Water-Quality Data from 2002 to 2003 and Analysis of Data Gaps for Development of Total Maximum Daily Loads in the Lower Klamath River Basin, California

By Lorraine E. Flint, Alan L. Flint, Debra S. Curry, Stewart A. Rounds, and Micelis C. Doyle

In cooperation with the North Coast Regional Water Quality Control Board

Scientific Investigations Report 2004-5255

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

U.S. Geological Survey, Reston, Virginia: 2005
For sale by U.S. Geological Survey, Information Services
Box 25286, Denver Federal Center

Denver, CO 80225

For more information about the USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: http://www.usgs.gov/

Suggested citation:
Flint, L.E., Flint, A.L., Curry, D.S., Rounds, S.A., and Doyle, M.C., 2005, Water-Quality Data from 2002 to 2003 and Analysis of Data Gaps for Development of Total Maximum Daily Loads in the Lower Klamath River Basin, California: U.S. Geological Survey Scientific Investigations Report 2004-5255, 77 p.

Contents

Figures

Tables

Conversion Factors and Abbreviations

SI to Inch/Pound

Multiply	By	To obtain
gram (g)	0.0353	ounce, avoirdupois (oz)
grams per day (g/day)	0.0353	pound avoirdupois per day (lb per day)
kilogram (kg)	2.205	pound avoirdupois (lb)
kilogram per day (kg/day)	2.205	pound avoirdupois per day (lb per day)
kilometer	0.6214	mile
liter (L)	61.02	cubic inch (in^3)
meter (m)	3.281	foot (ft)
square kilometer (km^2)	0.3861	square mile (mi^2)

Inch/Pound to SI

Multiply	By	To obtain
cubic foot per second (ft^3/s)	4.800	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
mile (mi)	1.6093	kilometer (km)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C= (°F-32)/1.8$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the National Geodetic Vertical Datum of 1929 (NGVD of 1929).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

BOD	biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
CIMIS	California Irrigation Management Information System
DEM	digital elevation model
DO	dissolved oxygen
EDNA	elevation derivatives for National application
FERC	Federal Energy Regulatory Commission
$g/m^2/day$	gram per square meter per day
mm	millimeter
mm Hg	millimeter of Mercury
NCDC	National Climatic Data Center

NCRWQCB	North Coast Regional Water Quality Control Board
NREL	National Renewable Energy Laboratory
NTU	nephelomatric turbidity units
NWIS	National Water Information System
RAWS	Remote Automated Weather Stations
SOD	sediment oxygen demand
SOD_{20}	sediment oxygen demand values corrected to 20°C
TOC	total organic carbon
TMDL	total maximum daily load
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WQRRS	Water Quality for River-Reservoir System
WRCC	Western Regional Climate Center

Water-Quality Data from 2002 to 2003 and Analysis of Data Gaps for Development of Total Maximum Daily Loads in the Lower Klamath River Basin, California

By Lorraine E. Flint, Alan L. Flint, Debra S. Curry, Stewart A. Rounds, and Micelis C. Doyle

Abstract

The U.S. Geological Survey (USGS) collected water-quality data during 2002 and 2003 in the Lower Klamath River Basin, in northern California, to support studies of river conditions as they pertain to the viability of Chinook and Coho salmon and endangered suckers. To address the data needs of the North Coast Regional Water Quality Control Board for the development of Total Maximum Daily Loads (TMDLs), water temperature, dissolved oxygen, specific conductance, and pH were continuously monitored at sites on the Klamath, Trinity, Shasta, and Lost Rivers. Water-quality samples were collected and analyzed for selected nutrients, organic carbon, chlorophyll-*a*, pheophytin-*a*, and trace elements. Sediment oxygen demand was measured on the Shasta River. Results of analysis of the data collected were used to identify locations in the Lower Klamath River Basin and periods of time during 2002 and 2003 when river conditions were more likely to be detrimental to salmonid or sucker health because of occasional high water temperatures, low dissolved oxygen, and conditions that supported abundant populations of algae and aquatic plants. The results were also used to assess gaps in data by furthering the development of the conceptual model of water flow and quality in the Lower Klamath River Basin using available data and the current understanding of processes that affect water quality and by assessing needs for the develoment of mathematical models of the system. The most notable gap in information for the study area is in sufficient knowledge about the occurrence and productivity of algal communities. Other gaps in data include vertical water-quality profiles for the reservoirs in the study area, and in an adequate understanding of the chemical oxygen demands and the sediment oxygen demands in the rivers and of the influence of riparian shading on the rivers. Several mathematical models are discussed in this report for use in characterizing the river systems in the study area; also discussed are the specific data needed for the models, and the spatial and temporal data available as boundary conditions. The models will be useful for the future development of TMDLs for temperature, nutrients, and dissolved oxygen and for assessing the role of natural and anthropogenic sources of heat, oxygen-producing and -consuming substances, and nutrients in the Klamath, Shasta, and Lost Rivers.

Introduction

The study area is the Lower Klamath River Basin and for this study includes the Klamath River and the Lost River systems in northern California (*fig. 1*). The 2001 and 2002 droughts in the Klamath River Basin in Oregon and California, along with Federal legal requirements regarding water use, resulted in a scarcity of water available both for agricultural use and for maintenance of water levels necessary to sustain threatened and endangered fish populations in the Klamath Basin. Low streamflows and agricultural return flows with concurrent high water temperatures, excess nutrients, and decreased dissolved oxygen may have contributed to a large die-off in September 2002 of Chinook salmon, and some Coho salmon, a threatened anadromous fish.

Three rivers in the Lower Klamath River Basin (*fig. 1*) are listed on California's 303(d) List of Impaired Water Bodies (California Environmental Protection Agency, accessed April 2004):

- The Lost River, owing to high water temperatures and excess nutrients that may be impairing the beneficial uses of the water body.
- The Klamath River, owing to high water temperatures, low dissolved oxygen, and excess nutrients.
- The Shasta River, which flows into the Klamath River, owing to high water temperatures and low dissolved oxygen.

Placement of a water body on the 303(d) List triggers action for developing a pollution control plan, called Total Maximum Daily Load (TMDL), for that water body and the associated pollutant/stressor on the list. The TMDL serves as the means to attain and maintain water-quality standards for the impaired water body.

