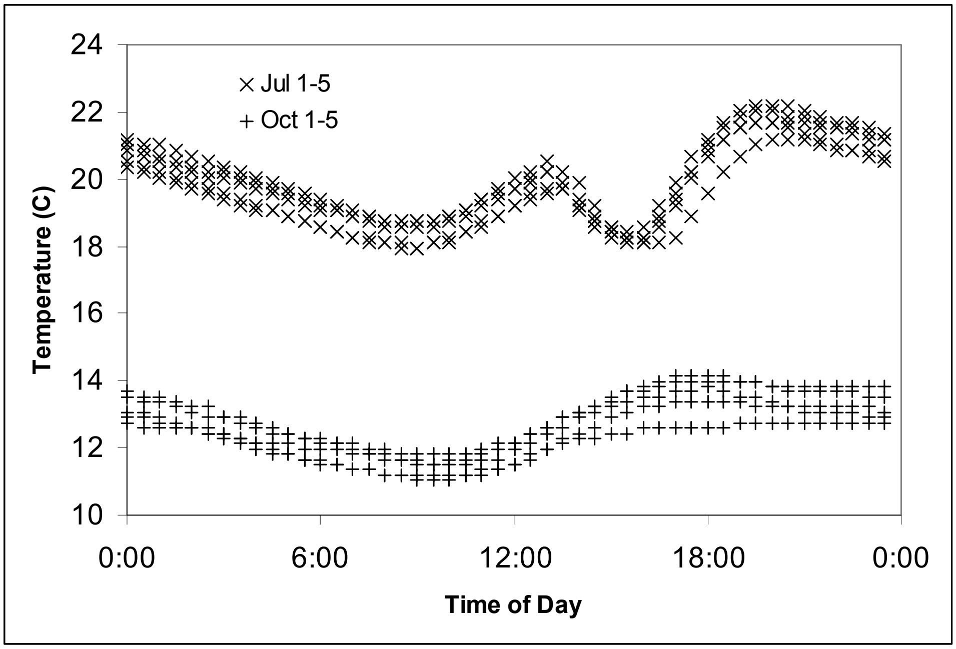


Figure 3.7-8. Water temperatures measured in the Klamath River above Shovel Creek (KR20645) during periods of peaking operation (July, top) and during nonpeaking discharge (October, bottom) in 2002.

3.7.2 Dissolved Oxygen

DO measurements were made during each site visit, using multiparameter water quality data sondes (YSI or Hyrolab). Vertical profiles of DO concentration were measured in the Project reservoirs during each sampling event.

DO concentration measured during site visits ranged from 0 to 17.1 mg/L during the period of data collection The median concentration of all samples was 7.8 mg/L (mean = 7.0 mg/L). This is low compared to the 8- to 10-mg/L range of saturation concentration that would be expected. DO concentrations are relatively high, near saturation, during the winter months with little variability. During the spring and summer months, however, DO concentration varies widely among the sites from completely anoxic to supersaturated (Figure 3.5-9). Detailed summaries of DO data are included in Appendices 3B and 3C.

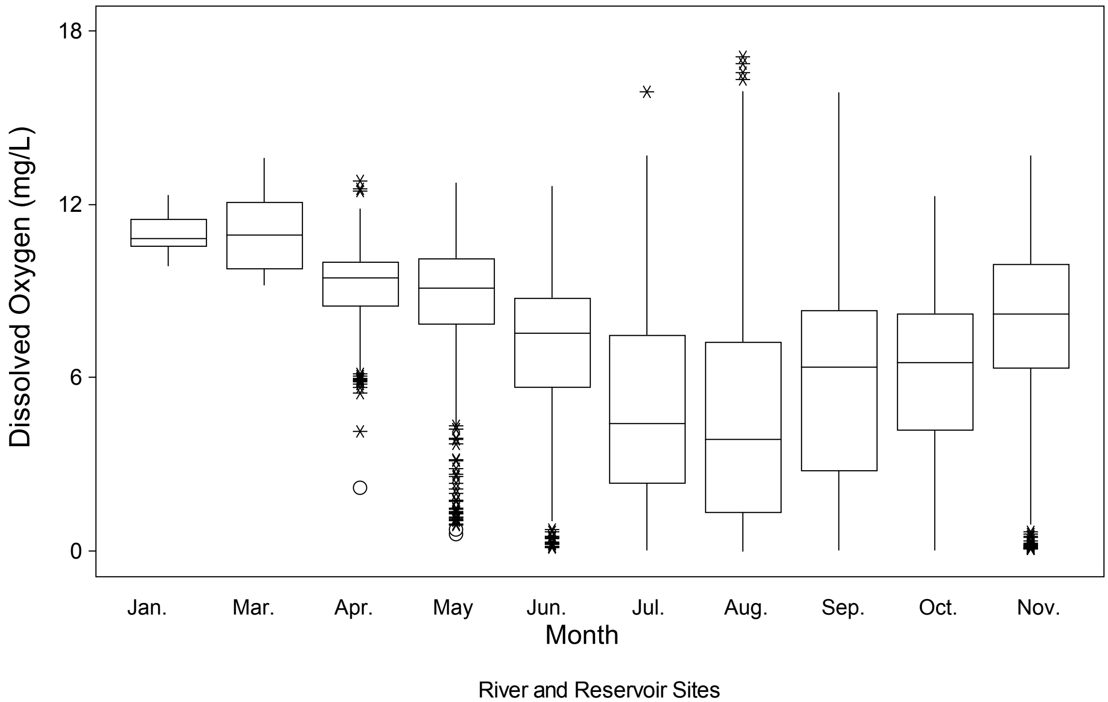


Figure 3.7-9. Box plot showing the distribution by month of DO concentration measured during regular sampling visits at river and reservoir sites in the Project area during 2000-2003.

The distribution of DO values by location is presented in Figure 3.7-10. The median values for DO are greater than 8 mg/L for most sites, with the exception of sites between the mouth of Link River and Keno dam. The sites in Lake Ewauna and Keno reservoir are notable for low median values, a preponderance of low values, and minimum concentrations of 0 mg/L. The site in the Klamath River near the Miller Island boat ramp (KR24589), with a median DO concentration of 4.3 mg/L, appears to be especially low relative to the other river sites.[3] Two sites in J.C. Boyle reservoir, KR22478 (near the dam) and KR22505 (at the deepest point), also exhibit occasional low DO concentration.

Copco and Iron Gate reservoirs experience low DO at depth during the period of stratification as the deeper water becomes depleted in oxygen and the surface waters become supersaturated, as shown in Figure 3.7-11. J.C. Boyle reservoir undergoes occasional episodes of reduced DO concentration. DO varies throughout the day in response to changes in ambient temperature, photosyntheses by aquatic plants, and respiration by aquatic organisms. Figure 3.7-12 shows the results of a short-term monitoring event during July 2002. DO concentration was recorded hourly for 3 days at several sites in the Project area. Site KR22822 (Klamath River above J.C. Boyle reservoir) represents the daily pattern typical of the river sites; site PC00 is in the tailrace from the J.C. Boyle powerplant. Site KR19874, Copco Reservoir (2 m depth), represents the changes that occur in the epilimnion of a productive reservoir.

[3] Data from the site near the Miller Island boat ramp may not be representative of ambient conditions. Water at the site was frequently disturbed by boat action, mixing bottom sediment into the water column (Cameron, 2003, pers. comm.).

DO concentration in the river above J.C. Boyle Reservoir (KR22822) varies between approximately 5.7 mg/L and 6.7 mg/L in a fairly regular cycle, with higher values during daylight hours as a result of the production of oxygen by photosynthetic organisms. The measured concentrations are approximately 75 percent of the saturation values at this site. Site PC00 exhibits changes in DO concentration as a function of powerplant operation. When the plant is offline, typically at night, there is less flow at the site and oxygen is depleted through respiratory activity of aquatic organisms. When water begins flowing, DO concentration rises. In Copco reservoir (KR19874), photosynthesis by abundant phytoplankton produces supersaturated conditions for DO during the day. Changes resulting from shading by clouds and occasional and irregular winds produce an irregular pattern of DO concentration. Diurnal changes in DO are discussed in more detail in Section 4.0 (Appendix 4A).

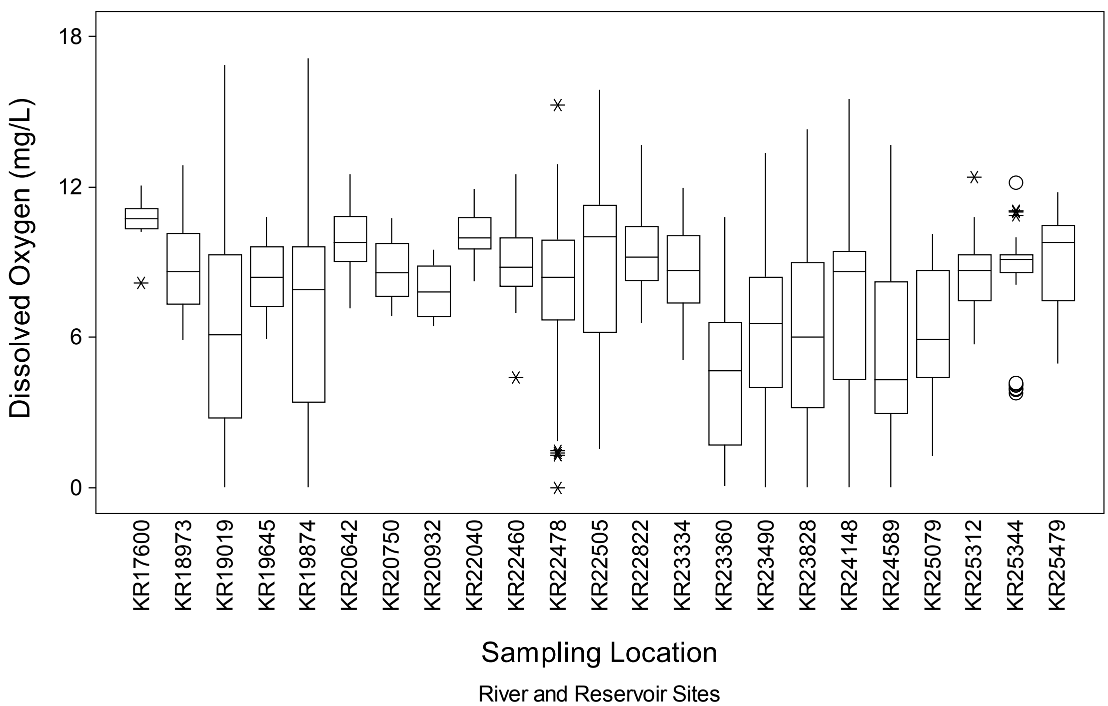


Figure 3.7-10. Plot showing distribution by location of DO concentration measured during regular sampling visits at river and reservoir sites in the Project area during 2000-2003. KR17600 – Klamath River upstream of Shasta River, KR18973 – Iron Gate dam outflow, KR19019 – Iron Gate reservoir near Hornbrook, KR19645 – Copco dam outflow, KR19874 – Copco Lake near Copco, KR20642 – Klamath River upstream of Shovel Creek, KR20750 – Klamath River above Copco, KR20932 – Klamath River near Stateline, KR22040 – J.C. Boyle bypass (bottom), KR22460 – Klamath River below J.C. Boyle dam, KR22478 – J.C. Boyle reservoir at log boom, KR22505 – J.C. Boyle reservoir at deepest point, KR22822 – Klamath River above J.C. Boyle reservoir, KR23334 – Klamath River below Keno dam, KR23360 – Keno reservoir at log boom, KR23490 – Klamath River at Keno Bridge (Hwy. 66), KR23828 – Klamath River directly south of Hill 4315, KR24148 – Klamath River upstream of Klamath Straits Drain, KR24589 – Klamath River at Miller Island boat ramp, KR25079 – Klamath River at South-Side Bypass bridge, KR25312 – Link River at mouth, KR25344 – Link River near powerhouse, KR25479 – Upper Klamath Lake at Fremont St. Bridge.

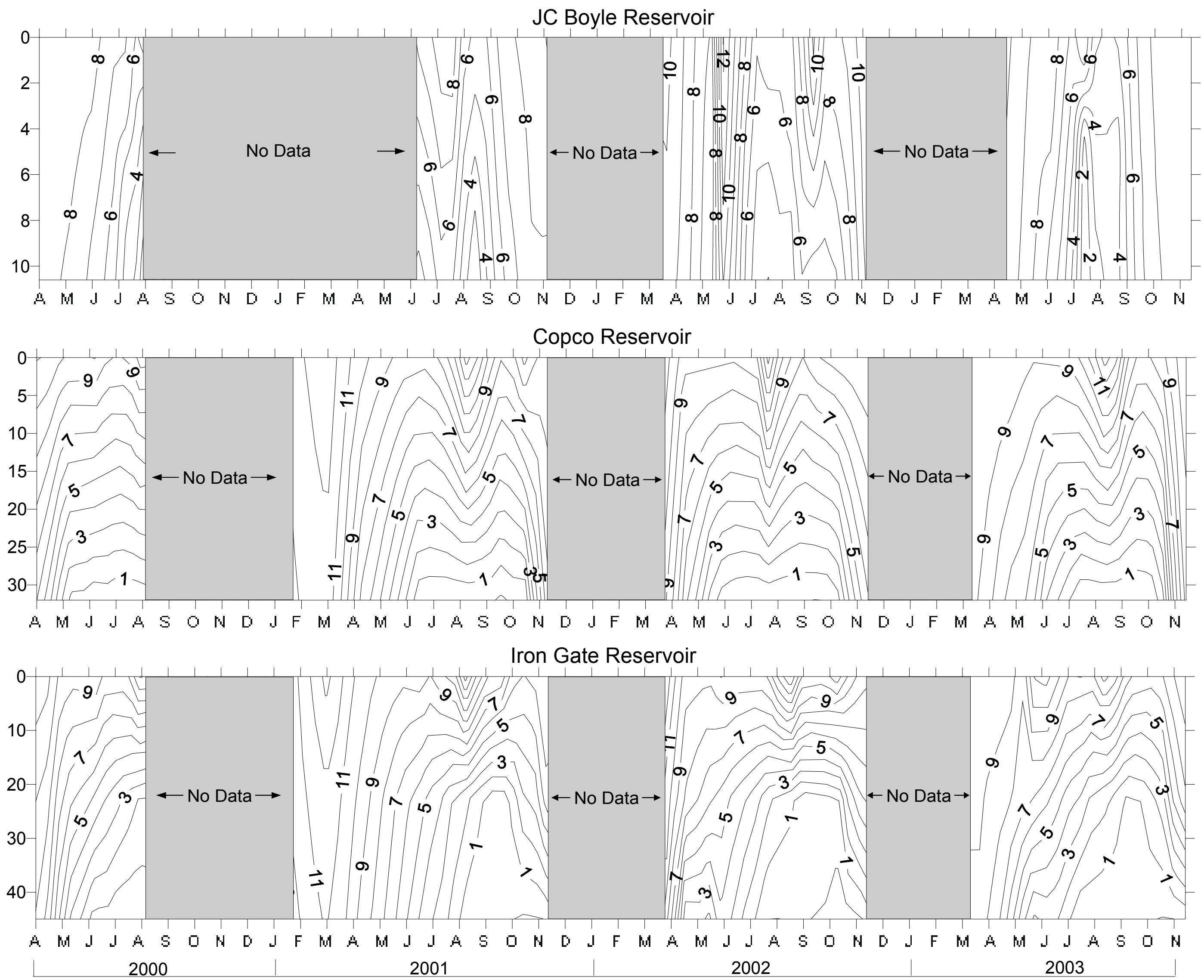


Figure 3.7-11. Isopleth diagram of DO for J. C. Boyle, Copco, and Iron Gate reservoirs for 2000-2003 showing the effects of thermal stratification on DO values.

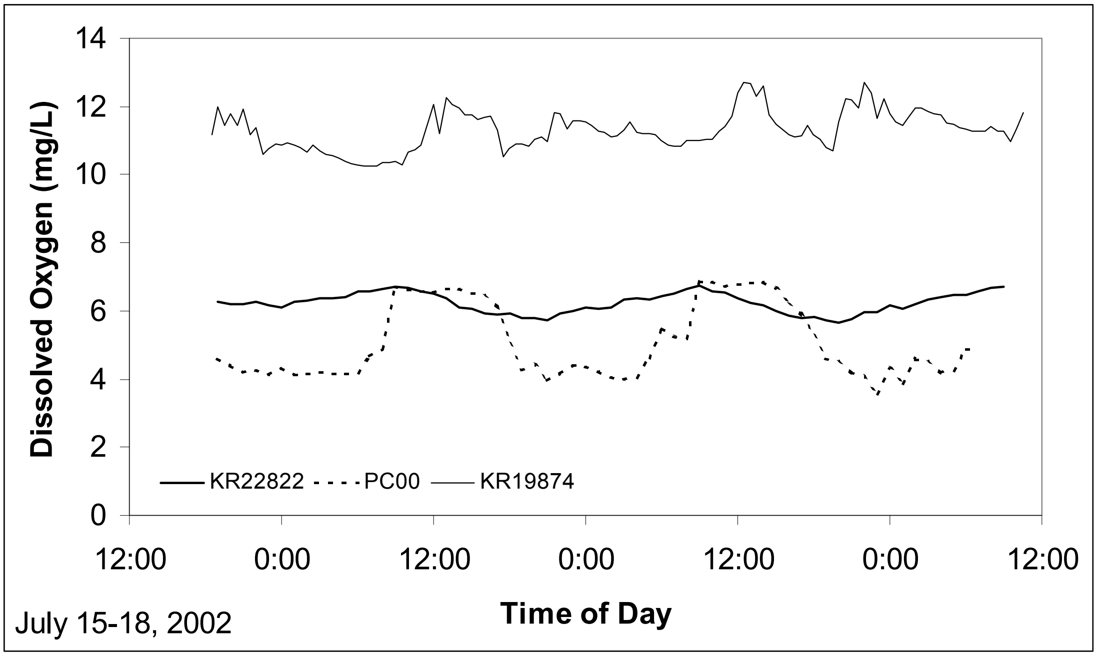


Figure 3.7-12. DO concentration measured hourly during July 2002 above J. C. Boyle Reservoir (KR22822, middle solid line), in the tailrace of J. C. Boyle powerhouse (PC00), and near the surface of Copco reservoir (KR19874).