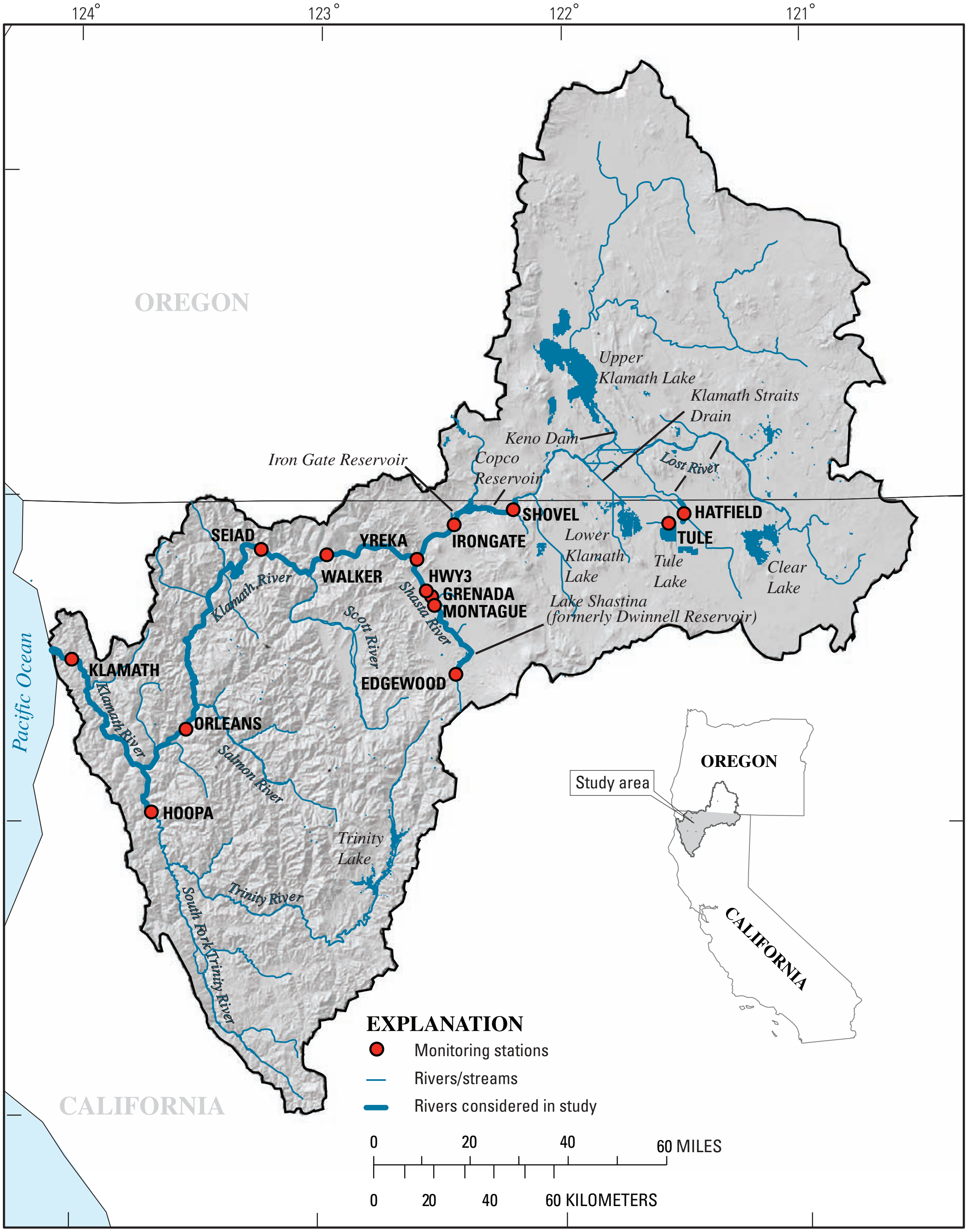

Figure 1. Location of Klamath River Basin, California, and water-quality monitoring sites.

The development of a TMDL is a long-term process. The U.S. Geological Survey (USGS), in cooperation with the North Coast Regional Water Quality Control Board (NCRWQCB), collected and analyzed water-quality and streamflow data to support that process for water bodies in the Lower Klamath River Basin.

Objective

The objective of this study is to collect and analyze water-quality data in order to provide hydrologic and water-quality information needed to develop TMDLs for the Klamath and the Lost Rivers. These data are being used for several purposes, including

- Characterizing the water quality of the Klamath and the Lost Rivers and identifying changes or trends in water quality over time—especially as related to land use and river modifications
- Providing specific data for water-quality models that will be used to develop TMDLs for water temperature, nutrients, and dissolved oxygen (DO)
- Identifying specific existing or emerging water-quality problems
- Developing analytical tools to support characterization of past or possible future conditions in these river systems
- Identifying data gaps and additional assessments and analyses needed to develop TMDLs

The purpose of this report is to summarize data collected during 2002 and 2003 and to identify gaps in information and additional water-quality investigations to support a more complete understanding of water-quality dynamics of the lower Klamath River. The report describes specific approaches for evaluating spatial and temporal variations in water quality and discusses data necessary in the development of a water-quality model of the Klamath River between Upper Klamath Lake and the Pacific Ocean, including that section of the Lost River from the California border to where the river flows into the Klamath River. Such a model can be used to assess

- Natural and anthropogenic sources and sinks of heat, DO, and nutrients
- Additional data needs (identification of data gaps) through model sensitivity analysis (such as the sensitivity of water temperature to shading), or needs for identifying, through additional monitoring or sampling, tributaries that affect water quality
- Gaps in the understanding of processes contributing to water quality through model sensitivity analysis (such as the role of attached algae in primary production of oxygen and carbon dioxide or the influence of sediment oxygen demand on DO)

This report presents the water-quality studies undertaken by the U.S. Geological Survey in the Lower Klamath River Basin, data collection methods and results for the Trinity, Klamath, Shasta, and Lost Rivers, the parcel-tracking study on the Klamath and Shasta Rivers, and the sediment oxygen demand study on the Shasta River. It also discusses and compares various models being considered for use in the basin, potential sources of data for those models, and existing gaps in the currently available data. Also included is a discussion of the methodology for correcting dissolved oxygen data from DataSonde sensors and the associated data uncertainty, using the data collected at sites on the Shasta River in 2002 and 2003 as an example (*appendix 2*).

Approach

Several approaches can be used to evaluate the quality and quantity of existing hydrologic and water-quality data and to identify additional data needs for better understanding of the river systems in the Lower Klamath River Basin. As a calibrated mathematical model is necessary for scenario development in the future preparation of TMDLs for the Klamath and Lost Rivers, it was decided to evaluate the data from a modeling perspective. This report provides an analysis of the data in the absence of a model, and in order to adequately evaluate the data and gaps in the data, includes a philosophical approach to modeling, and discusses the reasons why the integration of data collection and modeling would provide a better solution to determining data gaps and data adequacy. In the context of the available data, an analysis of potentially useful models for future development of TMDLs is included, along with possible sources for the additional data necessary to apply such models.

Sufficient data are currently available for rivers in the Lower Klamath River Basin to construct a conceptual and mathematical model that can be used to better evaluate where additional data are needed. The philosophical modeling approach used for this study provided a theoretical basis for evaluating the features, processes, and hydrological events in the river system that most influence the constituents being considered for the TMDLs. A numerical or process model developed using only the existing data could be used to develop TMDLs for this basin, but because of uncertainties associated with many of the parameters that are required as input, it is encouraged that the data gaps identified in this report be filled to provide a rigorous and defensible model. It is through the interactive process of data collection, data analysis, and model sensitivity analysis that a nexus can be achieved between a sufficiency of high-quality data and an adequate understanding of water-quality processes. Only then can sufficient data be acquired and an accurate and reliable model built to provide a foundation for preparing TMDLs.

Model Development

Models representing natural systems generally are composed of two parts: a conceptual model and a mathematical model (Hsieh and others, 2001). In general terms, a conceptual model is qualitative and is expressed by ideas, words, and figures. A mathematical model is quantitative and is expressed as mathematical equations. The two are closely related. In essence, the mathematical model results from translating the conceptual model into a well-posed mathematical problem that can be solved.

A key component to assessing data gaps is the integration of the available data and of information on the natural processes contributing to water quality into conceptual and mathematical models of a river system. When developed and supported by field data, models can be effective tools for understanding complex phenomena and for making informed predictions for a variety of future scenarios. However, model results are always subject to some degree of uncertainty owing to limitations in field data and incomplete knowledge of natural processes contributing to water quality.

To put the modeling development and implementation into a conceptual framework, the modeling process can be viewed as an iterative sequence of actions that includes (1) identifying a site-specific problem; (2) conceptualizing dominant features, processes, and hydrologic events; (3) implementing a quantitative description of each process; (4) collecting and assimilating field data, and using those data to calibrate the model and to evaluate its predictive capabilities; and (5) developing predictions for use in resolving the identified problem. This process is illustrated by the flow chart in *figure 2*. Once the problem has been established, the next goal (*fig. 2*) is to assess the available site-specific data. The following section describes the data collected by the USGS during 2002 and 2003 and provides preliminary analyses of that data.

Water Quality

Data collection was done at Klamath River and Lost River locations. There was continuous monitoring of dissolved oxygen, water temperature, specific conductivity, and pH for both 2002 and 2003. Monthly sampling for water-quality constituents was done in 2002 and parcel-tracking and sediment oxygen demand studies were conducted in 2003. Between June and November 2002, the USGS began using automated continuous monitors to determine water quality at 12 surface-water stations in the Lower Klamath River Basin: 6 stations on the Klamath River; 3 stations on the Shasta River, and 1 station on the Trinity River (the Shasta River and the Trinity River drain into the Klamath River); 1 station on the Lost River upstream of Tule Lake; and 1 station on the Lost River downstream from Tule Lake (*fig. 1*). The HATFIELD station represents water input from the upper Lost River system into Tule Lake, and the TULE station represents water that has moved through Tule Lake to be pumped westward into Lower Klamath Lake

In 2003, the stations on the Lost River (HATFIELD and TULE) and the Trinity River (HOOPA) were discontinued and an additional station was added on the Shasta River (HWY3). These 10 stations were monitored from April through November 2003. Monthly discrete/instantaneous samples for selected nutrient and trace element analyses were collected at the 10 monitoring stations in July, August, and September of 2002. In 2003, in order to get a better understanding of how water-quality processes changed between the various reaches of the Shasta River and Klamath River, a parcel-tracking (Lagrangian sampling) study was conducted during June and August at stations on the Klamath River, and during July and September at stations on the Shasta Rivers, where the same water-quality constituents were collected. A study also was conducted at six sites on the Shasta River to investigate sediment oxygen demand (SOD).

Data Collection and Analysis

Water-quality data have been collected by various agencies in the Klamath Basin for nearly 20 years. Because of the recent assignment of impairments on the Klamath, Shasta, and Lost Rivers, the USGS collected additional data in 2002 and 2003 for the purpose of supplying the NCRWQCB with information necessary for them to develop a TMDL and a Water Quality Management Plan for the Lower Klamath Basin.

Continuous Monitoring

Continuous water-quality monitoring instruments were installed at 12 locations in June and July 2002 (*fig. 1*; *table 1*). All the hourly data that had quality-control checks are shown in subsequent figures. The complete data set is archived in the U.S. Geological Survey (USGS) California District National Water Information System (NWIS) database. An additional site was installed in the Shasta River near Hwy 3 in April 2003 (HWY3); the HOOPA, TULE, and HATFIELD stations were discontinued after the 2002 season. Multi-parameter water-quality instruments from Yellow Springs Instruments, model 6920, were used to collect DO (mg/L), water temperature (°C), specific conductance (µS/cm), and pH on an hourly basis. Standard USGS protocols were used for site selection, verification of the representativeness of a stream cross section, cleaning and calibration of probes, quality assurance procedures, and the shifting of data to account for measured biofouling and instrument drift. These protocols are documented by Wagner and others (2000); some are also documented in a USGS National Field Manual by Wilde and Radtke (1998). Instrument maintenance was done approximately biweekly. A detailed accounting of station maintenance and data analysis, along with an assessment of the uncertainty in the DO data for the Shasta River, is included in *appendix 2*.

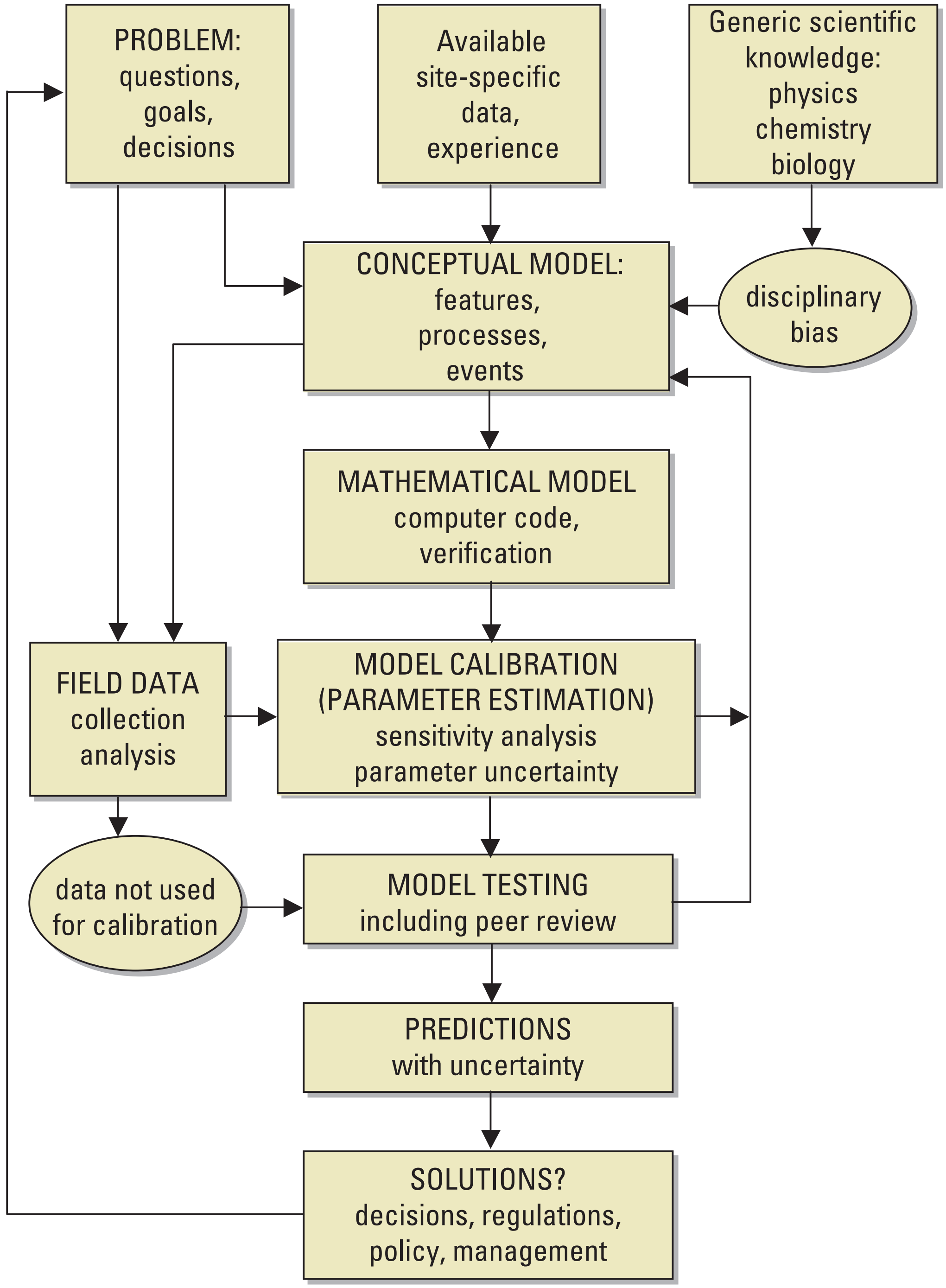

Figure 2. Flow chart illustrating the elements of the modeling process.

Table 1. Station location and measurement periods for continuous monitoring stations in the lower Klamath River Basin, California, 2002 and 2003.