3.7.3 Oxidation-Reduction Potential

Measurements of oxidation-reduction potential[4] were made during each site visit using multiparameter water quality data sondes (YSI or Hydrolab) to collect grab sample information at river sites and vertical profiles in the Project reservoirs. Values for ORP at all sites (n = 1904) ranged from -300 to 604 mv, with a median value of 159 mv and a mean of 152 mv.

Several sites exhibit ORP values approaching or exceeding -100 mv,[5] in particular Iron Gate, Copco, and J.C. Boyle reservoirs, and at several locations in Keno reservoir (Figure 3.7-13a). Low ORP conditions are most prevalent during mid- to late summer (Figure 3.7-13b). When plotted against depth (Figure 3.7-14), negative ORP values resolve into four groups.

- Negative ORP at depths less than approximately 5 meters (m) are from Lake Euwana and Keno reservoir.
- Values near 10 m are from J.C. Boyle reservoir.
- Values at 18 to 30 m are from Copco reservoir.
- Values at depths greater than 40 m are from Iron Gate reservoir.

[4] Oxidation is a process in which molecules or ions lose electrons. Reduction is a process by which electrons are gained. The measurement of the potential for these processes to occur is called oxidation-reduction potential (ORP).

[5] Such ORP values can promote release of phosphorus from sediments and favor presence of ammonia nitrogen.

Negative ORP appears to be fairly common at several depths in Keno and Copco reservoirs but occurs only rarely in the deepest part of Iron Gate reservoir.

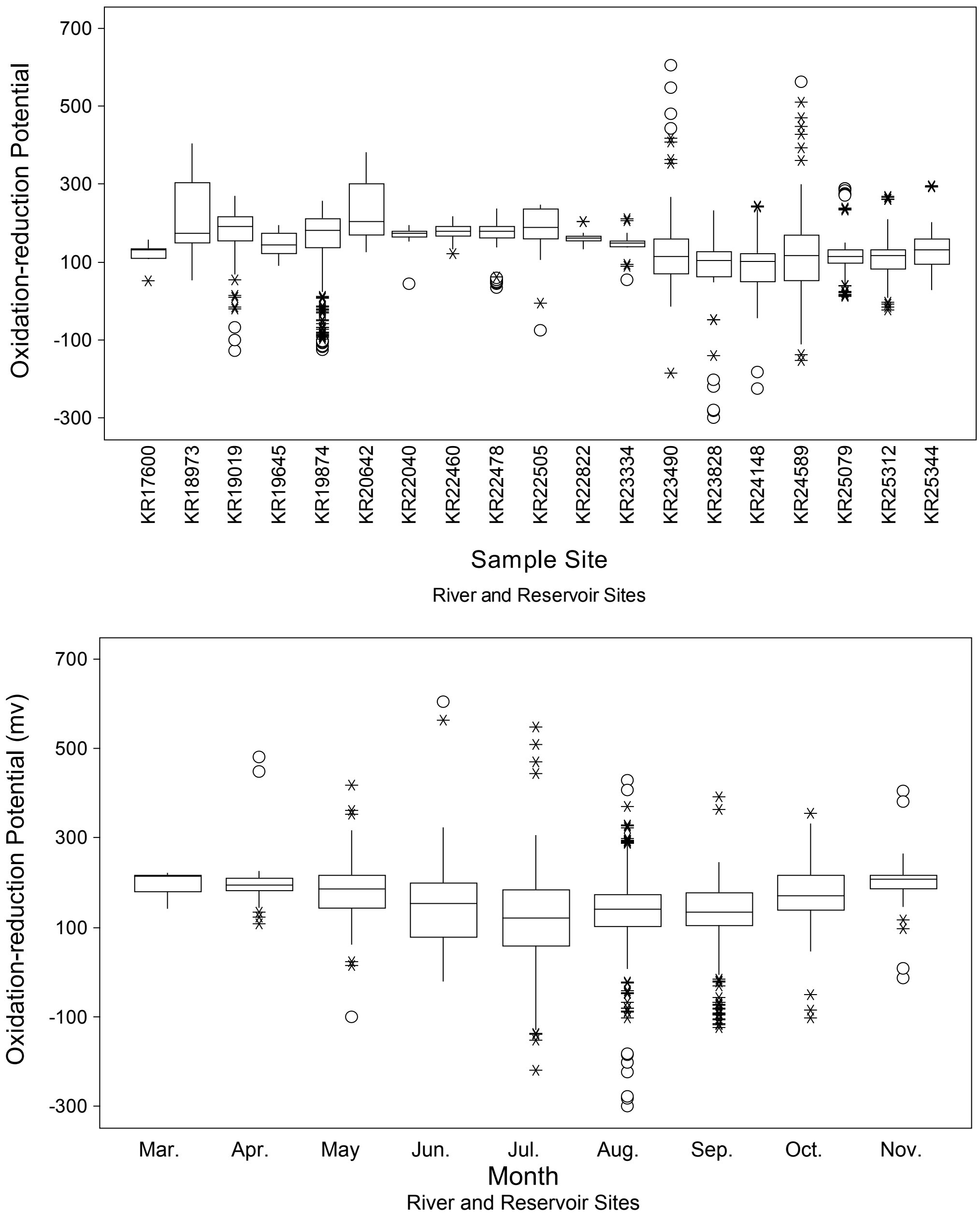


Figure 3.7-13. Box plot showing the distribution by location (top) and month (bottom) of values of ORP potential measured during regular sampling visits at river and reservoir sites in the Project area during 2000-2003. Month 1 = January, 2 = February, etc.) KR17600 – Klamath River upstream of Shasta River, KR18973 – Iron Gate dam outflow, KR19019 – Iron Gate reservoir near Hornbrook, KR19645 – Copco dam outflow, KR19874 – Copco Lake near Copco, KR20642 – Klamath River upstream of Shovel Creek, KR22040 – J.C. Boyle bypass (bottom), KR22460 – Klamath River below J.C. Boyle dam, KR22478 – J.C. Boyle reservoir at log boom, KR22505 – J.C. Boyle reservoir at deepest point, KR22822 – Klamath River above J.C. Boyle reservoir, KR23334 – Klamath River below Keno dam, KR23490 – Klamath River at Keno Bridge (Hwy. 66), KR23828 – Klamath River directly south of Hill 4315, KR24148 – Klamath River upstream of Klamath Straits Drain, KR24589 – Klamath River at Miller Island boat ramp, KR25079 – Klamath River at South-Side Bypass bridge, KR25312 – Link River at mouth, KR25344 – Link River near powerhouse.

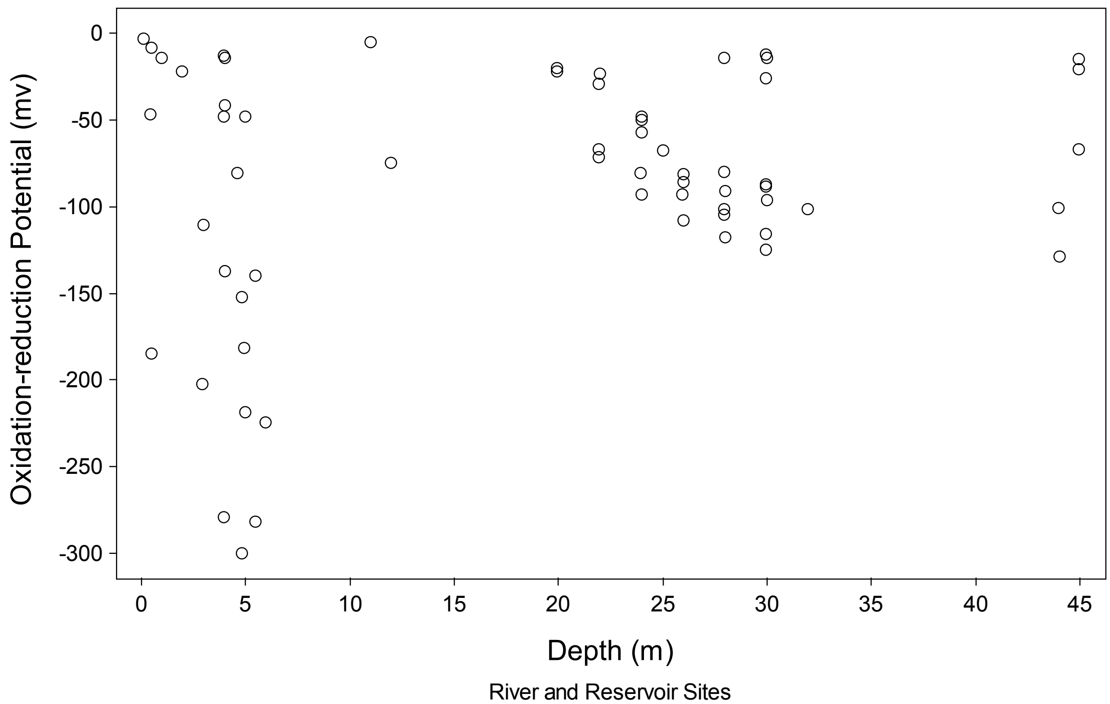


Figure 3.7-14. The depth of occurrence of negative ORP values measured in the Project area. Depths less than 10 m are from Lake Ewauna and Keno reservoir, depths between 10 and 20 m are from J.C. Boyle reservoir, depths between 20 and 35 m are from Copco reservoir, and depths greater than 35 m from Iron Gate reservoir.

3.7.4 pH

Measurements of pH were made during each site visit using multiparameter water quality data sondes (YSI or Hydrolab) to collect grab sample information at river sites and vertical profiles in the Project reservoirs. Values at all sites for pH ranged from 4.6—a very low value, possibly due to measurement error—to 9.9, with a median of 7.83 and a mean of 7.89. Detailed summaries of pH are provided in Appendices 3B and 3C.

As shown in Figure 3.7-15, pH varies among and within the river sites. Sites in Upper Klamath Lake and Link River (KR25479, KR25344, KR25312) have somewhat higher pH than other sites, while pH at sites above Keno dam are more variable than sites below it. There can be a diurnal component in pH values as a result of photosynthetic activity. Figure 3.7-16 demonstrates this diurnal cycle, as recorded from May 22 through May 24, 2002, in the Klamath River just upstream from J.C. Boyle reservoir (KR22822). There can also be a seasonal component to pH values, especially at locations strongly influenced by aquatic plants. In productive systems, pH tends to be higher during the summer months. This can be seen in the epilimnion of the reservoir, as shown in Figure 3.7-17, where months when algal blooms occur (typically March, May, and August) have higher median pH than in neighboring months. Thermal stratification during the summer in Copco and Iron Gate reservoirs allows a stable gradient of pH with depth to develop (Figure 3.7-18).

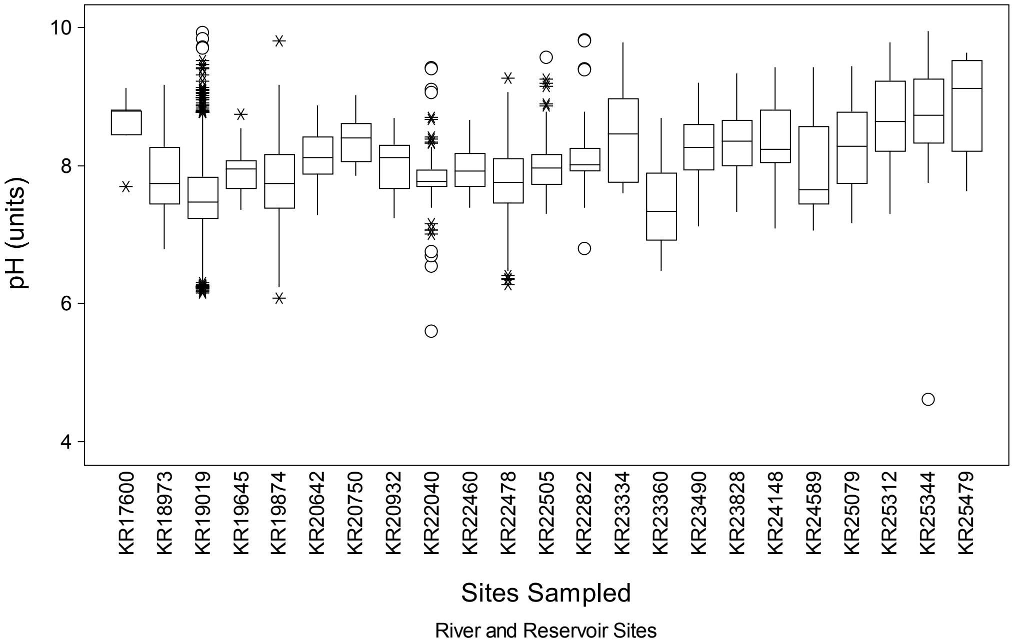


Figure 3.7-15. Box plot showing the distribution by site of pH values measured in the Project area during 2000-2003. KR17600 – Klamath River upstream of Shasta River, KR18973 – Iron Gate dam outflow, KR19019 – Iron Gate reservoir near Hornbrook, KR19645 – Copco dam outflow, KR19874 – Copco Lake near Copco, KR20642 – Klamath River upstream of Shovel Creek, KR20750 – Klamath River above Copco, KR20932 – Klamath River near stateline, KR22040 – J.C. Boyle bypass (bottom), KR22460 – Klamath River below J.C. Boyle dam, KR22478 – J.C. Boyle reservoir at log boom, KR22505 – J.C. Boyle reservoir at deepest point, KR22822 – Klamath River above J.C. Boyle reservoir, KR23334 – Klamath River below Keno dam, KR23360 – Keno reservoir at log boom, KR23490 – Klamath River at Keno Bridge (Hwy. 66), KR23828 – Klamath River directly south of Hill 4315, KR24148 – Klamath River upstream of Klamath Straits Drain, KR24589 – Klamath River at Miller Island boat ramp, KR25079 – Klamath River at South-Side Bypass bridge, KR25312 – Link River at mouth, KR25344 – Link River near powerhouse, KR25479 – Upper Klamath Lake at Fremont St. Bridge.

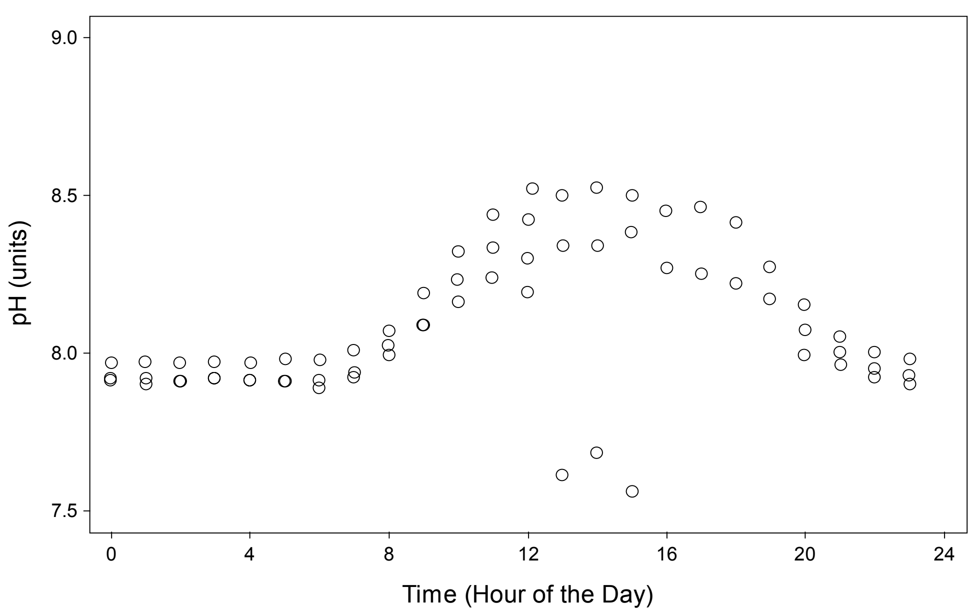


Figure 3.7-16. Diurnal variation in pH measured in the Klamath River upstream of J.C. Boyle reservoir (KR22822) during May 22-24, 2002. Low values near 7.5 were recorded when the instrument was out of the water.

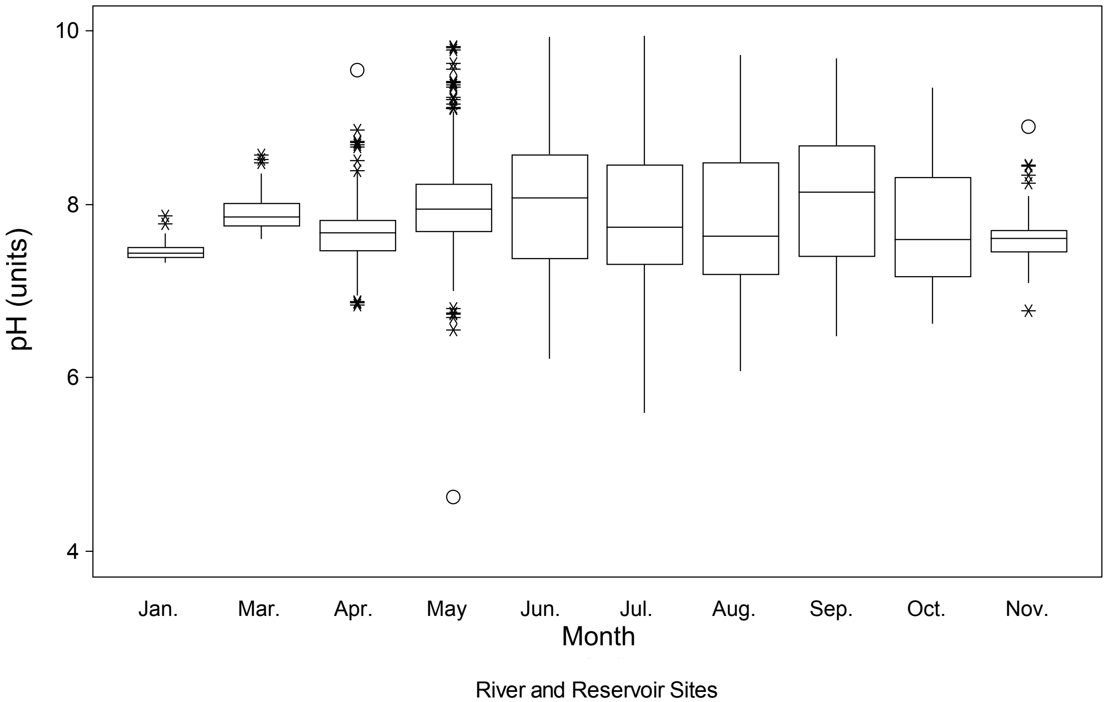


Figure 3.7-17. Box plot showing the distribution by month of pH values measured in the Project area during 2000-2003.