[Stations are listed in order from the mouth of the Klamath River upstream. The Shasta River near Grenada site (GRENADA) that was used in the parcel tracking study is included to provide location information. ID, U.S. Geolological Survey station identification number; Latitude and longitude are referenced to the North American Datum of 1983, NAD83; ft, foot; mi, mile; mi^2, square miles; latitude and longitude in decimal degrees; R., River; —, no drainage area information available]

Abbreviated station name	Station name	Station ID	Latitude	Longitude	Drainage area (mi^2)	Location	Measurement periods	
							2002	2003
KLAMATH	Klamath R. near Klamath	11530500	41.5143	−124.0004	12,100	0.2 mi upstream from Turwar Creek	7/10/02 – 11/1/02	4/29/03 – 11/30/03
HOOPA	Trinity R. at Hoopa	11530000	41.0499	−123.6720	2,853	Hoopa Valley Indian Res. 0.1 mi upstream from Supply Creek	6/27/02 – 10/28/02	
ORLEANS	Klamath R. at Orleans	11523000	41.3034	−123.5345	8,475	Orleans, 25 ft upstream from highway bridge	6/27/02 – 11/5/02	4/29/03 – 11/30/03
SEIAD	Klamath R. near Seiad Valley	11520500	41.8537	−123.2323	6,940	0.4 m upstream from Bittenbender Creek	6/28/02 – 11/5/02	4/29/03 – 11/30/03
WALKER	Klamath R. at Walker Bridge near Klamath R.	11517818	41.8376	−122.8645	5,885	1 mi downstream from Grouse Creek	6/28/02 – 11/5/02	4/29/03 – 11/30/03
YREKA	Shasta R. near Yreka	11517500	41.8229	−122.5956	793	Shasta R. just upstream of confluence with Klamath R.	6/29/02 – 11/6/02	5/14/03 – 11/30/03
HWY3	Shasta R. at Hwy 3 near Montague	11511705	41.7268	−122.5584	676	Shasta R. at Hwy 3		4/10/03 – 11/30/03
MONTAGUE	Shasta R. near Montague	11517000	41.7090	−122.5381	673	1 mi below Little Shasta R.	6/26/02 – 11/6/02	4/11/03 – 11/30/03
GRENADA	Shasta R. near Grenada	11516880	Not defined			6 mi upstream from Montague, at Hwy A–2		
EGEWOOD	Shasta R. near Edgewood	11516750	41.4713	−122.4409	70	0.8 mi downstream from Beaughton Creek	6/26/02 – 11/6/02	4/11/03 – 11/30/03
IRONGATE	Klamath R. below Iron Gate Dam	11516530	41.9279	−122.4442	4,630	0.1 mi downstream from Bogus Creek, 0.6 mi downstream from Iron Gate Dam	6/26/02 – 11/6/02	5/15/03 – 11/30/03
SHOVEL	Klamath R. above Shovel Creek near Copco	11510990	41.9724	−122.2020	4,164	0.1 mi upstream from Shovel Creek	7/20/02 – 11/6/02	4/30/03 – 11/30/03
TULE	Tule Lake Canal at Sheepy Ridge Pumping Station near Hatfield	11488510	41.9247	−121.5661	—	0.8 mi downstream from Tule Lake Sump	7/19/02 – 10/1/02	
HATFIELD	Lost River near Hatfield	11488495	41.9539	−121.5033	—	0.9 mi upstream from Tule Lake Sump	7/18/02 – 9/19/02	

Additional water-quality data are available on various websites. Compiling and reviewing this additional data might be useful to the TMDL process. A compilation of all other non-USGS data is not available at this time, but this process should be established as soon as possible for development of the TMDL. The database should include quality-control information on all data, as well as on the sources of the data.

Klamath River Locations

Continuous monitoring stations were installed at seven locations between Iron Gate Dam and the mouth of the Klamath River. Fall-run Chinook salmon spawn in the main stem Klamath River in a 13-mile reach from Iron Gate Dam to the mouth of the Shasta River (Leidy and Leidy, 1984). The range of the spawning area for Coho salmon is not as well defined for the Klamath River Basin but they are much less prevalent. Chinook, Coho, and Steelhead currently are raised at the hatchery at the Iron Gate Dam (*fig.1*).

Temperature requirements vary with life stage: adult (migration and spawning), egg incubation and larvae, and juvenile rearing. Optimum temperatures for adult Chinook salmon are roughly 6 ° C to 14°C, and excessive temperatures may arrest fish migration, predispose adults to disease, accelerate or retard maturation, and generally provide stress to the fish. Temperatures exceeding 21°C arrest the migration of spawning adult Chinook salmon and cause mortality when the temperature is exceeded for extended periods. Thus, 21°C is considered the maximum temperature threshold. Chinook salmon become susceptible to lethal diseases when temperatures attain 16°C (Deas, 2000). The spawning Coho salmon have an acute response to water temperatures exceeding 25.8°C (Deas, 2000). The acute minimum threshold for DO for salmonid populations occurs at levels of 4.25 mg/L or less, with initial oxygen distress occurring at 6 mg/L (Davis, 1975) and chronic stress occurring at 7 mg/L (Campbell, 1995). The water-quality objectives for salmonids for the Karuk Tribe of California, who occupy much of the land bordering the lower one-third of the Klamath River, include acute minimum DO levels of 6 mg/L and minimum levels during salmonid egg incubation of 9 mg/L (Karuk Tribe of California, 2003). The NCRWQCB water-quality objectives define minimum levels of DO as 7.0 mg/L for tributaries to the Klamath River and 8.0 mg/L for the Klamath River mainstem (Deas, 2000).

Data collected from the 12 stations in 2002 and from the 10 stations in 2003 are illustrated in *appendix 1*. These stations are located from the mouth of the Klamath River upstream to the Lost River. Time gaps in the data for these stations generally were due to equipment failure or to extreme biofouling of the DO sensor. A more direct comparison of the data is shown in *figure 3* for water temperature and in *figure 4* for DO for 8 stations: 6 stations along the Klamath River, as well as the 1 station (HOOPA) on the Trinity River and 1 station (YREKA) on the Shasta River, both of which drain into the Klamath River.

Water Temperature

Water temperatures (*fig. 3A* and *B*) for the stations closest to the mouth of the Klamath River show less variation among stations and on a daily basis than temperatures farther upstream. The SHOVEL station (*fig. 1*), above the Copco Reservoir, generally had the coolest water temperatures, never rising above 25°C, and never above 22°C during August, possibly because of cool ground-water accretions in the Klamath River between this station and the Keno Dam below Lower Klamath Lake (Rykbost, 2001). Once the water travels through the Copco and the Iron Gate Reservoirs and is released from the Iron Gate Reservoir, the diurnal variation is greatly reduced. In 2002, the diurnal variation generally exceeded the daily maximum temperatures only at the SHOVEL station and only by about 1°C, except in the fall when heat stored in the reservoir water was still having an effect at IRONGATE. In 2003, the diurnal variation at SHOVEL was larger, with daily maximum temperatures often exceeding those at IRONGATE.

The water flowing into the Klamath River from the Shasta River, measured just upstream on the Shasta River at the YREKA station, had large diurnal fluctuations and the highest temperatures along the Klamath River system, reaching nearly 30°C in mid July (*fig. 3A*). Mid-August daily maximum temperatures reached 27°C. Temperatures at the YREKA station exceeded the 21°C maximum threshold for salmonid stress (Deas, 2000) on a daily basis for nearly the entire period between early July and mid September 2002. Farther downstream at the WALKER station, the downstream station of an in-between reach that only minor tributaries flow into, had measured water temperatures that were similar to those at the IRONGATE station; however, variations in daily temperatures at the WALKER station were greater. The water temperature at WALKER also exceeded the 21°C salmonid maximum stress threshold for all July and most of August. The water temperature at SEIAD, farther downstream, is very similar to that at WALKER. The temperature at ORLEANS was within the same range as that at SEIAD, had very little daily variation, and exceeded the 21°C threshold throughout July and August. The Trinity River delivers cooler water to the Klamath River, as indicated by a lower water temperature at KLAMATH during July. The temperature at KLAMATH exceeded the 21°C salmonid threshold for all of July and August 2002.

Water-temperature data for the stations along the Shasta River for 2002 and 2003 (*fig. 5A*) show that diurnal temperatures exceeded the 21°C salmonid threshold for the entire summer season (through September) of both 2002 and 2003. In 2002, the diel variation at the EDGEWOOD station, upstream of Lake Shastina, was larger than that at the other two stations (MONTAGUE and YREKA). In 2003, the three stations downstream from Lake Shastina (MONTAGUE, HWY3, and YREKA) had similar water temperatures throughout the summer season, with slightly higher temperatures at the YREKA station. The water temperatures at EDGEWOOD were lower than the temperatures at the other three stations for the entire 2003 measurement period, although the diurnal temperature also exceeded 21°C in mid July.

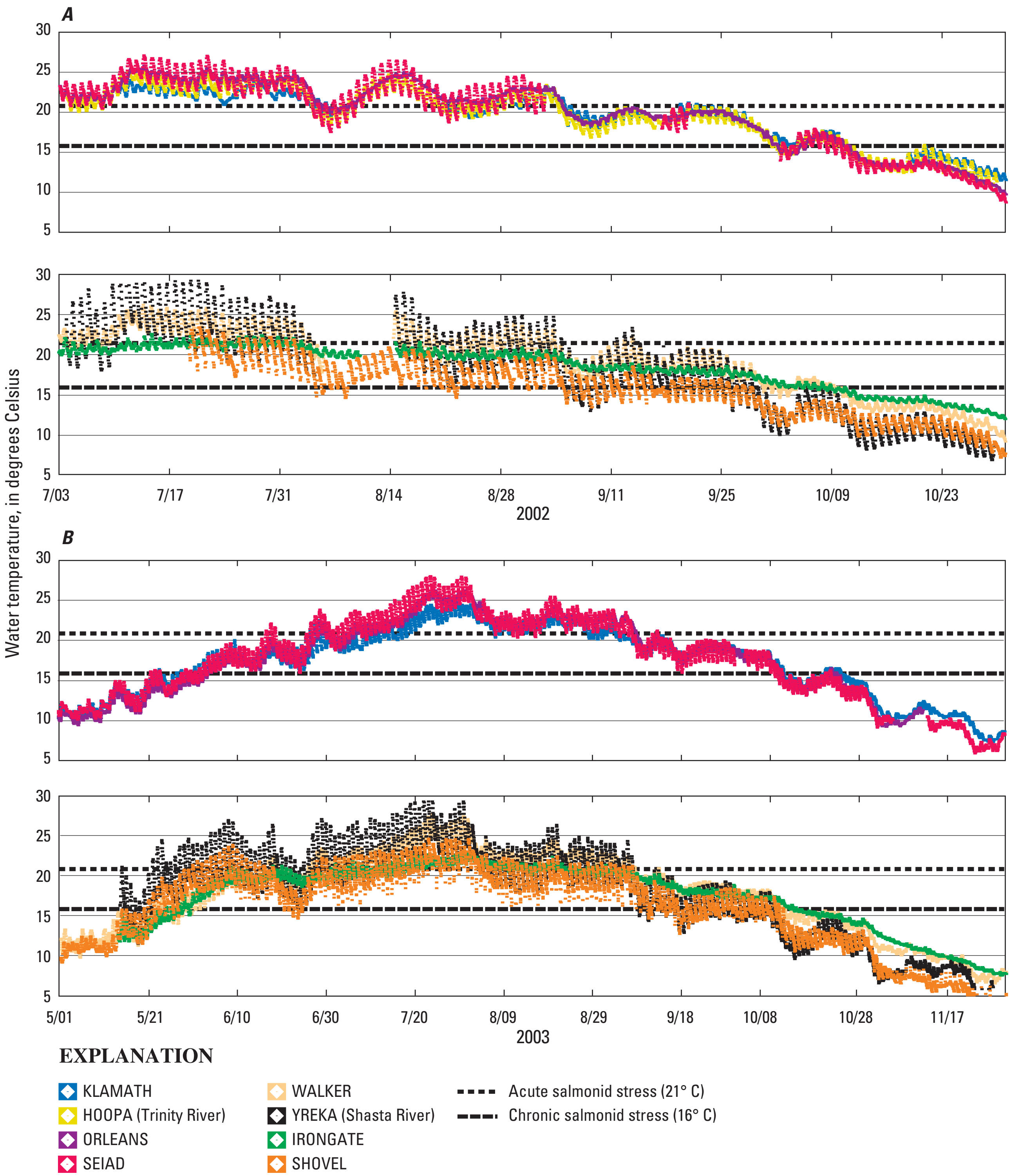

Figure 3. Water temperatures at continuous monitoring stations along the Klamath River in the Lower Klamath River Basin, California. ***A***, 2002. ***B***, 2003.