3.7.5 Specific Conductance

Conductivity, or specific conductance (corrected to 25°C), is an indirect measure of the amount of dissolved solids in the water. It was measured during each site visit using data sondes to collect grab sample information at river sites and vertical profiles in the Project reservoirs. For consistency in interpretation, values recorded in the field as conductivity (not automatically corrected for temperature) were corrected to 25°C. Specific conductance values at all sites ranged from 46 microSiemens per centimeter (µS/cm) to 1,046 µS/cm, with a mean of 188 µS/cm and a median of 173 µS/cm. Detailed summaries of specific conductance data are included in Appendices 3B and 3C.

Specific conductance does not vary systematically by season, but does vary by site. Figure 3.7-19 shows box plots of specific conductance at river and reservoir sites collected in 2000 through 2003. Specific conductance of water entering the Project from Klamath Lake is relatively low, but it increases noticeably downstream from the mouth of Klamath Straits Drain (RM 240). This reflects the influence of water from Klamath Straits Drain (median specific conductance = 888 µS/cm). Several locations exhibit anomalous values for specific conductance. Site KR23360, at the log boom above Keno dam is unusually low and constant relative to nearby sites, as is site KR22040, at the bottom of the J.C. Boyle bypass reach. Specific conductance was measured at site KR23360 only during 2001, a year when water diversion to the Project was severely restricted and specific conductance throughout the system was relatively low (Figure 3.7-20). Site KR22040 reflects the influence of groundwater and the lack of Klamath River water flowing in the bypass reach.

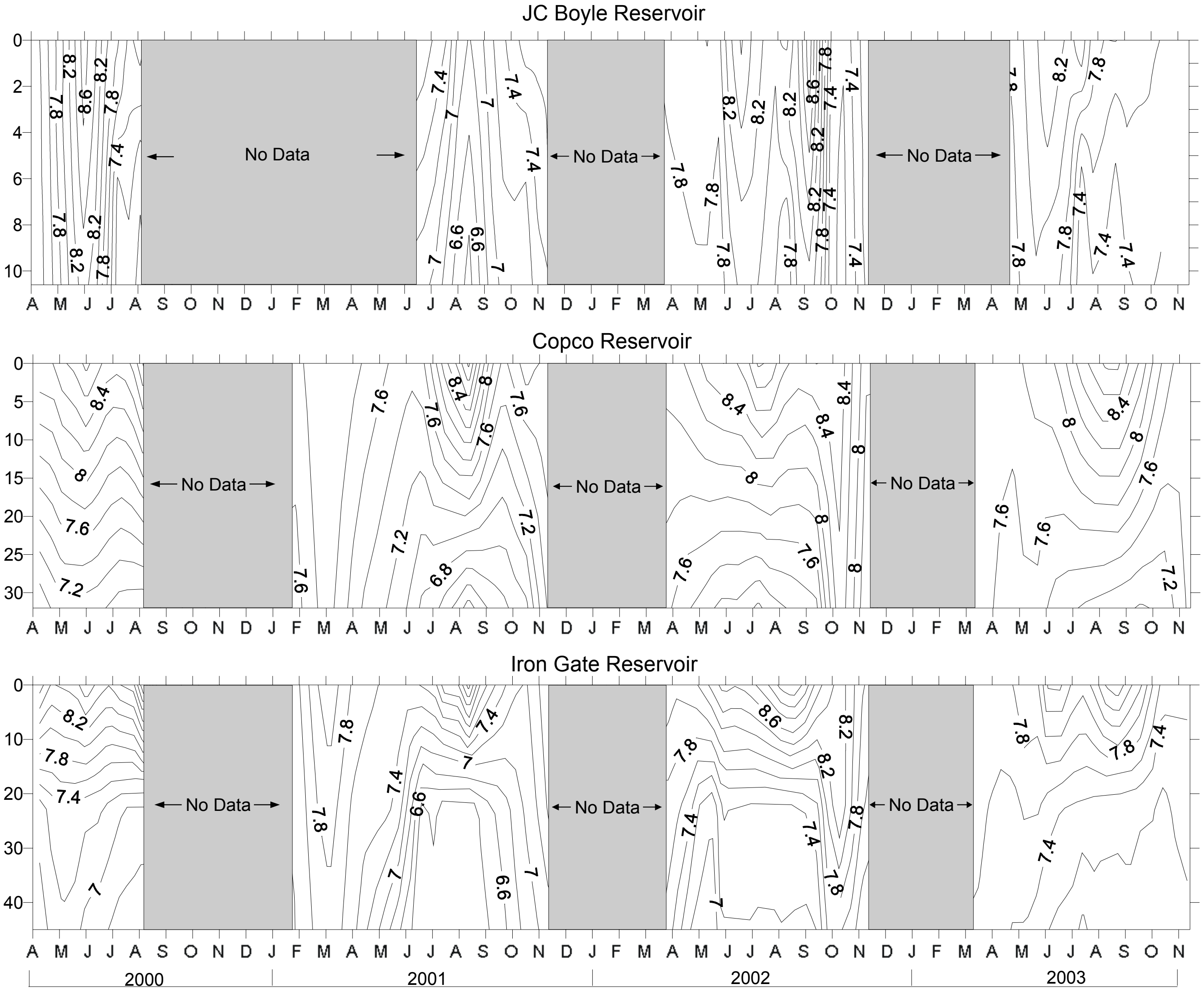


Figure 3.7-18. Isopleth diagram of pH for J. C. Boyle, Copco, and Iron Gate reservoirs for 2000-2003, showing the effects of thermal stratification on DO values.

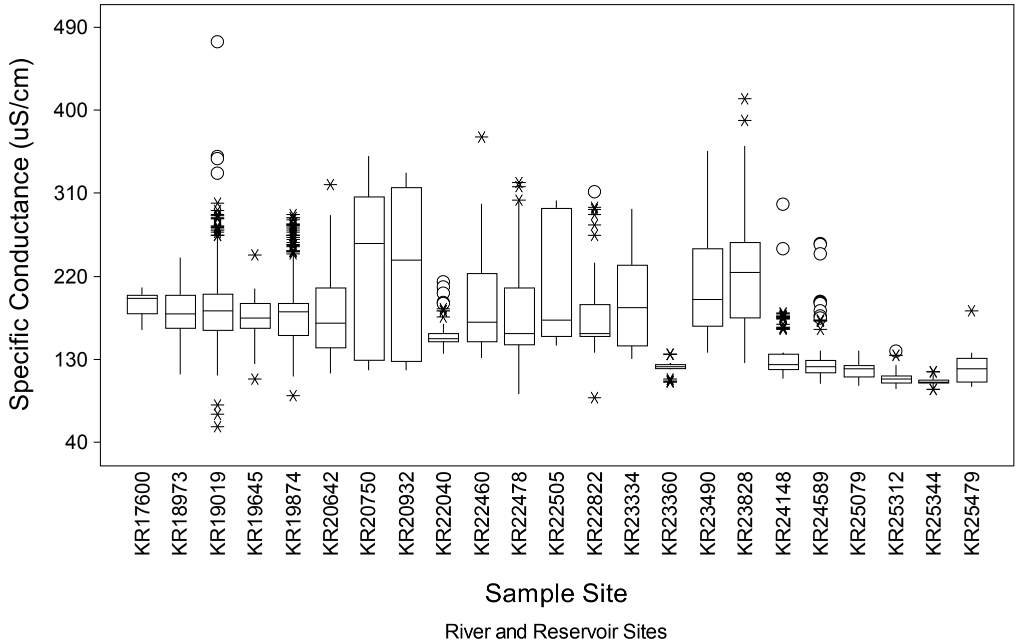


Figure 3.7-19. Box plot showing the distribution by month of specific conductance values measured in the Project area during 2000-2003. KR17600 – Klamath River upstream of Shasta River, KR18973 – Iron Gate dam outflow, KR19019 – Iron Gate reservoir near Hornbrook, KR19645 – Copco dam outflow, KR19874 – Copco Lake near Copco, KR20642 – Klamath River upstream of Shovel Creek, KR20750 – Klamath River above Copco, KR20932 – Klamath River near stateline, KR22040 – J.C. Boyle bypass (bottom), KR22460 – Klamath River below J.C. Boyle dam, KR22478 – J.C. Boyle reservoir at log boom, KR22505 – J.C. Boyle reservoir at deepest point, KR22822 – Klamath River above J.C. Boyle reservoir, KR23334 – Klamath River below Keno dam, KR23360 – Keno reservoir at log boom, KR23490 – Klamath River at Keno Bridge (Hwy. 66), KR23828 – Klamath River directly south of Hill 4315, KR24148 – Klamath River upstream of Klamath Straits Drain, KR24589 – Klamath River at Miller Island boat ramp, KR25079 – Klamath River at South-Side Bypass bridge, KR25312 – Link River at mouth, KR25344 – Link River near powerhouse, KR25479 – Upper Klamath Lake at Fremont St. Bridge.

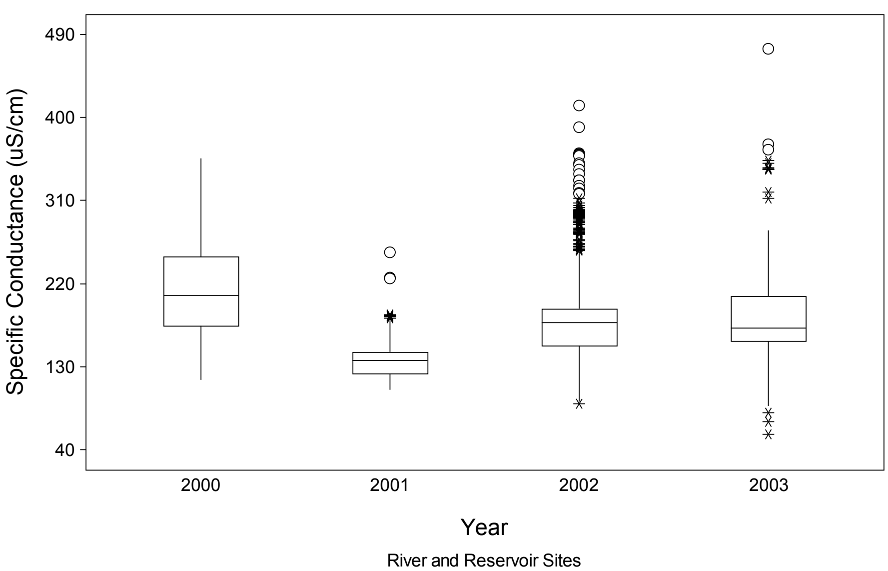


Figure 3.7-20. Box plot showing the distribution by year of specific conductance values measured at all sites in the Project area during 2000-2003.

3.7.6 Nutrients

Measurements for nitrogen and phosphorus were made by a commercial laboratory on samples collected during each site visit. Samples were analyzed for nitrate nitrogen (NO_3), ammonia nitrogen (NH_3), total Kjeldahl nitrogen, orthophosphate phosphorus (PO_4), and total phosphorus (PT). Detailed summaries of nutrient data are presented in Appendices 3B and 3C.

3.7.7 Phosphorus

Values for total phosphorus (n = 689) ranged from non-detect (< 0.027 mg/L as P) to 1.35 mg/L as P, with a median of 0.21 mg/L and a mean of 0.26 mg/L. Orthophosphate phosphorus (n = 683) ranged from non-detect (< 0.011 mg/L as P) to 0.94 mg/L, with a median of 0.14 mg/L and a mean of 0.168 mg/L.

Total phosphorus concentrations in water entering Lake Ewauna from Link River are relatively low compared to other sites in the Project (Figure 3.7-21). Median phosphorus concentrations increase noticeably at sites in Keno reservoir downstream from the mouth of Klamath Straits Drain (RM 240), which has a higher median total phosphorus concentration (0.42 mg/L) than the other river and reservoir sites. Median values of total phosphorus concentration downstream of the J.C. Boyle bypass reach (RM 220.4) are slightly lower than those in Link River.

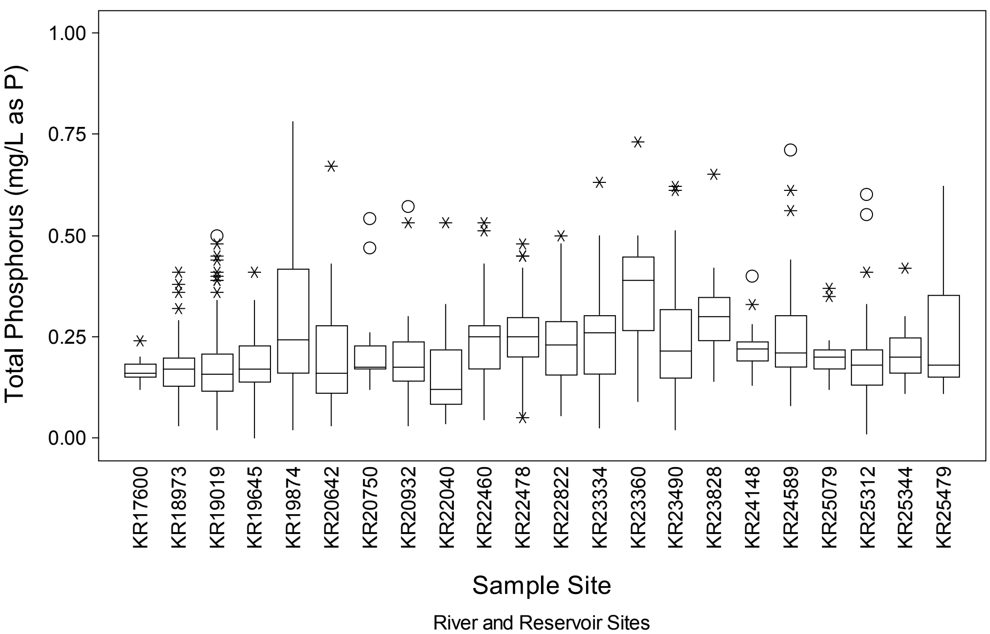


Figure 3.7-21. Box plot showing the distribution by site of total phosphorus values measured in the Project area during 2000-2003. KR17600 – Klamath River upstream of Shasta River, KR18973 – Iron Gate dam outflow, KR19019 – Iron Gate reservoir near Hornbrook, KR19645 – Copco dam outflow, KR19874 – Copco Lake near Copco, KR20642 – Klamath River upstream of Shovel Creek, KR20750 – Klamath River above Copco, KR20932 – Klamath River near stateline, KR22040 – J.C. Boyle bypass (bottom), KR22460 – Klamath River below J.C. Boyle dam, KR22478 – J.C. Boyle reservoir at log boom, KR22822 – Klamath River above J.C. Boyle reservoir, KR23334 – Klamath River below Keno dam, KR23360 – Keno reservoir at log boom, KR23490 – Klamath River at Keno Bridge (Hwy. 66), KR23828 – Klamath River directly south of Hill 4315, KR24148 – Klamath River upstream of Klamath Straits Drain, KR24589 – Klamath River at Miller Island boat ramp, KR25079 – Klamath River at South-Side Bypass bridge, KR25312 – Link River at mouth, KR25344 – Link River near powerhouse, KR25479 – Upper Klamath Lake at Fremont St. Bridge.

There appears to be a seasonal trend in total phosphorus concentration, with values during the summer months being somewhat higher than those during the winter (Figure 3.7-22). March has been omitted from the plot because samples were collected for total phosphorus only in 2002.

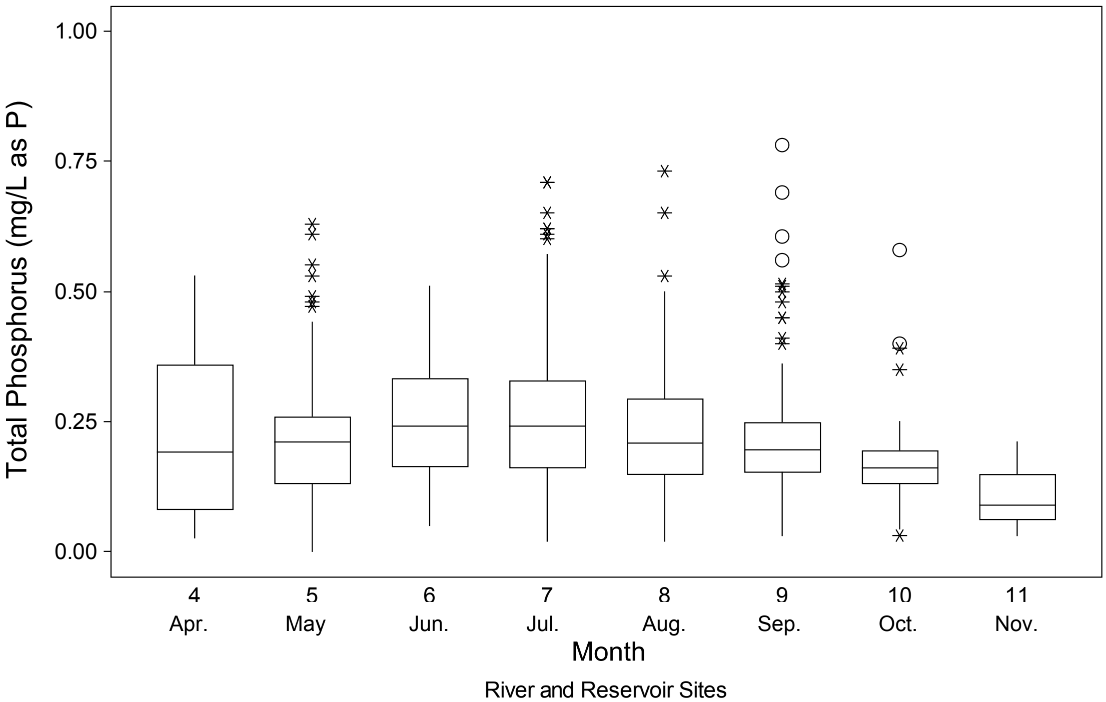


Figure 3.7-22. Box plot showing the distribution by month of total phosphorus values measured in the Project area during 2000-2003.