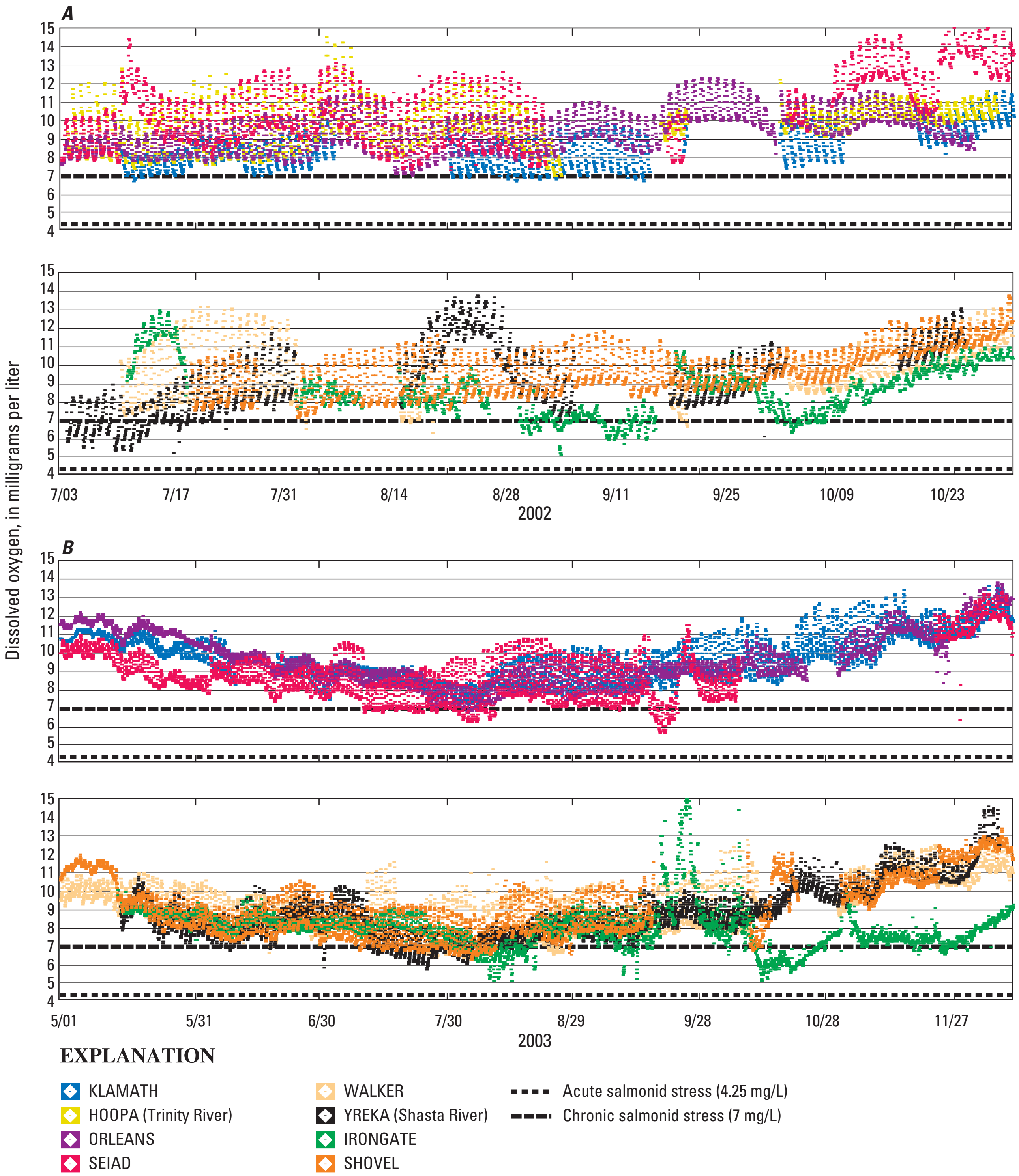

Figure 4. Dissolved oxygen at continuous monitoring stations along the Klamath River in the Lower Klamath River Basin, California. ***A.*** 2002. ***B.*** 2003.

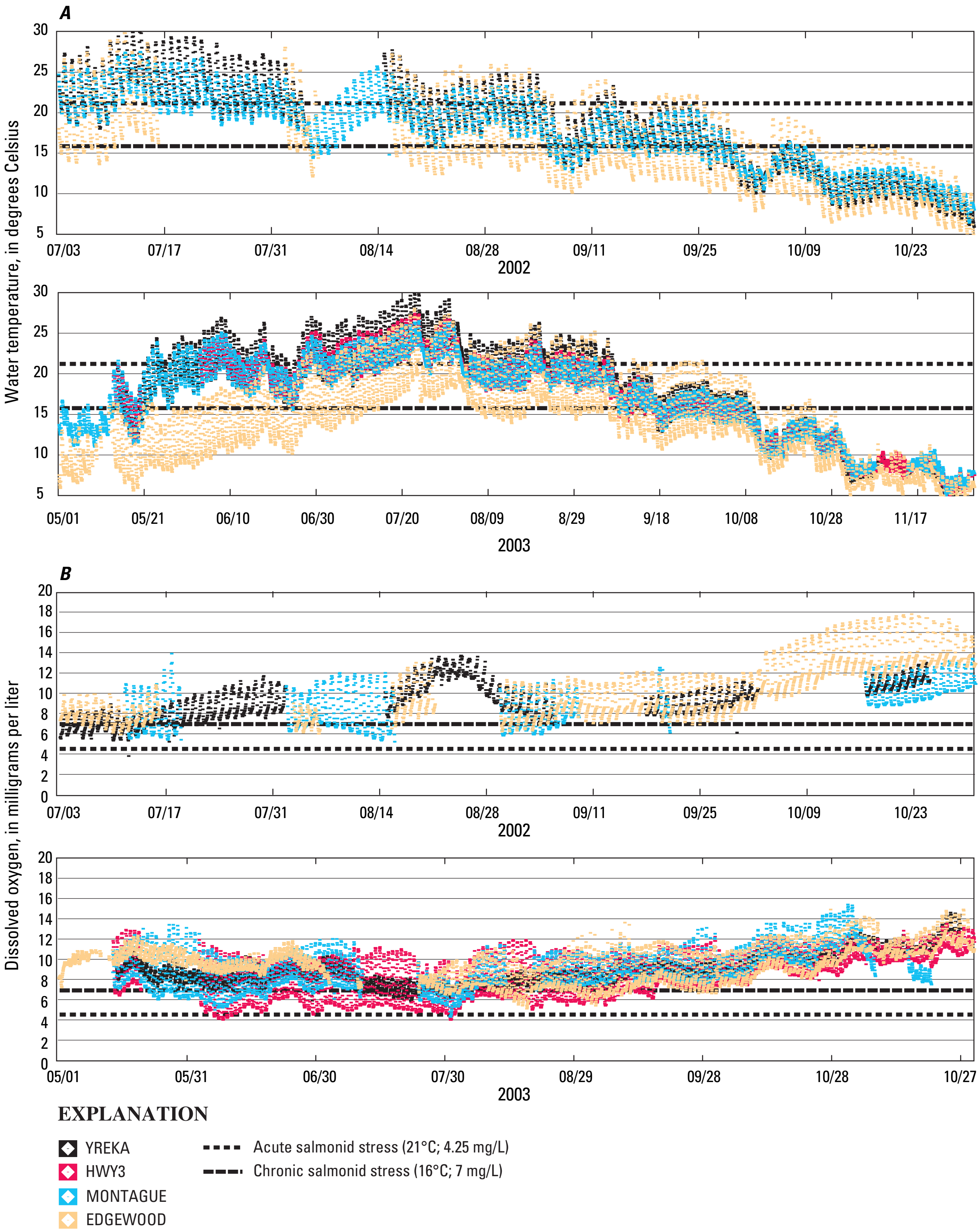

Figure 5. Measurements of (***A***) water temperature and (***B***) dissolved oxygen at continuous water-quality monitoring stations along the Shasta River in the Lower Klamath River Basin, California, 2002 and 2003.

Dissolved oxygen

Dissolved oxygen data for stations along the Shasta River for 2002 and 2003 (*fig. 5B*) show that during mid summer concentrations frequently dipped below the chronic level acceptable for salmonid health. The YREKA station had the smallest diurnal variation in DO, and the stations at MONTAGUE and EDGEWOOD had the largest. In addition, the large daily variations in DO and the frequent occurrence of supersaturated conditions are indicative of the presence of a strong influence of photosynthesis and respiration by algae and (or) aquatic plants at these sites.

Although the solubility of DO is such that DO and water temperature should be negatively correlated, relations between these two constituents at most of the stations on the Klamath River do not follow the dictates of solubility because of the influence other processes, such as algal photosynthesis, respiration, and decomposition. *Figure 6* illustrates the variation in the relation by showing DO data from three stations compared with water temperature and the calculated solubility (DO saturation calculated on the basis of barometric pressures in *table 2*). The region above and to the right of the line of solubility represents measurements when photosynthetic processes dominate the DO balance, and the region below and to the left of the line of solubility (saturation) represents measurements taken at periods of time when sediment oxygen demand (SOD) and biological oxygen demand (BOD) dominate the DO balance. The relation of DO to water temperature at the SHOVEL station was affected somewhat by photosynthetic processes between October and November. The SEIAD station was affected by algal photosynthesis and respiration between July and September and was not affected or only slightly affected between April and June. Data from the KLAMATH station, which had the smallest range in water temperature, showed the least effects owing to DO solubility.

The DO figures (*fig. 4A* and *B*) show the chronic (7 mg/L) and acute (4.25 mg/L) minimum thresholds for salmonids (Davis, 1975). Beginning upstream, the DO at the SHOVEL station, although extremely variable on a daily basis, never fell below the chronic threshold for salmonids in 2002. The relation between water temperature and DO at this location best represents a condition where flow is stable and relatively cool, and nutrient loads are low enough to not substantially influence the algal production that influences DO levels (*fig. 6*).

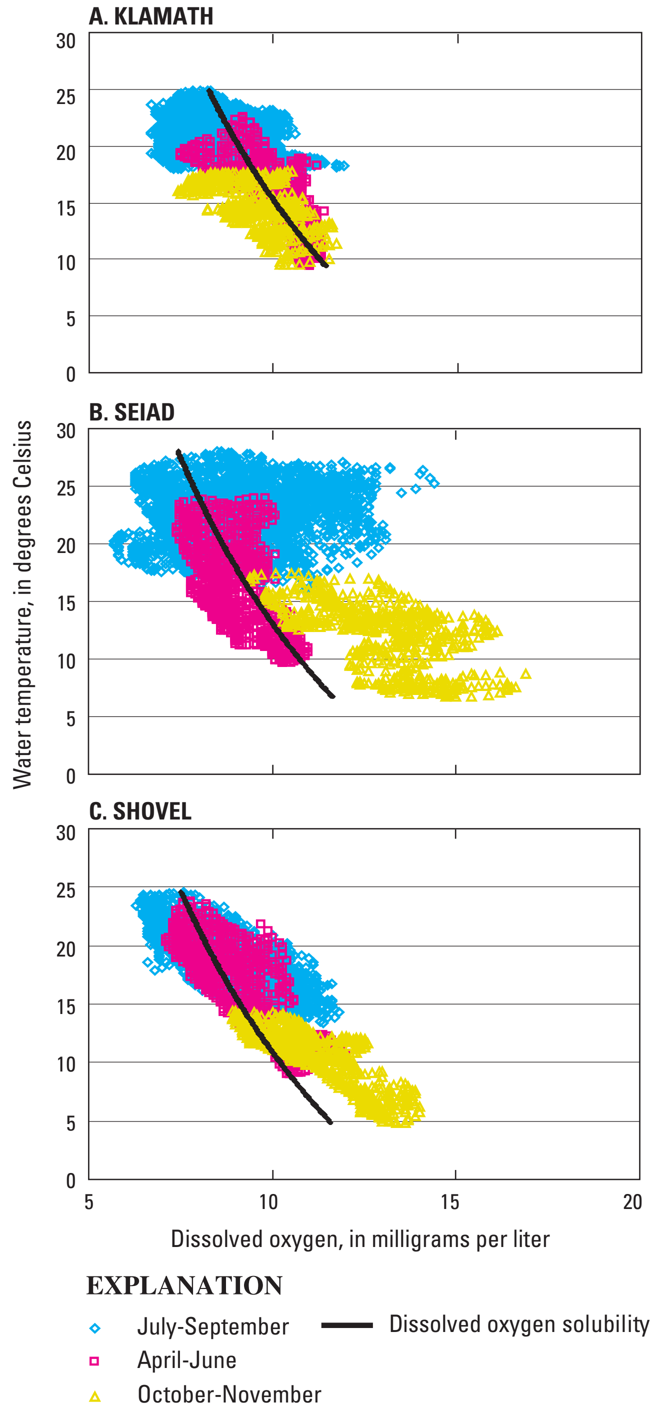

Figure 6. Relation between water temperature and dissolved oxygen (DO) for continuous water-quality monitoring stations at in the Lower Klamath River Basin, California, 2002 and 2003. ***A,*** KLAMATH; ***B,*** SEIAD; and ***C,*** SHOVEL.

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Abbreviated station name	Date	Time	Instan-taneous discharge (ft^3/s) [00061]	Turbidity (NTU) [99872]	Barometric pressure (mm Hg) [00025]	Dissolved oxygen (mg/L) [00300]	Dissolved oxygen (percent saturation) [00301]	pH, (field standard units) [00400]	Specific conduc-tance, unfiltered water (µS/cm) [00095]	Water temperature (°C) [00010]	Alkalinity, water disrict fet lab (mg/L as $CaCO_3$) [29801]
KLAMATH	7/15/02	1255	3020	2	760	8.2	94	8.4	170	22.0	75
	8/20/02	1400	2110	2.1	764	9.2	103	8.7	178	21.0	83
	9/24/02	1340	2030	E1.6	758	9.0	100	8.6	183	20.0	E82
HOOPA	7/9/02	1155	1010	1	750	8.1	94	8.6	149	22.0	68
	8/12/02	1350	707	1.6	745	9.2	112	7.7	142	24.0	68
	9/16/02	1130	631	0.7	750	9.8	106	7.5	145	18.5	E67
ORLEANS	7/9/02	1520	1820	0.8	747	8.9	105	8.3	180	22.5	77
	8/13/02	1055	1260	1.8	745	7.5	91	8.1	194	24.0	84
	9/16/02	1525	1290	1.1	747	10.4	116	8.4	193	19.5	E85
SEIAD	7/10/02	0840	1200	1.1	722	8.6	105	8.3	224	22.5	90
	8/13/02	1550	774	2.7	722	8.7	114	9.8	207	26.0	87
	9/17/02	0800	844	1.4	720	8.5	95	7.8	205	18.0	E88
WALKER	7/10/02	1315	1010	2.4	712	8.8	111	8.6	218	23.5	85
	8/14/02	1020	758	4.2	713	8.1	99	8.3	202	22.0	88
	9/17/02	1245	832	1.8	712	11.2	128	8.4	200	18.5	E85
YREKA	7/10/02	1645	21	2.6	735	7.1	98	8.6	590	30.0	280
	8/14/02	1340	17	3.8	702	9.4	124	8.4	642	25.0	310
	9/17/02	1515	24	1.1	703	9.4	110	8.5	627	19.0	E304
MONTAGUE	7/11/02	1130	38	2.3	692	8.2	106	8.4	516	23.0	234
	8/15/02	0925	25	2.9	693	7.2	86	7.9	503	19.0	233
	9/18/02	1615	33	2.9	696	11.0	130	8.3	522	19.0	E246

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Abbreviated station name	Date	Time	Instantaneous discharge (ft^3/s) [00061]	Turbidity (NTU) [99872]	Barometric pressure (mm Hg) [00025]	Dissolved oxygen (mg/L) [00300]	Dissolved oxygen (percent saturation) [00301]	pH, (field standard units) [00400]	Specific conductance, unfiltered water (µS/cm) [00095]	Water temperature (°C) [00010]	Alkalinity, water disrict fet lab (mg/L as $CaCO_3$) [29801]
EDGEWOOD	7/11/02	1330	9	1.6	682	7.5	108	8.9	238	28.0	120
	8/15/02	1130	12	2.8	680	9.9	127	8.0	219	22.0	111
	9/19/02	0815	12	1.6	685	10.4	106	7.7	201	11.5	E104
IRONGATE	7/11/02	0820	897	1.7	700	7.1	86	8.4	209	20.5	80
	8/14/02	1610	665	3.4	702	9.9	122	8.7	182	21.5	81
	9/18/02	0845	773	1.7	703	8.7	99	8.1	183	17.5	e77
SHOVEL	7/2/02	1225	414	3	688	9.0	111	9.0	149	20.5	67
	8/20/02	1125	428	1.9	690	9.9	111	8.4	176	16.0	80
	9/19/02	1315	706	2.7	693	10.0	110	8.3	226	15.5	e84
TULE	8/19/02	1445	151	11	654	9.2	120	9.8	570	20.5	137
	9/19/02	1630	219	6.5	655	11.3	145	9.5	530	20.0	E141
HATFIELD	7/18/02	1315	52	5.8	655	9.7	137	8.2	167	25.0	72
	8/19/02	1305	126	4.5	654	6.9	89	7.2	220	20.0	192
	9/19/02	1345	207	4.9	658	9.4	115	7.6	253	18.0	E114