Orthophosphate concentrations at the river sites are generally lower than total phosphorus concentrations. The pattern of orthophosphate concentration between sites is similar to that of total phosphorus, except that orthophosphate concentration does not appear to decrease below J.C. Boyle dam (KR22460) (Figure 3.7-23).

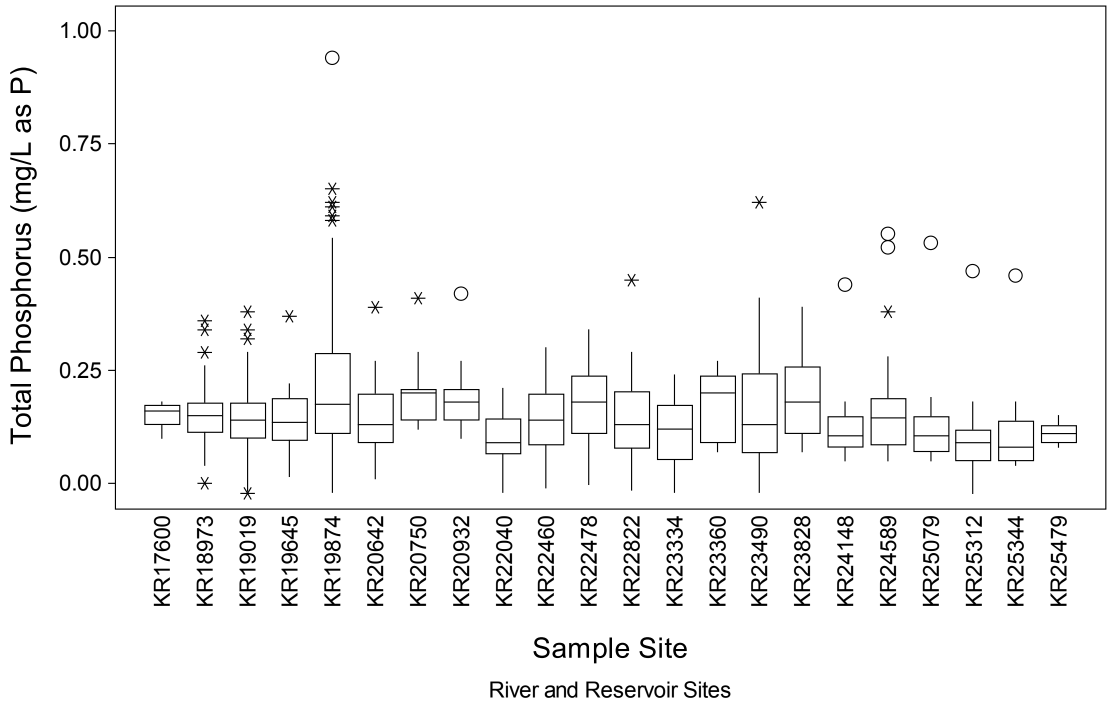


Figure 3.7-23. Box plot showing the distribution by site of orthophosphate phosphorus values measured in the Project area during 2000-2003. KR17600 – Klamath River upstream of Shasta River, KR18973 – Iron Gate dam outflow, KR19019 – Iron Gate reservoir near Hornbrook, KR19645 – Copco dam outflow, KR19874 – Copco Lake near Copco, KR20642 – Klamath River upstream of Shovel Creek, KR20750 – Klamath River above Copco, KR20932 – Klamath River near stateline, KR22040 – J.C. Boyle bypass (bottom), KR22460 – Klamath River below J.C. Boyle dam, KR22478 – J.C. Boyle reservoir at log boom, KR22822 – Klamath River above J.C. Boyle reservoir, KR23334 – Klamath River below Keno dam, KR23360 – Keno reservoir at log boom, KR23490 – Klamath River at Keno Bridge (Hwy. 66), KR23828 – Klamath River directly south of Hill 4315, KR24148 – Klamath River upstream of Klamath Straits Drain, KR24589 – Klamath River at Miller Island boat ramp, KR25079 – Klamath River at South-Side Bypass bridge, KR25312 – Link River at mouth, KR25344 – Link River near powerhouse, KR25479 – Upper Klamath Lake at Fremont St. Bridge.

3.7.7.1 Nitrogen

Values for nitrate nitrogen (NO_3, n = 645) ranged from non-detect (< 0.011 mg/L as N) to 2.3 mg/L, with a median of 0.200 mg/L and a mean of 0.320 mg/L. Ammonia nitrogen values (n = 671) were slightly lower, ranging from non-detect (< 0.016 mg/L as N) to 2.47 mg/L, with a median of 0.120 mg/L and a mean of 0.217 mg/L. Total Kjeldahl nitrogen (n = 680) ranged from 0.1 mg/L as N to 5.49 mg/L, with a median of 1.00 mg/L and a mean of 1.24 mg/L. Additional summaries of nitrogen data are provided in Appendices 3B and 3C.

Nitrate nitrogen exhibits low median values at sites from Upper Klamath Lake to below Keno dam (KR23334). Median nitrate concentration, and range of variability, increases noticeably in the Klamath River beginning just above J.C. Boyle reservoir (KR22822) and remains relatively high until below Iron Gate dam (Figure 3.7-24). The pattern of ammonia nitrogen and total Kjeldahl nitrogen is approximately the converse of nitrate nitrogen, with relatively high, variable values at the upstream sites and lower, less variable values at the downstream sites. The range of higher values for NH_3 and TKN extends farther downstream, through J.C. Boyle reservoir to just below J.C. Boyle dam (KR22460). The specific cause of the noticeably higher levels of NH_3 and TKN in Keno reservoir at the log boom (KR23360) is not known.

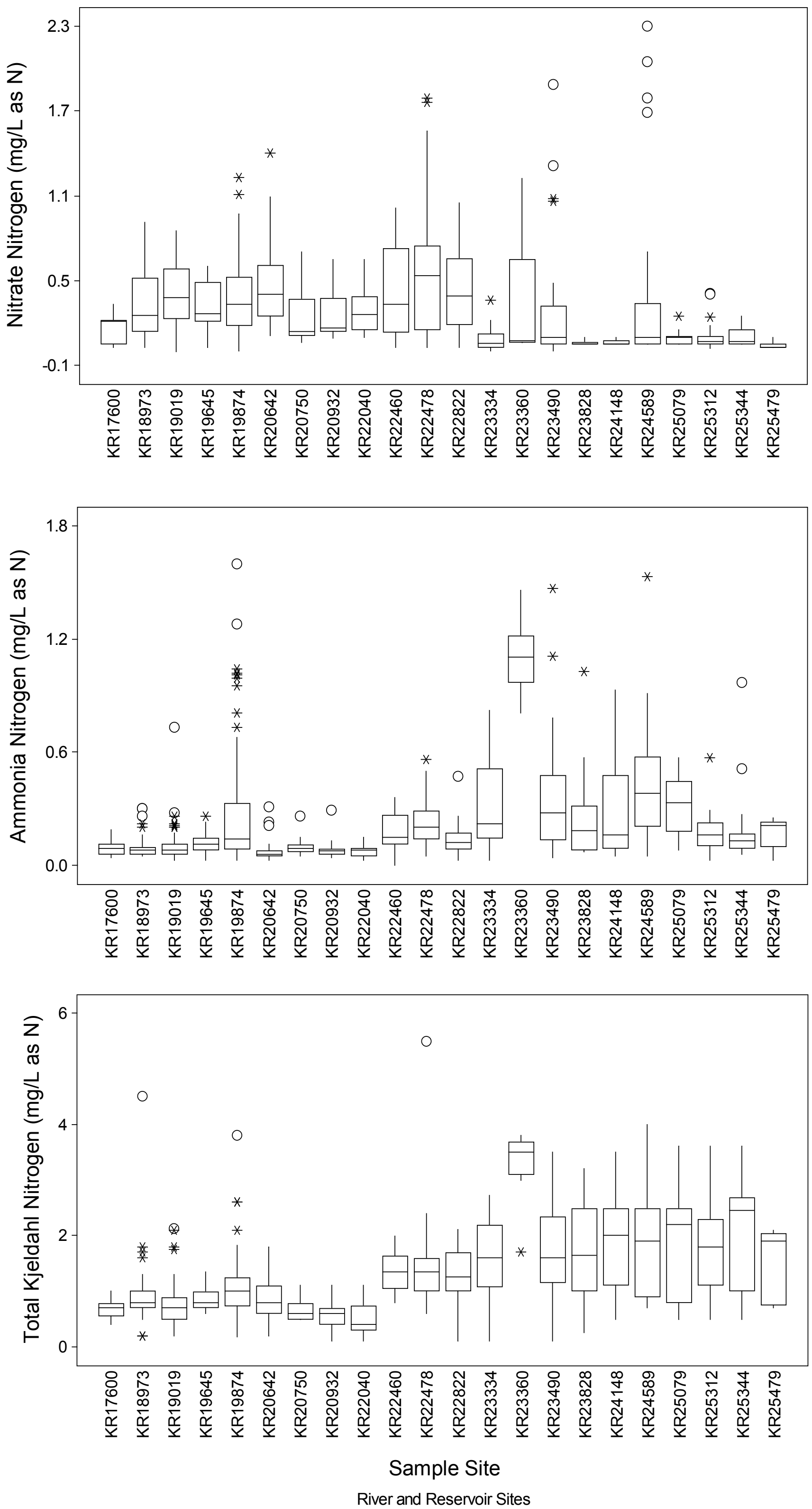


Figure 3.7-24. Box plot showing the distribution by site of nitrogen values measured in the Project area during 2000-2003. KR17600 – Klamath River upstream of Shasta River, KR18973 – Iron Gate dam outflow, KR19019 – Iron Gate reservoir near Hornbrook, KR19645 – Copco dam outflow, KR19874 – Copco Lake near Copco, KR20642 – Klamath River upstream of Shovel Creek, KR20750 – Klamath River above Copco, KR20932 – Klamath River near stateline, KR22040 – J.C. Boyle bypass (bottom), KR22460 – Klamath River below J.C. Boyle dam, KR22478 – J.C. Boyle reservoir at log boom, KR22822 – Klamath River above J.C. Boyle reservoir, KR23334 – Klamath River below Keno dam, KR23360 – Keno reservoir at log boom, KR23490 – Klamath River at Keno Bridge (Hwy. 66), KR23828 – Klamath River directly south of Hill 4315, KR24148 – Klamath River upstream of Klamath Straits Drain, KR24589 – Klamath River at Miller Island boat ramp, KR25079 – Klamath River at South-Side Bypass bridge, KR25312 – Link River at mouth, KR25344 – Link River near powerhouse, KR25479 – Upper Klamath Lake at Fremont St. Bridge.

All three nitrogen species display a general seasonal trend of higher and more variable values in mid- to late summer and lower values in the winter (Figure 3.7-25).

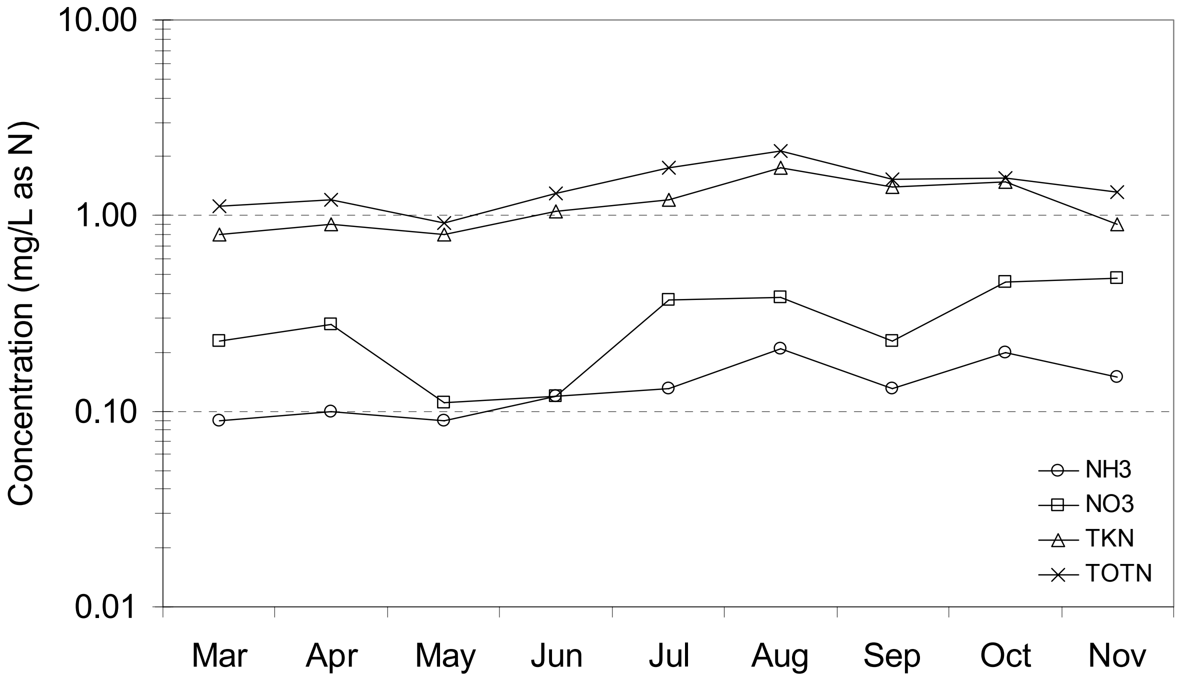


Figure 3.7-25. Monthly medians of nitrogen values measured in the Project area in 2000 through 2003. NO_3 = nitrate nitrogen, NH_3 = ammonia nitrogen, TKN = total Kjeldahl nitrogen, TOTN = total nitrogen (TKN + NO_3).

3.7.8 Chlorophyll *a*

Values for chlorophyll *a* concentration ranged from below detection (< 0.01 μg/L) to 288 μg/L, with a median value of 5.9 μg/L and a mean of 17.6 μg/L for all samples (n = 583). The high mean value relative to the median indicates that the distribution is skewed by several high values. There is a general trend in chlorophyll *a* concentration from extremely high and variable values at the upstream sites (Figure 3.7-26), especially those in Upper Klamath Lake (KR25479) and Link River (KR25344, KR25312), to low values with little variability at the downstream sites.

This is particularly evident when sample sites are grouped geographically by reach (Figure 3.7-27). Sample sites in the larger reservoirs near the dams—Copco (KR19874) and Iron Gate (KR19019)—follow the general trend but have occasional high values, reflecting algal blooms that occur during the year.

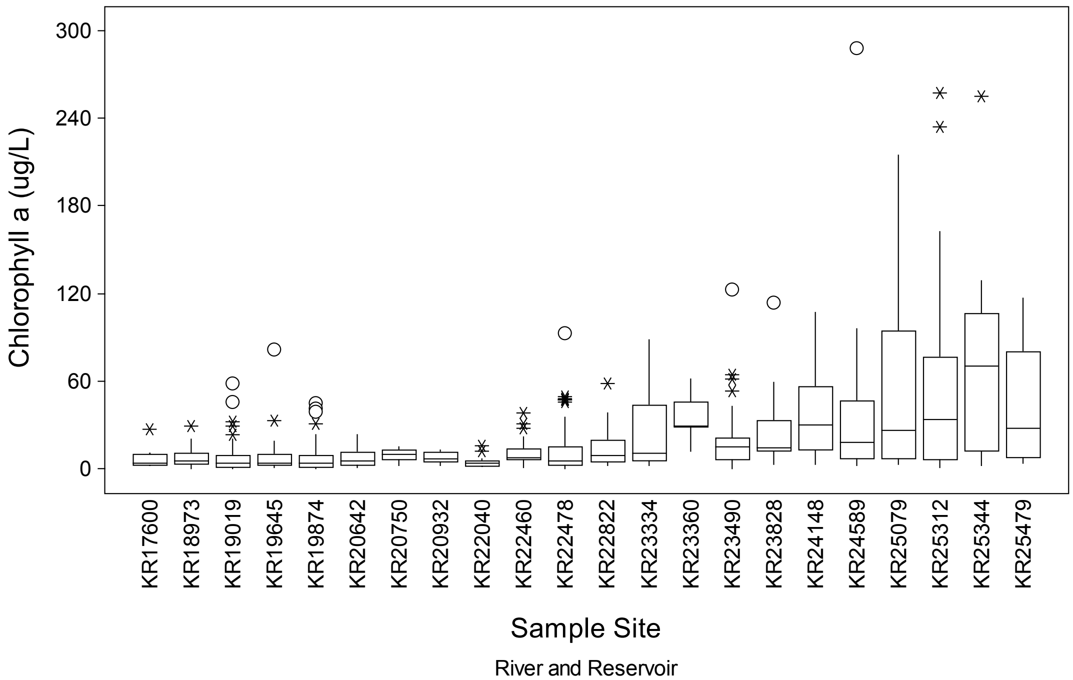


Figure 3.7-26. Box plot showing the distribution by site of chlorophyll *a* values measured at the river sites (top) and in the reservoirs (Copco and Iron Gate, bottom) of the Project area during 2000-2003. KR17600 – Klamath River upstream of Shasta River, KR18973 – Iron Gate dam outflow, KR19019 – Iron Gate reservoir near Hornbrook, KR19645 – Copco dam outflow, KR19874 – Copco Lake near Copco, KR20642 – Klamath River upstream of Shovel Creek, KR20750 – Klamath River above Copco, KR20932 – Klamath River near stateline, KR22040 – J.C. Boyle bypass (bottom), KR22460 – Klamath River below J.C. Boyle dam, KR22478 – J.C. Boyle reservoir at log boom, KR22822 – Klamath River above J.C. Boyle reservoir, KR23334 – Klamath River below Keno dam, KR23360 – Keno reservoir at log boom, KR23490 – Klamath River at Keno Bridge (Hwy. 66), KR23828 – Klamath River directly south of Hill 4315, KR24148 – Klamath River upstream of Klamath Straits Drain, KR24589 – Klamath River at Miller Island boat ramp, KR25079 – Klamath River at South-Side Bypass bridge, KR25312 – Link River at mouth, KR25344 – Link River near powerhouse, KR25479 – Upper Klamath Lake at Fremont St. Bridge.

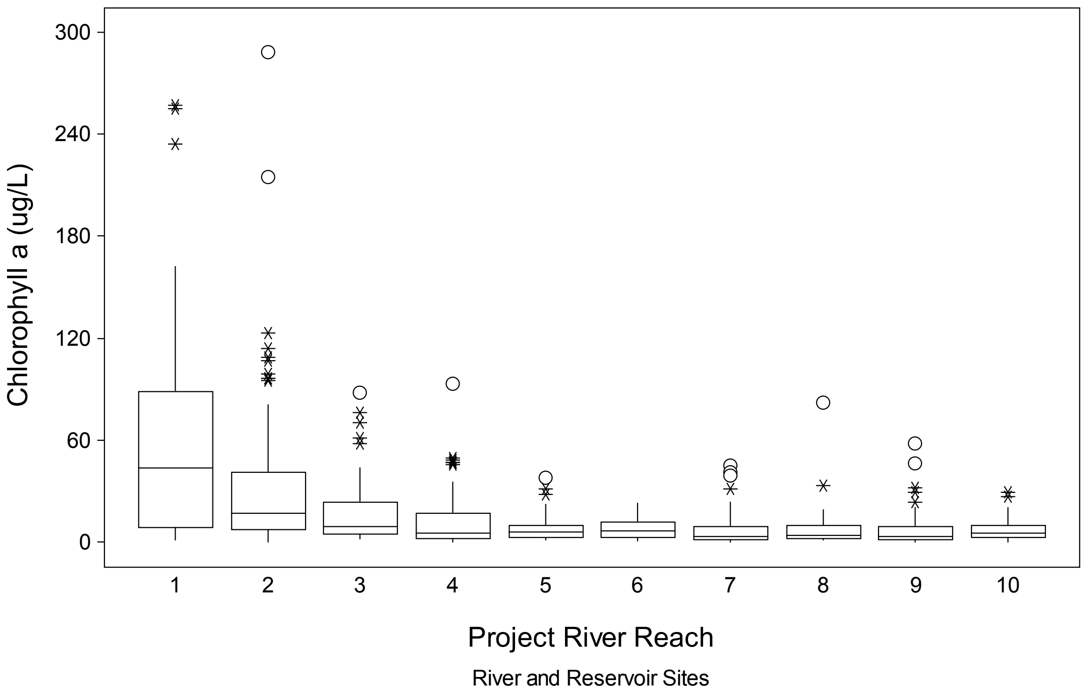


Figure 3.7-27. Box plot showing the distribution by reach of chlorophyll *a* values measured at the river sites (top) and in the reservoirs (Copco and Iron Gate, bottom) of the Project area during 2000-2003. Reach 1 = Link River/Upper Klamath Lake, 2 = Lake Ewauna/Keno, 3 = Keno reach, 4 = J.C. Boyle reservoir, 5 = J.C. Boyle bypass reach, 6 = J.C. Boyle peaking reach, 7 = Copco reservoir, 8 = Copco to Iron Gate, 9 = Iron Gate reservoir, 10 = Below Iron Gate dam.

There is a seasonal cycle in chlorophyll *a* concentration that reflects the growth of phytoplankton (algae) in the system. Chlorophyll *a* concentration by month is presented in Figure 3.7-28. Median values do not vary much month-to-month, but the number of high values changes seasonally. Chlorophyll *a* is relatively high in March, decreases noticeably in April, increases to a mid-summer peak in July, decreases again in August, and increases to higher values in September and October. By November, chlorophyll *a* concentration is quite low. This seasonal pattern is seen throughout the system, although the absolute value of chlorophyll *a* concentration varies from site to site.

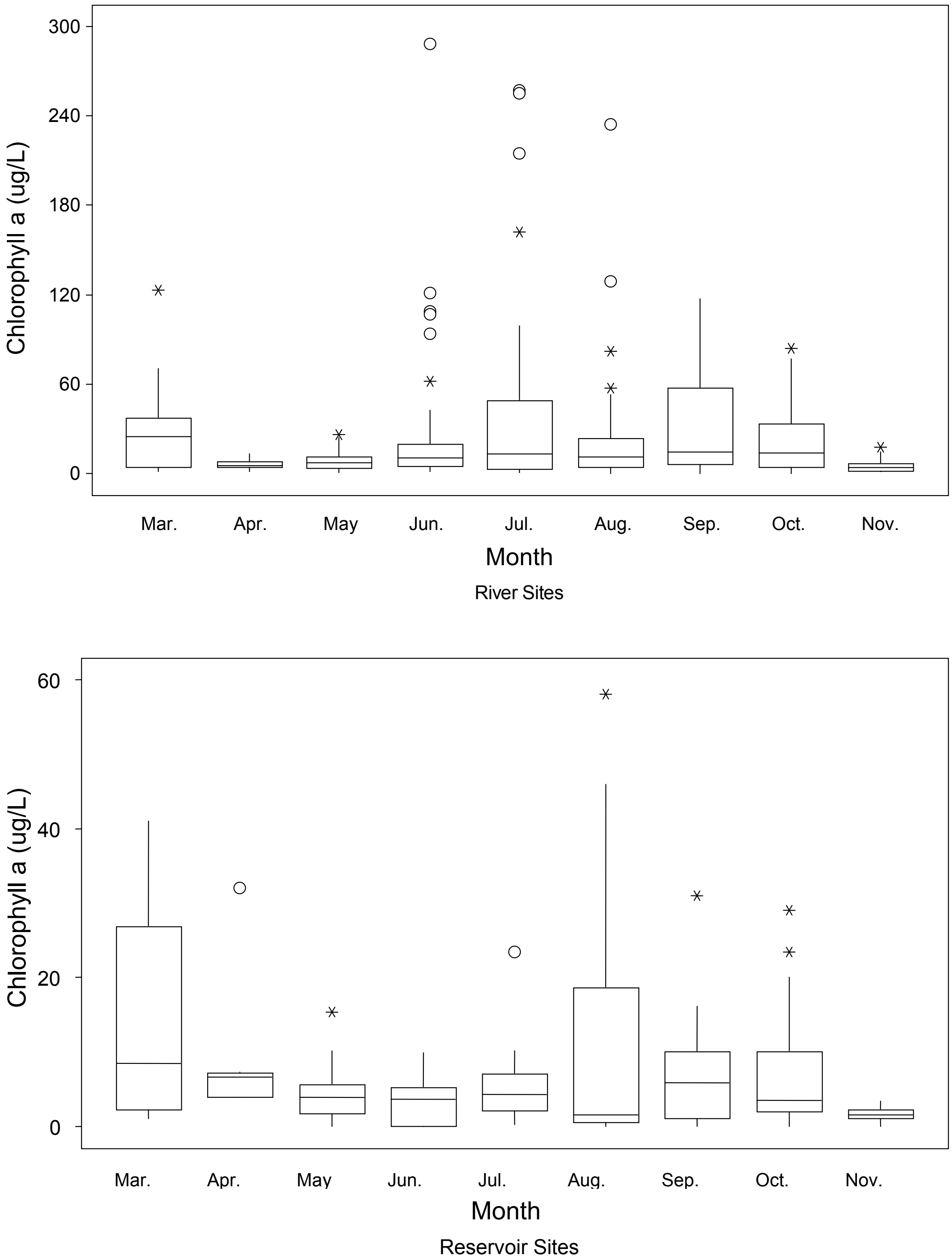


Figure 3.7-28. Box plot showing the distribution by month of chlorophyll *a* values measured at the river sites (top) and in the reservoirs (Copco and Iron Gate, bottom) of the Project area during 2000-2003.

3.8 DISCUSSION

Water quality sampling sites in the Project area can be divided into four groups, based on their physiographical characteristics. They are (1) Lake Ewauna and Keno reservoir from the mouth of Link River to Keno dam, (2) the Klamath River from below Keno dam to Copco reservoir, (3) the large Project reservoirs formed by Copco and Iron Gate dams, and (4) the Klamath River below Iron Gate dam.

Lake Ewauna and Keno reservoir form a long, shallow, slow-moving, highly productive body of water rich in nutrients and organic matter. From Keno dam to Copco reservoir the river is generally steep and fast-flowing, except through J.C. Boyle reservoir, which is more characteristic of a slow-moving river than a reservoir. Copco and Iron Gate reservoirs are characteristic of lakes in which water quality processes are dominated by the thermal stratification that occurs annually during the summer. Below Iron Gate dam water quality conditions are a function of ambient climate conditions and tributary inflows acting on the water that leaves Iron Gate reservoir.

3.8.1 Lake Ewauna and Keno Reservoir

Water entering Lake Ewauna from Link River carries a high load of organic nitrogen and other organic matter and is well seeded with algae, as evidenced by an average chlorophyll *a* concentration greater than 50 µg/L. The abundant algae delivered from Upper Klamath Lake continue to grow in Lake Ewauna and reach chlorophyll *a* concentrations averaging between 20 and 40 µg/L, peaking near 300 µg/L. The respiration demands of such abundant algal production combine with the BOD to consume much of the oxygen in the water. Although sediment oxygen demand contributes to the oxygen depletion, recent work indicates that sediment oxygen demand in Lake Ewauna is not unusually high (in the range of 0.5 to 3.0 grams per square meter per day [g/m^2/day) and that BOD demand in the water is the major cause of DO depletion in Lake Ewauna (see Section 9.0 of this FTR: Determination of Sediment Oxygen Demand in Selected Project Reservoirs). There is sufficient oxygen demand to result in complete anoxia during certain periods.

The low DO concentration can lead to low ORP at the sediment-water interface that promotes the release of phosphorus from the sediments and favors the presence of ammonia nitrogen. ORP values of -100 mv and below were recorded at several sites in Keno reservoir in July and August 2002. Under these conditions, phosphorus could be released from the sediments. In a phosphorus-limited system, this could stimulate algal growth.

The entire Klamath River system is high in phosphorus, including the tributary streams, with median total phosphorus concentration (0.21 mg/L) well above values commonly considered to indicate a eutrophic system (0.08 mg/L; Wetzel, 2001, p. 283), but water entering the reach from Link River is relatively low in phosphorus compared to Lake Ewauna. Klamath Straits Drain, however, provides phosphorus in abundance (median PT = 0.43 mg/L). The contribution of the Klamath Straits Drain to the Klamath River can be observed as a noticeable increase in total phosphorus concentration in Keno reservoir below Klamath Straits Drain (KR23828). The concentration of nitrogen in the Klamath system (median = 1.3 mg/L) is lower than that generally considered characteristic of eutrophic systems (1.8 mg/L).

The ratio of total nitrogen to total phosphorus (N:P) in the Klamath River system is below 7 (median = 6.6). The ratio of nitrogen to phosphorus in algal cells (Redfield ratio) is relatively constant at about 7:1 by weight. Reference to this ratio has been used as an approximate indicator of relative nutrient limitation of phytoplankton in lakes. A ratio of N:P greater than about 10:1 (by weight) is generally considered to indicate phosphorus limitation. The median N:P ratio in the Project area is 6.6:1. Only about 20 percent of all values are greater than 10:1. This condition holds from Link dam to Iron Gate dam, which suggests that phytoplankton growth in the Klamath River is strongly nitrogen-limited. Abundant phosphorus, coupled with limited nitrogen and warm water, provides advantageous conditions for nitrogen-fixing species, so it is not surprising that the project reservoirs support blooms of the nitrogen-fixing cyanophyte *Aphanizomenon flos-aquae.*

Lake Ewauna and Keno reservoir are shallow and exposed to the effects of wind; therefore, they do not experience stable thermal stratification, although periods of calm during warm weather may result in short-term stratification. The slow movement of water downstream through the reach simulates a large flow-through reactor and results in longitudinal rather than vertical gradients of constituents. This condition is illustrated in Figure 3.8-1. As water flows through the reservoir (moving from right to left on the figure), temperature (top panel) increases from Link River (RM 253) to Miller Island (RM 246), decreases slightly to RM 241 upstream of Klamath Straits Drain, increases to a maximum at RM 238 downstream of Klamath Straits Drain, and then decreases to RM 235 (Highway 66 at Keno).

DO also undergoes a longitudinal gradient, increasing from Link River to RM 241, then decreasing to a minimum at RM 238 downstream of Klamath Straits Drain, before increasing again toward RM 235. This longitudinal gradient persists throughout the year, although it can be modified with a vertical component during warm weather, as illustrated in Figure 3.8-2.

The longitudinal changes, combined with inflow of water high in nutrients and dissolved solids from Klamath Straits Drain (Table 3.8-1), cause the water quality at site KR23828 in Keno reservoir downstream from Klamath Straits Drain to be different from water quality at sites upstream. It is more similar to the Klamath River at Keno (KR23490), at Keno dam (KR23360), and below Keno Dam (KR23334). Site KR23828 has higher specific conductance, total phosphorus, and orthophosphate phosphorus; more frequent low ORP values (less than -100 mv); and lower BOD, chlorophyll, and nitrate nitrogen than sites upstream.

Table 3.8-1. Descriptive statistics for Klamath Straits Drain (Site KS01).

Variable	N	Mean	Minimum	Median	Maximum
NH_3	28	0.558	0.070	0.410	2.470
NO_3	23	0.602	0.060	0.370	2.290
PO_4	28	0.350	0.050	0.360	0.680
PT	28	0.470	0.100	0.425	0.900
SPC	63	559	262	565	1046

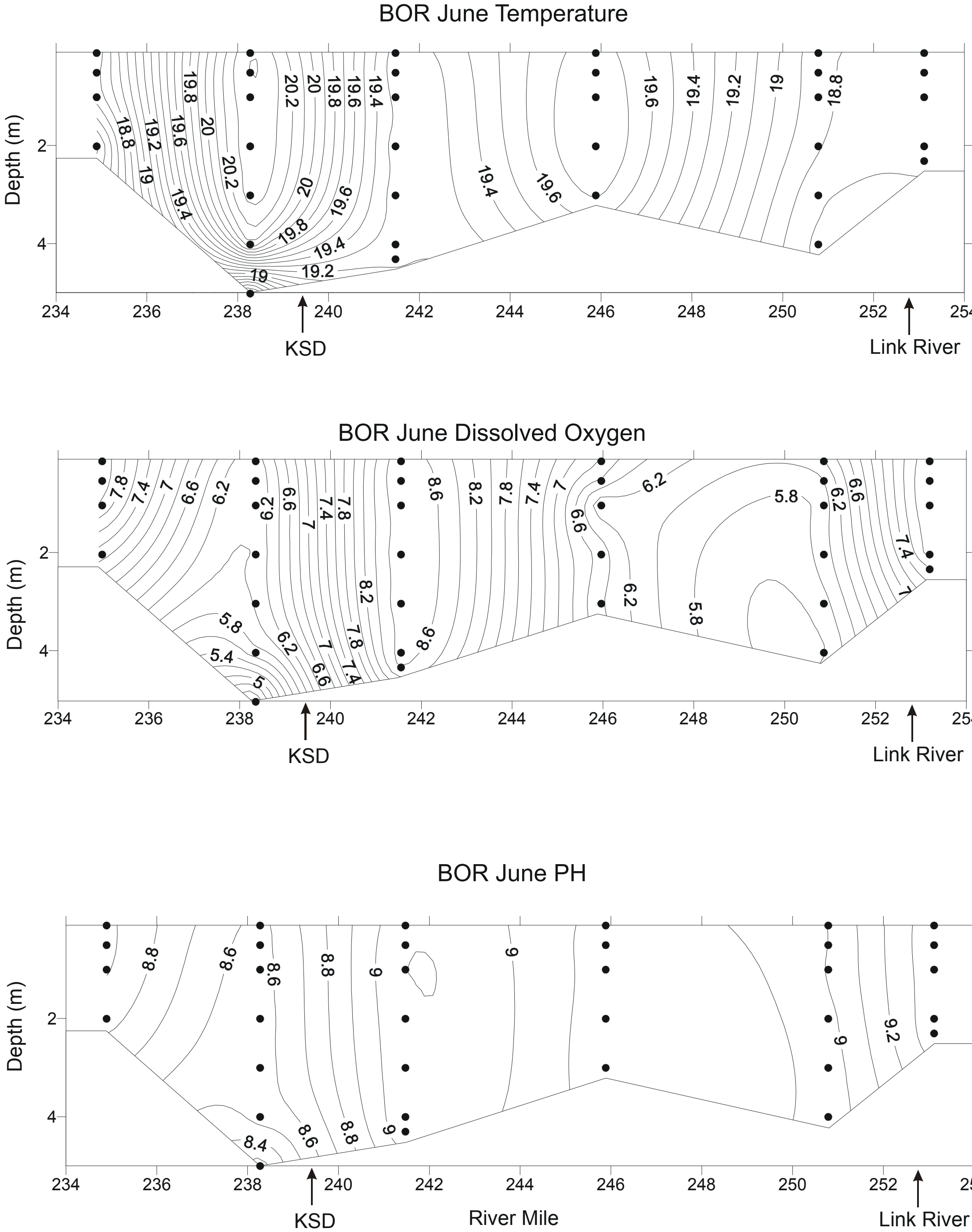


Figure 3.8-1. Isopleth diagram for water temperature, DO, and pH in Lake Ewauna and Keno reservoir for June 2002. Based on profile data collected at the following sites: KR25312, Link River at Mouth; KR25173, Lake Ewauna at railroad bridge drawspan; KR24589, Klamath River at Miller Island boat ramp; KR24248, Klamath River upstream of Klamath Strait Drain; KR23828, Klamath River south of Hill 4315; and KR23490, Klamath River at Keno (Highway 66 bridge).

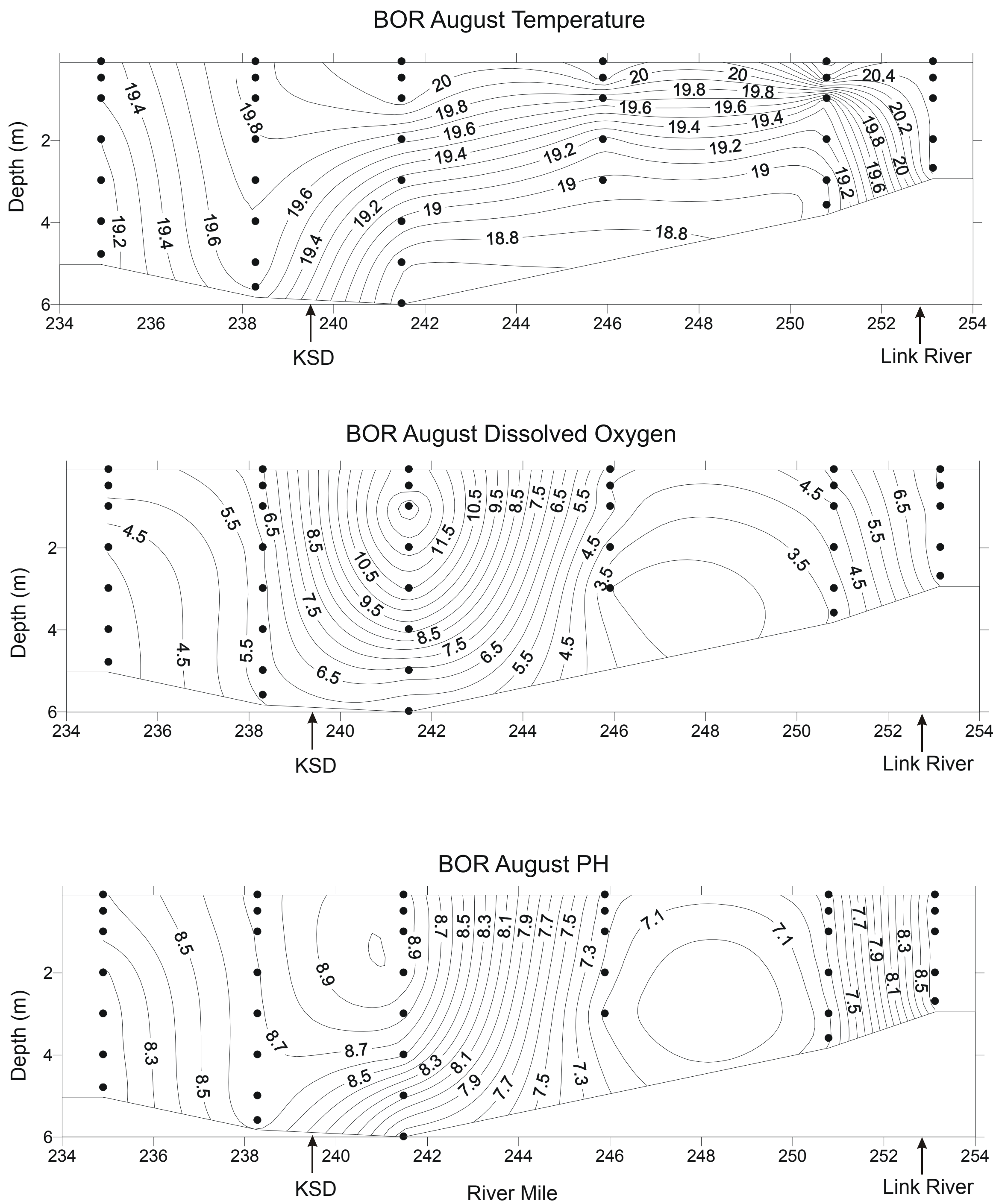


Figure 3.8-2. Isopleth diagram for water temperature, DO, and pH in Lake Ewauna and Keno reservoir for August 2002. Based on profile data collected at the following sites: KR25312, Link River at mouth; KR25173, Lake Ewauna at railroad bridge drawspan; KR24589, Klamath River at Miller Island boat ramp; KR24248, Klamath River upstream of Klamath Straits Drain; KR23828, Klamath River south of Hill 4315; and KR23490, Klamath River at Keno (Highway 66 bridge).

3.8.2 River Reaches

This section includes the portion of the Project area from below Keno dam to Copco reservoir. J.C. Boyle reservoir is included in this discussion because the short residence time and shallow depth of this reservoir are more characteristic of a slow-moving river than a reservoir. Water quality measurements taken at the surface and near the bottom of J.C. Boyle reservoir near the dam show no significant difference in most constituents (Table 3.8-2). J.C. Boyle reservoir does not experience stable vertical stratification. However, a localized depression in the bottom topography of the reservoir near the dam permits a small pool of stagnant water to persist in the deepest portion of the reservoir. This may account for the difference in DO and ammonia nitrogen between near-surface and near-bottom measurements.

Table 3.8-2. Comparison water quality constituents measured at the surface (1 m) and bottom (7 m) of J.C. Boyle reservoir near the dam (KR22478).

Constituent	**P value (paired t test)**
Temperature	0.180
DO	0.001
PT	0.52
TKN	0.33
PO_4	0.76
NO_3	0.09
NH_3	0.003

Several geomorphic characteristics of the Klamath River between Keno dam and Copco reservoir have consequences for water quality. From Keno dam to J.C. Boyle reservoir, the river is steep and fast-flowing, providing good mixing and aeration. The river flows more slowly through J.C. Boyle reservoir to J.C. Boyle dam, where much of the flow is diverted to the J.C. Boyle powerhouse to re-enter the main channel about 4 miles downstream. In this 4-mile bypass reach, significant inflow of groundwater (estimated at about 220 to 270 cfs) alters the quality of the river water. Some of these changes persist through the peaking reach and are evident in Copco and Iron Gate reservoirs.

The inflow of approximately 220 cfs of groundwater into the river between J.C. Boyle dam and the J.C. Boyle powerhouse (the bypass reach) enhances water quality in the peaking reach. In the summer, daily average water temperature decreases between Keno dam and Copco reservoir (see Figure 3.7-5). Data from 2002 suggest that this is not an effect of the mode of power operations. Table 3.8-3 shows the difference in average water temperature for a 1-week period in 2002 during peaking operation and during steady flow conditions. There is a substantial decrease in water temperature between the outlet of J.C. Boyle dam (KR22460) and the Klamath River upstream of Shovel Creek (KR20642). There is relatively little difference between the outlet of J.C. Boyle dam and Keno dam (KR23334).

Table 3.8-3. Change in average water temperature between sites in the Klamath River during peaking and nonpeaking operations. Sites include KR23334 – Klamath River below Keno dam, KR22460 – Klamath River below J.C. Boyle dam, and KR20642 – Klamath River upstream of Shovel Creek.

Site	Peaking 9/11/02-9/18/02	Nonpeaking 9/25/02-10/02/02
KR23334 – KR22460	0.43	0.64
KR22460 – KR20642	2.23	2.28

Median total phosphorus concentration is lower in the J.C. Boyle bypass reach and at sites downstream than at sites upstream (see Figure 3.7-21). Orthophosphate phosphorus concentration, although slightly lower in the J.C. Boyle bypass reach, is not markedly different entering Copco reservoir than it is below Keno dam (see Figure 3.7-23). The increase in orthophosphate phosphorus observed downstream of Klamath Straits Drain appears to persist until Copco reservoir.

Nitrogen undergoes somewhat more complex changes (see Figure 3.7-24). Median concentrations of TKN are high in Lake Ewauna and decrease downstream through the system. Ammonia nitrogen follows a similar pattern, with the notable exception of Copco reservoir (KR19874). The pattern of median nitrate nitrogen concentration is approximately the converse of TKN and NH_3. Concentrations are quite low in Lake Ewauna above Klamath Straits Drain and then increase to maximum in J.C. Boyle reservoir (KR22478), returning to relatively low values below Iron Gate dam.

The spatial changes in nitrogen and phosphorus are illustrated for one day, June 18, 2002, in Figure 3.8-3. Between the site below Keno dam (RM 233) and upstream of J.C. Boyle reservoir (RM 228), nitrate nitrogen concentration increases, TKN and BOD concentration decrease, and ammonia nitrogen concentration remains more or less constant, resulting in a net increase in inorganic nitrogen. Phosphorus concentration increases below Klamath Straits Drain (RM 240) and stays fairly constant through the rest of the Project area. These changes suggest that phosphorus is present in the system in abundance relative to the needs of aquatic plants and that decomposition of organic matter and nitrification of ammonia nitrogen are actively occurring in the Klamath River between Keno dam and J.C. Boyle reservoir. This change in nutrient availability does not appear to be reflected in the abundance of phytoplankton, because the chlorophyll *a* concentration decreases markedly below Keno dam. It is more likely, however, that the apparent decrease in chlorophyll represents a shift from the free-living phytoplankton dominant in the reservoirs to attached forms that are not captured with the current sampling protocol. By RM 176, upstream from the Shasta River, total nitrogen (NO_3 + TKN) has decreased to less than half the concentration found in Lake Ewauna (Figure 3.8-4).

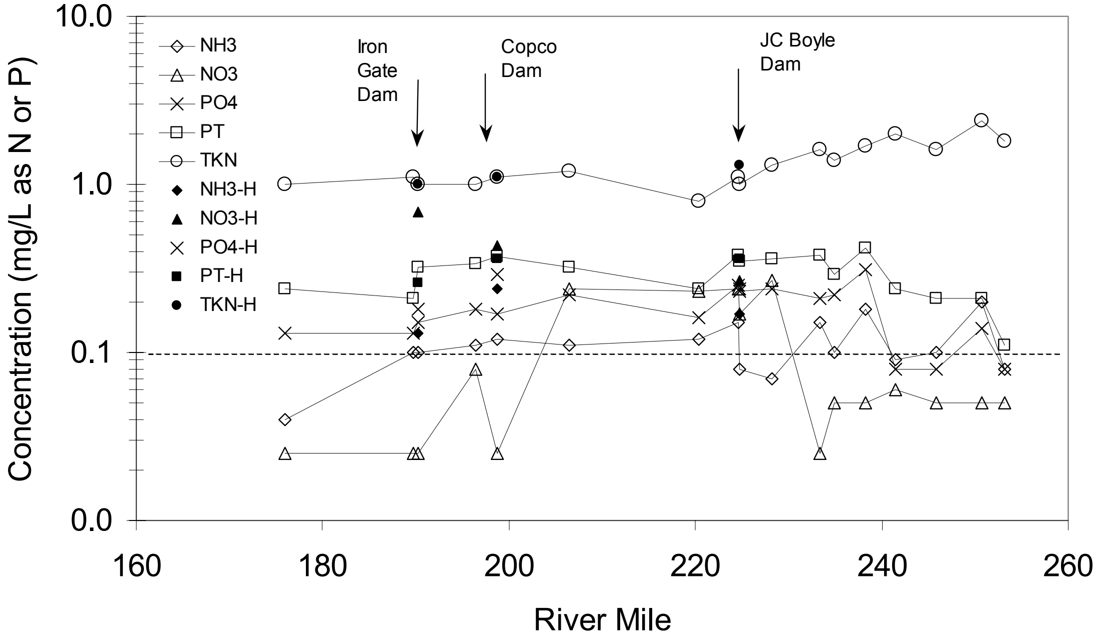


Figure 3.8-3. Concentration of nutrients measured at various sites in the Project area, June 18, 2002. NO_3 = nitrate nitrogen, NH_3 = ammonia nitrogen, TKN = total Kjeldahl nitrogen, PT = total phosphorus, PO_4 = orthophosphate phosphorus (H suffix designates hypolimnetic values). The horizontal dashed line represents the method reporting limit for ammonia and nitrate. Values below this line are considered to be estimated values.

Temperature and DO in the Klamath River between Keno dam and Copco reservoir are generally in equilibrium with the ambient conditions as a result of the free-flowing nature of the river in this area. DO in the river is near saturation because there is ample opportunity for re-aeration. The Klamath River cools slightly as it flows downstream, from Keno dam to J.C. Boyle reservoir, and considerably from J.C. Boyle dam to Copco reservoir—the result of groundwater discharge in the J.C. Boyle bypass reach (see Figure 3.7-5).

The operation of J.C. Boyle dam in peaking mode influences the temperature in the Klamath River below the dam through the interaction of cool water flowing constantly from the bypass reach and warm water flowing intermittently from the power plant. Peaking operation tends to increase the range of the diurnal temperature cycle near the upstream end of the peaking reach, and produces a more complex daily temperature cycle in the river near the downstream end of the peaking reach.

The high concentration of algal nutrients supplied from Upper Klamath Lake and Keno reservoir to the Klamath River in the Project area leads to changes in pH through the action of algal photosynthesis. Algal uptake of carbon dioxide results in high pH during the day, while respiration by algae and other organisms at night tends to depress pH. This creates a large diurnal range in pH values. This is especially prevalent in the surface waters of the Project reservoirs and, to a lesser extent, in the free-flowing sections of the river. The deeper waters in the Project reservoir outside the zone of active photosynthesis, and dominated by respiration processes, do not exhibit high pH values.

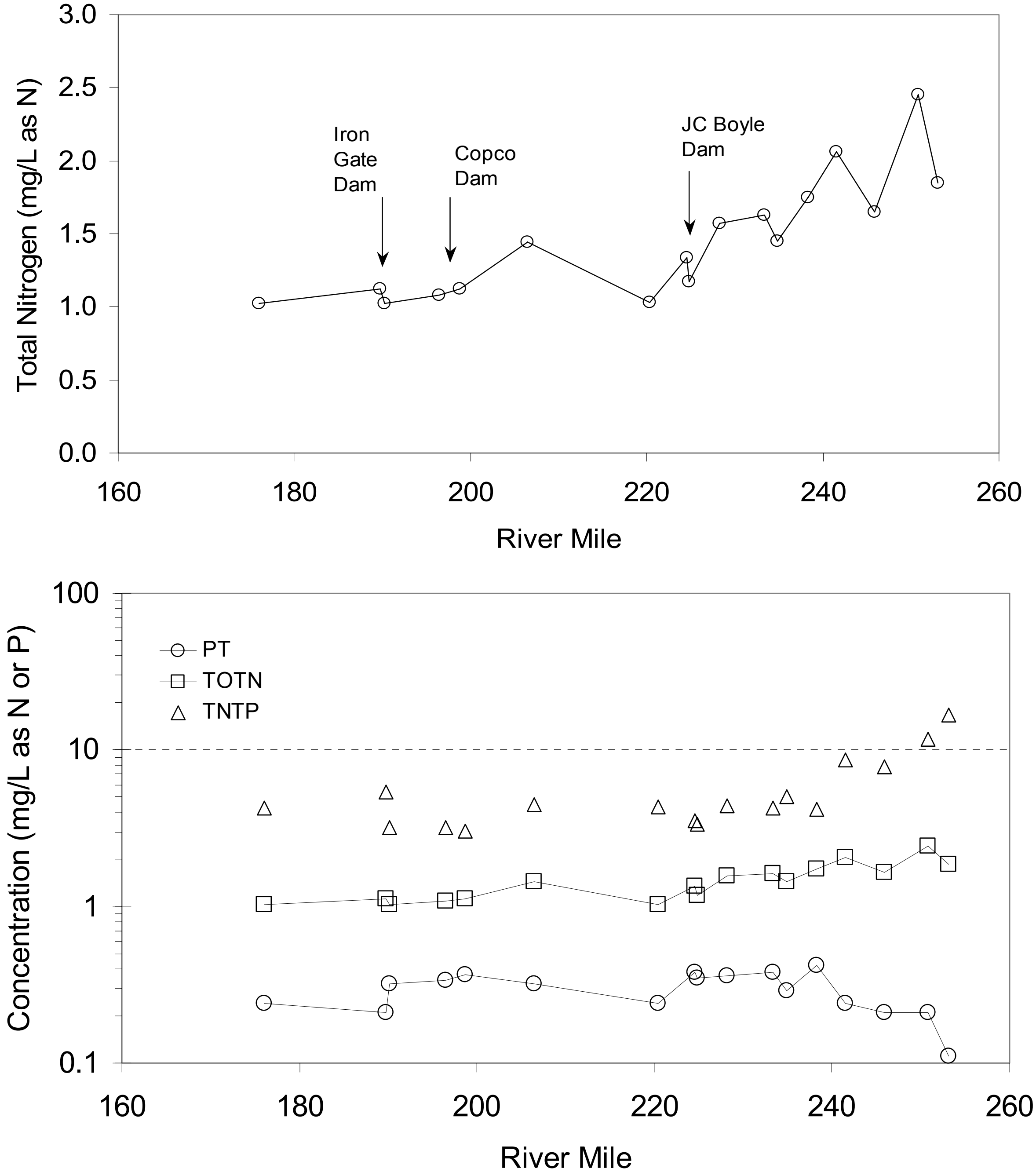


Figure 3.8-4. Concentration of nutrients measured at various sites in the Project area, June 18, 2002.

3.8.3 Reservoirs

Water quality processes in Copco and Iron Gate reservoirs are dominated by the thermal stratification that occurs annually in both reservoirs (Figures 3.7-3). Although these two reservoirs differ in shape, size, and mode of operation, the pattern of stratification in each is similar. In the spring as the surface waters warm, a density gradient with depth is established. When wind energy is no longer sufficient to overcome this gradient, the temperature of the surface water diverges from the deeper water and thermal stratification occurs. This usually happens in March. The surface waters continue to warm until reaching a maximum, usually in late August, at which time they begin to cool. As the surface waters cool, the density gradient lessens and wind energy is sufficient to mix the water to deeper depths until, usually in mid-November, the reservoir becomes isothermal. This is illustrated in Figure 3.8-5, which shows hourly water temperature data from several depths in Copco and Iron Gate reservoirs.

Superimposed on this overall pattern are shorter duration patterns. As indicated in Figure 3.8-5, the surfaces of Copco and Iron Gate reservoirs are subject to diurnal water temperature changes as a result of solar heating and variation on the order of several days in response to changing weather patterns. Diurnal variations are not evident in the deeper waters of these reservoirs because they are isolated by the density gradient.

There is, however, a definite, approximately daily, temperature fluctuation at about the 40-foot depth in Copco reservoir and at the 40- to 60-foot depth in Iron Gate reservoir. This reflects the effect of peaking operation of J.C. Boyle and Copco reservoirs. As a result of either the conservation of momentum in the water column when power generation ceases or the influence of rapid changes in the flow entering the reservoir, or a combination of both, an internal wave (seiche) is created at the depth where the temperature gradient is most intense. As this wave passes the stationary temperature data logger, it causes a fluctuation in the recorded temperature. The seiche also induces some mixing at depth in the reservoirs, resulting in the gradual warming of the deeper layers. Note in Figure 3.8-5 that this warming in the deeper water continues even as the water at shallower depths is cooling rapidly.

Thermal stratification has a number of effects. It isolates the deep water (hypolimnion) from the surface, preventing reaeration. Consequently, respiration by organisms in the hypolimnion, such as bacteria decomposing organic matter, can deplete the oxygen in the hypolimnion and lead to the release of nitrogen and phosphorus from the sediment. The thermal gradient also controls the depth to which inflowing water moves as it enters the reservoir. Cooler water will sink to a depth that matches its density while warmer water will tend to move across the surface of the reservoir. Cold, well-oxygenated water from tributaries can provide a source of oxygen to the hypolimnion.

Both Copco and Iron Gate reservoirs exhibit the characteristics of productive, stratified lakes. Water temperatures in the hypolimnion are lower than in the epilimnion (surface), DO concentration in the hypolimnion is lower than in the epilimnion, the pH is lower in the hypolimnion than the epilimnion, and chlorophyll *a* concentration is much higher in the epilimnion than in the hypolimnion (Table 3.8-4). However, Copco reservoir has a much higher concentration of ammonia (as N), orthophosphate (as P), total phosphorus, and TKN in the hypolimnion than in the epilimnion while in Iron Gate reservoir those constituents are the same concentration in both epilimnion and hypolimnion, or even lower in the hypolimnion than the epilimnion.

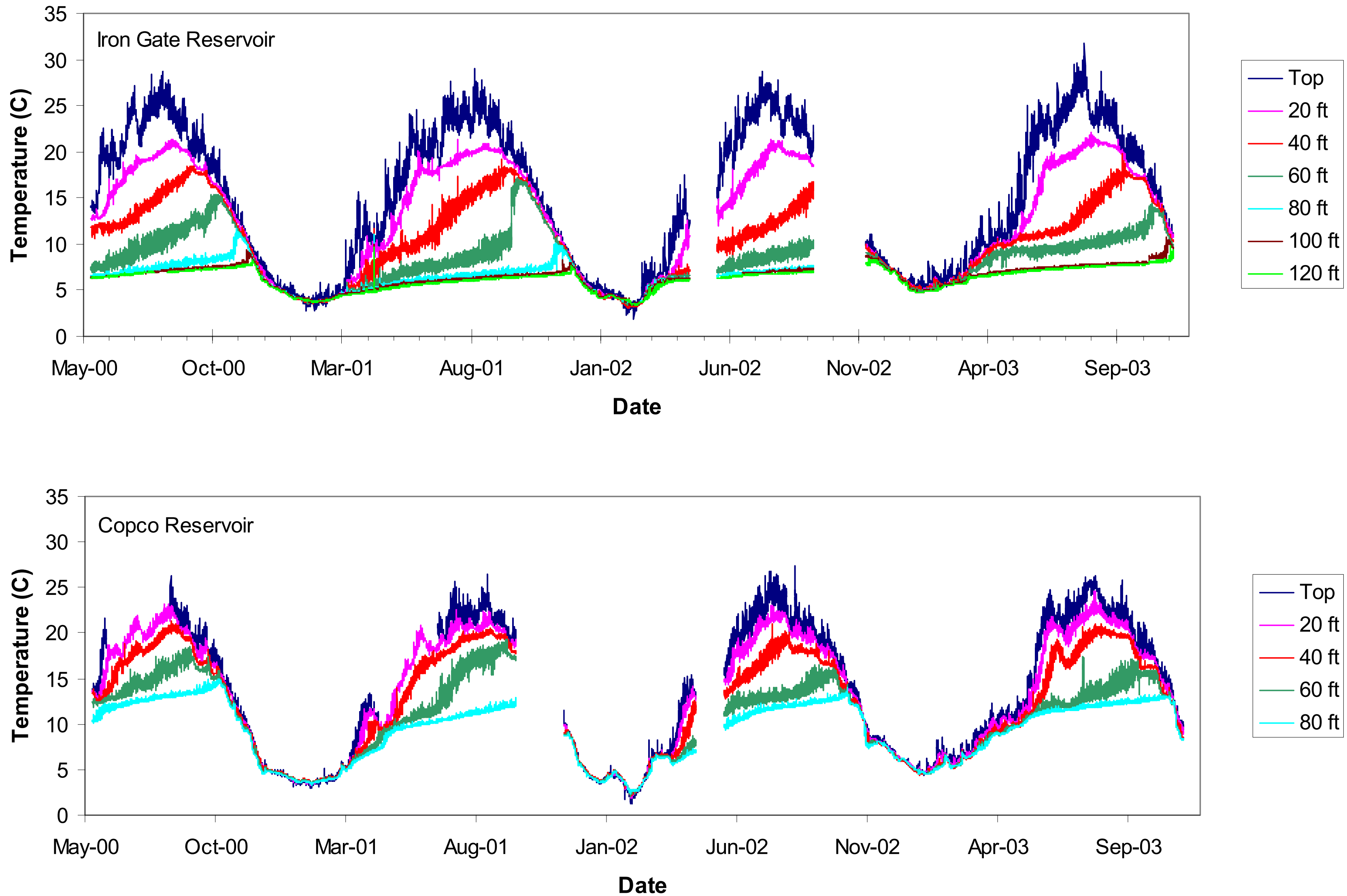


Figure 3.8-5. Hourly water temperature measurements from Copco (top) and Iron Gate (bottom) reservoirs.

The volume of Iron Gate reservoir below the depth of mixing (approximately 10 m) is nearly three times as great as the comparable volume of Copco reservoir (28 million cubic meters versus 11 million cubic meters). Consequently, Copco reservoir is more likely to become anoxic, as indicated in Figure 3.7-11. The hypolimnion of Copco reservoir is essentially lacking in oxygen (DO < 2 mg/L) beginning in early May most years and extending until mid-October, while the hypolimnion in Iron Gate reservoir does not reach that condition until late May, June, or even mid-July.

Table 3.8-4. Comparison of means of monthly water quality constituents in Copco and Iron Gate reservoirs.

	Copco Reservoir		**Iron Gate Reservoir**	
Constituent	**Epilimnion**	**Hypolimnion**	**Epilimnion**	**Hypolimnion**
Alkalinity (mg/L)	68.6	72.7	69.9	66.2
BOD (mg/L)	5.8	4.4	4.1	2.2
Chlorophyll *a* (ug/L)	11.7	5.2	11.9	6.4
Conductivity (uS/cm)	140	135	139	127
DO (mg/L)	9.2	3.1	8.8	4.1
Ammonia-N (mg/L)	0.12	0.59	0.097	0.11
Nitrate-N (mg/L)	0.38	0.4	0.27	0.5
ORP (mv)	155	118	159	203
pH	8.2	7.3	8.1	7.2
PO_4-P (mg/L)	0.18	0.37	0.15	0.18
Total P (mg/L)	0.26	0.47	0.295	0.2
Redox (mv)	155	116	160	203
Specific Conductance (µS/cm)	166	174	163	175
Temperature (°C)	15.5	10.4	15.6	7.2
TKN (mg/L)	1.12	1.27	0.89	0.57

Extended periods of anoxia promote conditions that result in the reduction of nitrate nitrogen to ammonia nitrogen and can lower ORP to the point that phosphorus is released from the sediment. Such conditions occur regularly in Copco reservoir, especially in August and September, but rarely in Iron Gate reservoir (Figure 3.8-6). The differences in ORP in the reservoirs are reflected in nutrient concentrations in the hypolimnion: orthophosphate and ammonia nitrogen are noticeably more abundant in the hypolimnion of Copco reservoir than in Iron Gate reservoir (Figure 3.8-7).

The depth of the discharge from a reservoir can have a strong effect on conditions in the reservoir and in the river below the dam. A deep discharge from a stratified reservoir can discharge water that is very low in oxygen to the detriment of downstream organisms. The power plant intakes for both Copco and Iron Gate reservoirs are fairly shallow, and they draw most of their water from the epilimnion and metalimnion—the region of thermal gradient in the reservoir. In Iron Gate reservoir, the power intake is at about a 30-foot depth. While the intake draws water from a range of depths, the temperature of the water leaving the reservoir is similar to the temperature at a depth of 10 feet within the reservoir (Figure 3.8-8). Copco reservoir also discharges from a depth that lies within the epilimnion.

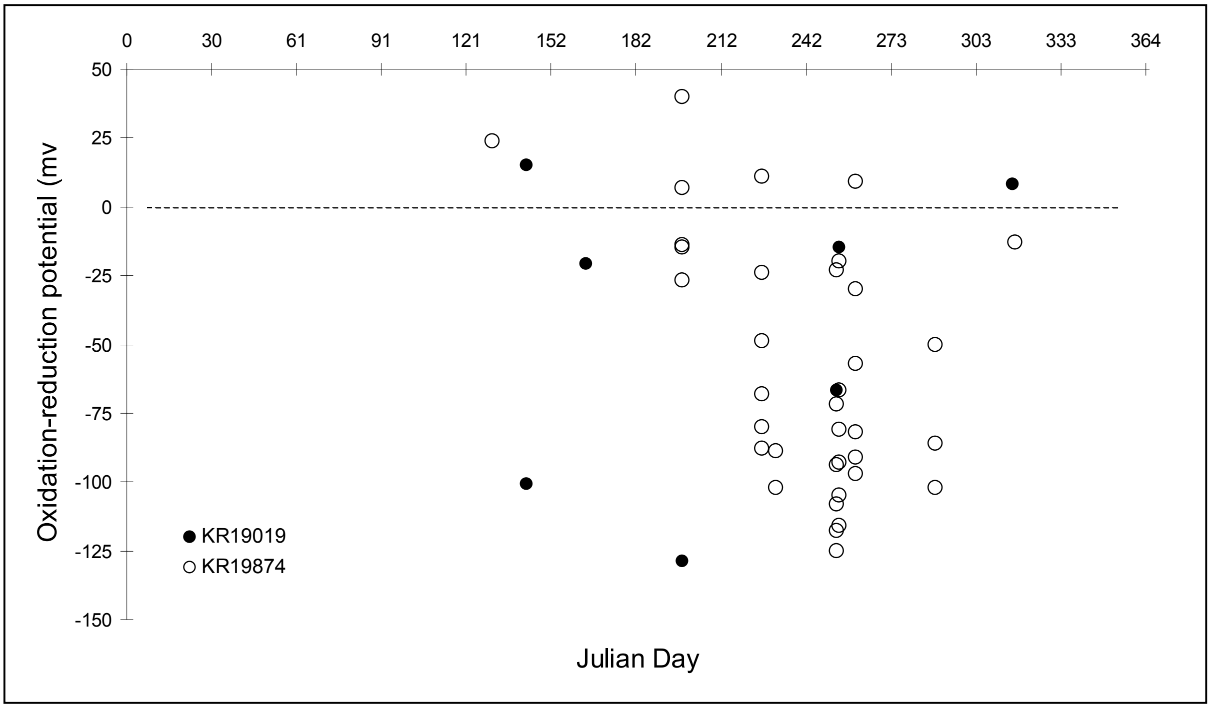


Figure 3.8-6. Oxidation-reduction values measured in Copco (KR19874) and Iron Gate (KR19019) reservoirs at depths > 10 m in 2002 and 2003.

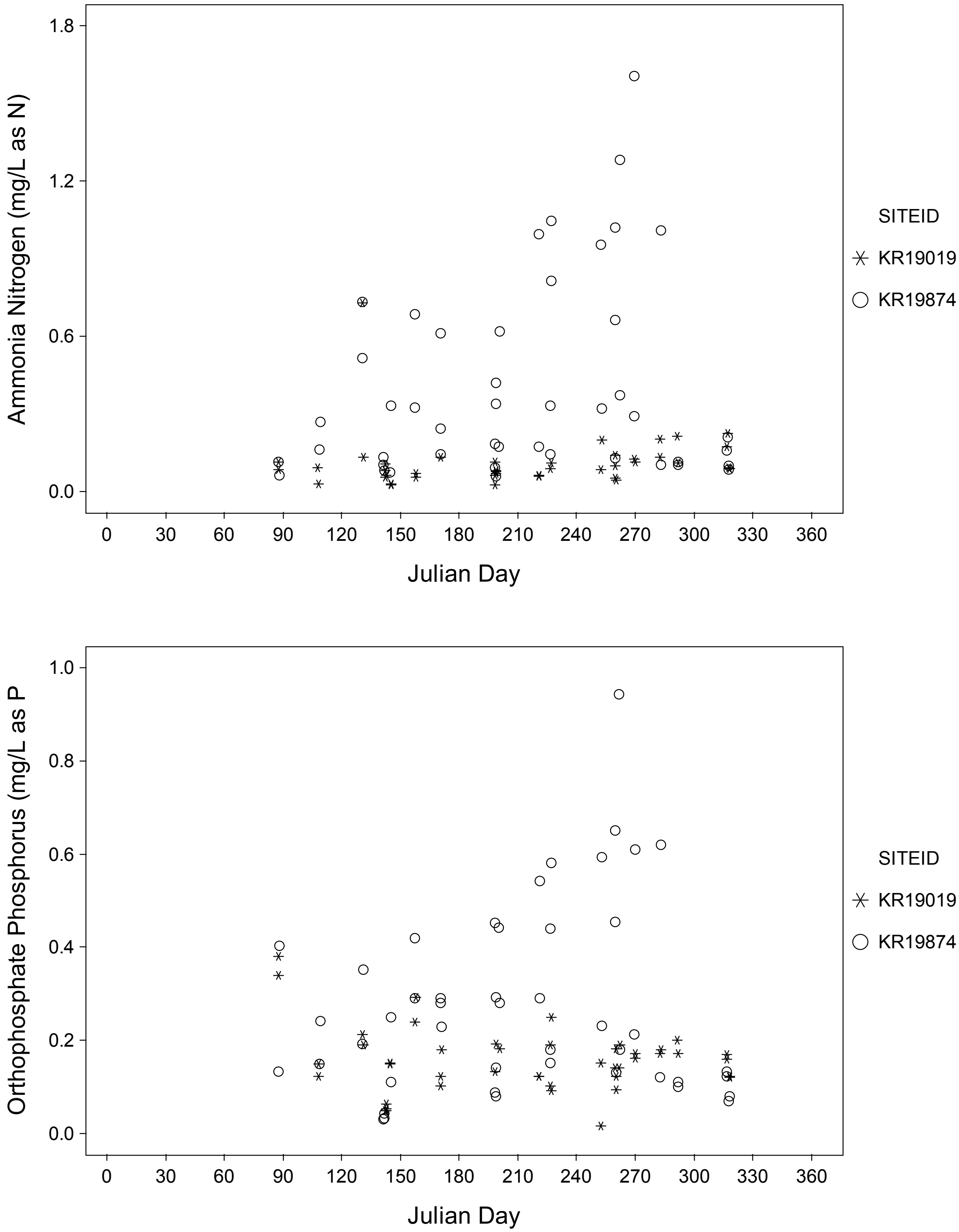


Figure 3.8-7. Ammonia nitrogen and orthophosphate phosphorus measured at depths > 10 m in Copco (KR19874) and Iron Gate (KR19019) reservoirs in 2000 through 2003.

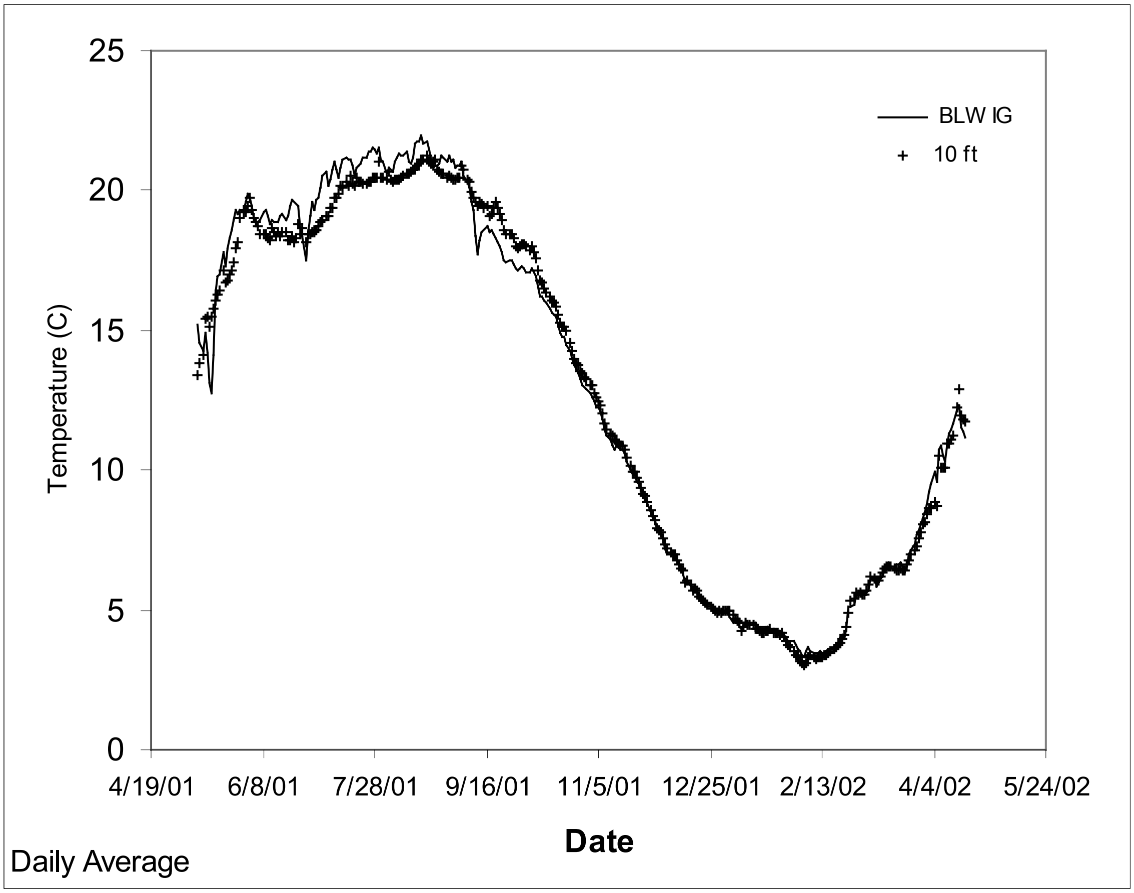
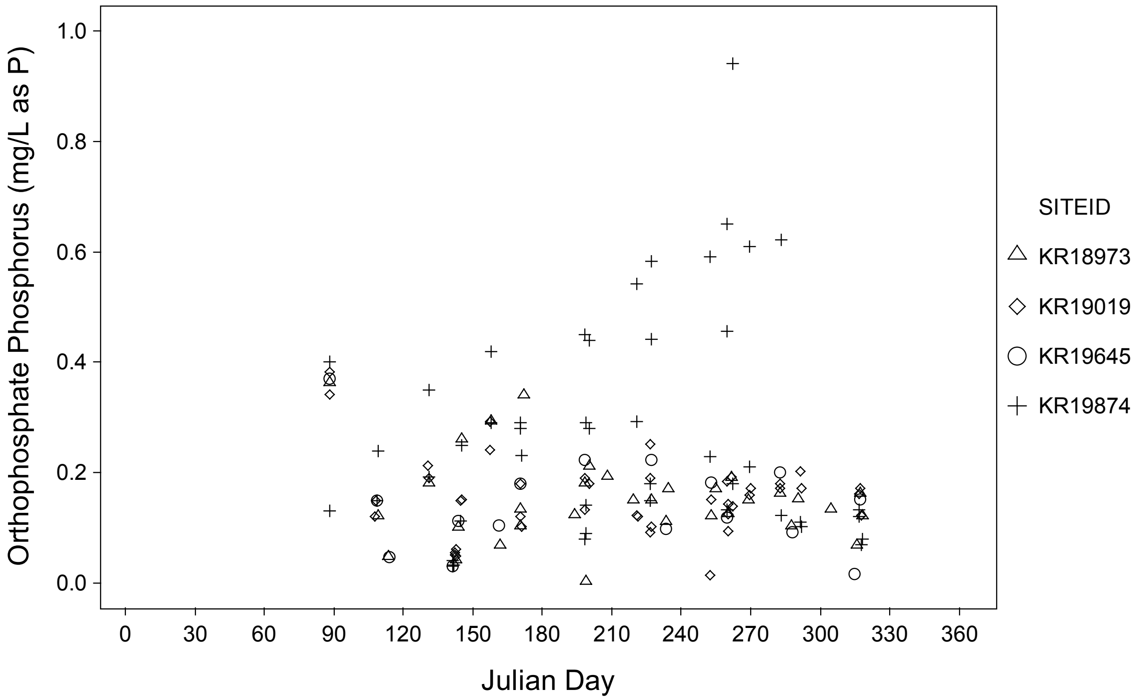


Figure 3.8-8. Daily average water temperature data from below Iron Gate dam and Iron Gate reservoir, showing the correspondence between the temperature in the reservoir at a 10-foot depth and the temperature in the Klamath River below Iron Gate dam (BLW IG).)

The location of the power intakes in Copco and Iron Gate reservoirs suggests the possibility that water flowing through the hydropower project from J.C. Boyle reservoir may short-circuit and flow directly into the lower Klamath River with little mixing in Copco or Iron Gate reservoirs. Water flowing in the Klamath River from J.C. Boyle reservoir at a temperature near 15° to 18°C, even though cooler than when it left Keno reservoir, would not penetrate the thermocline in Copco reservoir; instead, it would flow in the epilimnion to be discharged to the epilimnion of Iron Gate reservoir, from where it could discharge to the Klamath River. A result of this potential short-circuit is that higher nutrient concentrations in the hypolimnion of Copco reservoir during summer are sequestered in the hypolimnion. Figure 3.8-9 shows that increasing concentration of orthophosphate phosphorus and ammonia in the hypolimnion of Copco reservoir does not correspond to increasing concentration in the discharge from Copco reservoir, the hypolimnion of Iron Gate reservoir, or the discharge from Iron Gate reservoir.



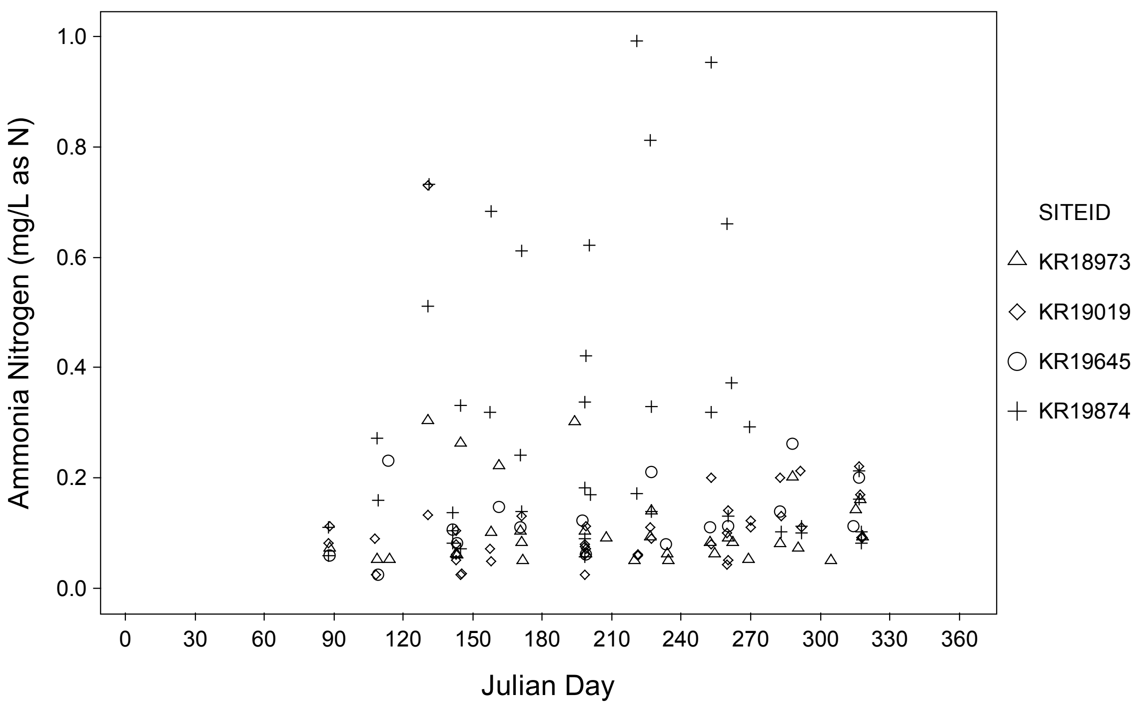


Figure 3.8-9. Orthophosphate phosphorus and ammonia nitrogen measured in the outflows from Copco (KR19645) and Iron Gate (KR18973) reservoirs, and at depths > 10 m in Copco (KR19874) and Iron Gate (KR19019) reservoirs in 2000 through 2003.

Chlorophyll *a* was analyzed on a 10-m-depth-integrated sample taken at the surface near the log boom in each reservoir. Occasional additional samples were taken at greater depths, and some surface grab samples were taken during obvious algal blooms. It is difficult to collect chlorophyll data that adequately represent the condition of the reservoirs during an algal bloom. Integrated samples may underestimate the local abundance of algae, while grab samples taken from a concentrated region of the bloom may substantially overestimate algal abundance.

Copco and Iron Gate reservoirs are highly productive, with many samples greater than 15 μg/L, a value commonly used as an indicator of eutrophic conditions. There is a predictable seasonal sequence of algae groups in the reservoirs. There is typically a bloom of diatoms in March, followed by a period of relatively low chlorophyll abundance. Another peak in chlorophyll occurs in July and August when dense blooms of the nitrogen-fixing cyanophyte (blue-green alga) *Aphanizomenon flos-aquae* occur. Later in the fall another, smaller bloom of diatoms occurs (see Figure 3.7-28).

Aphanizomenon can regulate their buoyancy to concentrate into a shallow zone at the surface of the water and may drift with the wind to form highly a concentrated accumulation in a restricted area. Chlorophyll measured in the center of one of these accumulations exceeded 2,000 μg/L chlorophyll *a*, but the 10-m integrated sample at that spot was less than 40 μg/L.

3.8.4 Klamath River below Iron Gate Dam

Water quality in the Klamath River immediately below Iron Gate dam is similar to water quality in the epilimnion of Iron Gate reservoir and in the Klamath River above Iron Gate reservoir. As water progresses downstream from Iron Gate dam, water quality conditions change fairly rapidly. Historical data (see Chapter 2) indicate that nutrient concentration has increased just a few hundred meters downstream of Iron Gate dam. The changes are in excess of what would be expected as the result of in-river processes, and suggest that there is a source of nutrients entering the Klamath River below Iron Gate dam.

Data collected in 2000 through 2003 below Iron Gate dam (KR18973) and above the Shasta River (KR17600) were compared to data collected in Iron Gate reservoir (KR19019) and at the site just upstream from Iron Gate reservoir just below the Copco No. 2 powerhouse tailrace (KR19645). The nonparametric Kruskal-Wallis analysis of variance followed by pairwise comparisons were used to detect differences among the sites for nitrate nitrogen, amonia nitrogen, orthophosphate, total phosphorus, and TKN (Table 3.8-5). No significant differences were found between the sites for ammonia nitrogen, orthophosphate, or total phosphorus. The hypolimnion of Iron Gate reservoir had significantly higher concentration of NO_3 than the other sites, which did not differ from each other. The epilimnion of Iron Gate reservoir and the site below Iron Gate dam (KR19873) had lower concentration of TKN than the hypolimnion of Iron Gate reservoir (KR19019).

Table 3.8-5. Results of Kruskal-Wallis nonparametric analysis of variance for selected constituents at sites above and below Iron Gate dam ($P < 0.05$ indicates a significant difference)

Constituent	P value
NH_3	0.28
PO_4	0.73
PT	0.92
NO_3	0.00
TKN	0.00

Seasonal changes in water quality constituents below Iron Gate dam are not large (Table 3.8-6). DO decreases through the summer, although results from year to year are quite variable. Ammonia remains fairly constant throughout the year, with occasional high values. NO_3 tends to increase slightly in the fall. PO_4 and PT are more variable in March through June than in other months. This corresponds to the period of year when concentrations of phosphorus are greatest in Klamath Straits Drain. TKN is higher in June and August when algal blooms occur in the reservoir.

The water temperature of water leaving Iron Gate reservoir is less variable than the water temperature in the river above Copco reservoir. In the fall, before the breakdown of stratification, the water temperature leaving Iron Gate reservoir is warmer than the temperature in the Klamath River above Copco reservoir (Figure 3.8-10). This phenomenon is discussed in more detail in Section 4.0 (Appendix 4A).

Table 3.8-6. Water quality constituents at sites sampled downstream from Iron Gate dam.

	Iron Gate Dam Discharge (KR19873), Median of All Years (mg/L)					Above Shasta River (KR17600), 2002 Data (mg/L)				
Month	**PT**	**DOCON**	**NH_3**	**NO_3**	**TKN**	**PT**	**DOCON**	**NH_3**	**NO_3**	**TKN**
March	0.38	12.4	0.07	0.23	0.70					
April	0.16	10.8	0.05	0.34	0.76					
May	0.22	10.2	0.16	0.12	0.40	0.16	11.2	0.06	0.02	0.70
June	0.21	9.11	0.10	0.11	0.80	0.24	10.2	0.04	0.02	1.00
July	0.17	8.06	0.10	0.28	0.80	0.15	10.7	0.06	0.07	0.40
August	0.15	7.98	0.06	0.24	1.3	0.12	10.4	0.13	0.22	0.90
September	0.18	7.51	0.08	0.57	0.90	0.17	11.1	0.19	0.23	0.60
October	0.16	6.59	0.08	0.49	0.70	0.15	8.16	0.09	0.21	0.50
November	0.12	8.64	0.14	0.42	0.70	0.20	15.0	0.10	0.33	0.70

DOCON = DO concentration.

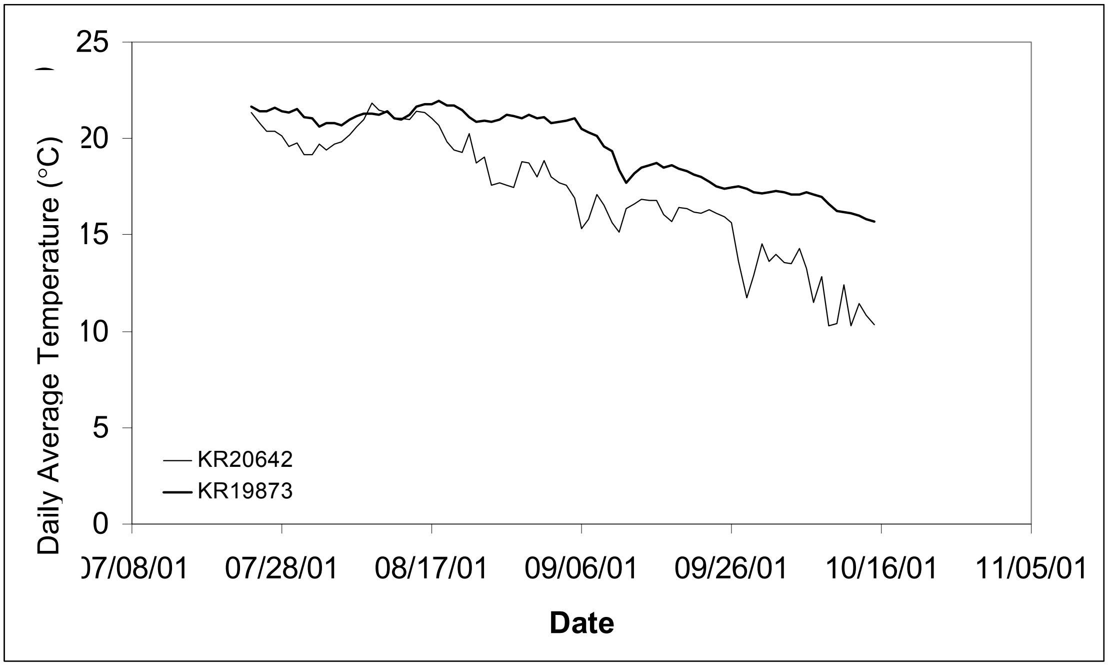


Figure 3.8-10. Hourly water temperature measured in the Klamath River upstream of Shovel Creek (KR20645) and just downstream of Iron Gate Dam (KR18973).

3.9 CONCLUSION

The driving force influencing water quality in the Project area is the quality of water entering the project from Upper Klamath Lake and Klamath Straits Drain. Water entering Lake Ewauna is rich with algae; high in BOD, organic nitrogen, and phosphorus; and at equilibrim water temperature with the ambient conditions. As water moves through the system from Link River to below Iron Gate dam, organic nitrogen is converted to inorganic nitrogen, total nitrogen concentration is reduced, phosphorus concentration remains relatively constant, and algal abundance, as measured by chlorophyll *a*, is reduced. The system appears to be a net sink for nitrogen and phosphorus.

The two large reservoirs, Copco and Iron Gate stratify during the summer and experience oxygen depletion in the hypolimnion. Only Copco reservoir regularly experiences high hypolimnetic nutrient conditions. Conditions in the hypolimnion of the reservoirs have relatively little effect on conditions downstream of the reservoirs because the location of the outlet structures near the depth of the thermocline promotes short-circuit flow through the epilimnion.

Water quality in the outflow from Iron Gate dam is affected by conditions in the reservoir. DO concentration is reduced, and TKN is increased during periods of heavy algal blooms in the reservoir. Water temperature is affected as well. The median temperature of water leaving Iron Gate dam is approximately the same as median water temperatures in Lake Ewauna above the Project, and maximum water temperatures are a bit lower. Seasonal variation in water temperature is somewhat different. During the fall when the river is cooling rapidly, but before thermal stratification has broken down in Iron Gate reservoir, temperatures leaving the dam can be several degrees (C) warmer than the water temperature of the river entering the reservoir.