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Abbreviated station Name	Date	Time	Nitrogen, ammonia, dissolved		Nitrogen, ammonia + organics, dissolved		Nitrogen, $NO_2 + NO_3$, dissolved		Total inorganic nitrogen (mg/L as N)	Nitrogen/orthophosphate (N/PO_4)	Orthophosphate, dissolved (mg/L as P) [00671]
			(mg/L as N) [00608]	(kg/d as N)	(mg/L as N) [00623]	(kg/d as N)	(mg/L as N) [00631])	(kg/d as N)			
KLAMATH	7/15/02	1255	<0.015	<110.8	0.11	813	E0.009	67.0	0.024	E1.2	E0.02
	8/20/02	1400	<0.015	<77.4	0.18	929	<0.013	<67.0	0.028	—	—
	9/24/02	1340	<0.015	<74.5	0.18	894	E0.009	45.0	0.024	0.8	0.03
HOOPA	7/9/02	1155	<0.015	<37.1	E0.05	124	0.011e	27.0	0.026	<1.3	<0.02
	8/12/02	1350	<0.015	<26.0	<0.1	<173	<0.013	<23.0	0.028	<1.4	<0.02
	9/16/02	1130	<0.015	<23.2	E0.05	77	<0.013	<20.0	0.028	<1.4	<0.02
ORLEANS	7/9/02	1520	<0.015	<66.8	0.21	935	<0.013	<58.0	0.028	0.7	0.04
	8/13/02	1055	<0.015	<46.2	0.29	894	<0.013	<40.0	0.028	0.7	0.04
	9/16/02	1525	<0.015	<47.3	0.33	1,042	<0.013	<41.0	0.028	0.4	0.07
SEIAD	7/10/02	0840	<0.015	<44.0	0.39	1,145	<0.013	<38.0	0.028	0.4	0.08
	8/13/02	1550	<0.015	<28.4	0.54	1,020	<0.013	<25.0	0.028	0.3	0.11
	9/17/02	0800	E0.01	20.7	0.51	1,050	0.069	140.0	0.079	0.7	0.12
WALKER	7/10/02	1315	<0.015	<37.1	0.48	1,186	<0.013	<32.0	0.028	0.3	0.1
	8/14/02	1020	0.017	31.5	0.59	1,090	0.115	213.0	0.132	1.1	0.12
	9/17/02	1245	E0.011	22.4	0.55	1,120	0.127	259.0	0.138	1.0	0.14
YREKA	7/10/02	1645	0.03	1.5	0.52	27	0.016	0.80	0.046	0.2	0.29
	8/14/02	1340	E0.01	0.4	0.59	25	<0.013	<0.50	0.023	0.1	0.32
	9/17/02	1515	E0.009	0.5	0.47	28	0.015	0.90	0.024	0.1	0.26
MONTAGUE	7/11/02	1130	E0.009	0.8	0.33	31	<0.013	<1.2	<0.022	0.1	0.16
	8/15/02	0925	<0.015	<0.9	0.22	14	<0.013	<0.80	<0.028	0.2	0.15
	9/18/02	1615	<0.015	<1.2	0.18	15	<0.013	<1.0	<0.028	0.2	0.16

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Abbreviated station Name	Date	Time	Nitrogen, ammonia, dissolved		Nitrogen, ammonia + organics, dissolved		Nitrogen, $NO_2 + NO_3$, dissolved		Total inorganic nitrogen (mg/L as N)	Nitrogen/orthophosphate (N/PO_4)	Orthophosphate, dissolved (mg/L as P) [00671]
			(mg/L as N) [00608]	(kg/d as N)	(mg/L as N) [00623]	(kg/d as N)	(mg/L as N) [00631])	(kg/d as N)			
EDGEWOOD	7/11/02	1330	E0.009	0.2	0.32	6.7	E0.012	0.30	E0.021	0.3	0.07
	8/15/02	1130	<0.015	<0.4	0.23	6.8	<0.013	<0.40	<0.028	0.6	0.05
	9/19/02	0815	<0.015	<0.4	0.16	4.7	<0.013	<0.40	<0.028	0.5	0.06
IRONGATE	7/11/02	0820	0.032	70.2	0.54	1,190	0.073	160.0	0.105	1.0	0.11
	8/14/02	1610	0.039	63.5	0.66	1,070	0.131	213.0	0.17	1.7	0.1
	9/18/02	0845	0.027	51.1	0.55	1,040	0.214	405.0	0.241	1.6	0.15
SHOVEL	7/2/02	1225	0.018	18.2	0.47	476	0.466	472.0	0.484	3.7	0.13
	8/20/02	1125	0.013	13.6	0.44	461	0.200	210.0	0.213	1.9	0.11
	9/19/02	1315	E0.009	15.5	0.76	1,310	0.211	365.0	0.22	1.8	0.12
TULE	8/19/02	1445	E0.013	4.8	1.8	670	<0.013	<4.8	0.026	0.9	0.03
	9/19/02	1630	0.02	10.7	1.9	1,020	<0.013	<7.0	0.033	1.7	0.02
HATFIELD	7/18/02	1315	0.036	4.6	0.95	120	0.277	35.2	0.313	1.3	0.24
	8/19/02	1305	0.078	24.0	0.98	302	0.385	119.0	0.463	1.9	0.24
	9/19/02	1345	0.069	35.0	0.95	481	0.294	149.0	0.363	1.4	0.26

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Orthophosphate		Phosphorus total		Total organic carbon	Pheophytin-*a* phytoplankton		Chlor-*a* phytoplankton chromoflurom	
			(kg/d as P)	(mg/L as P) [00665]	(kg/d as P)	(mg/L as C) [00680]	(kg/d as C)	(µg/L) [62360]	(g/d)	(µg/L) [70953]	(g/d)
KLAMATH	7/15/02	1255	150	E0.03	220	1.7	13,000	0.9	7,000	2.9	21,000
	8/20/02	1400	—	E0.03	150	2.4	12,000	2.2	11,000	2.3	12,000
	9/24/02	1340	150	E0.05	250	4.3	21,000	2.8	14,000	2.8	14,000
HOOPA	7/9/02	1155	<50	<0.06	<150	0.8	2,000	0.3	700	0.2	500
	8/12/02	1350	<35	<0.06	<100	0.9	1,600	0.3	500	0.2	300
	9/16/02	1130	<31	<0.06	<90	1.2	1,900	0.8	1,000	0.4	600
ORLEANS	7/9/02	1520	E180	E0.05	220	2.7	12,000	0.7	3,000	0.7	3,000
	8/13/02	1055	120	0.06	190	4	12,000	3.1	9,600	2.3	7,100
	9/16/02	1525	220	0.1	320	4.1	13,000	2.6	8,200	1.9	6,000
SEIAD	7/10/02	0840	230	0.1	290	5.7	17,000	2.5	7,300	1.3	3,800
	8/13/02	1550	210	0.15	280	6.5	12,000	5.2	9,800	3.2	6,100
	9/17/02	0800	250	0.14	290	6.2	13,000	11.2	23,100	6	12,000
WALKER	7/10/02	1315	250	0.14	350	6.5	16,000	2.7	6,700	2.1	5,200
	8/14/02	1020	220	0.16	300	7.1	13,000	8.1	15,000	9.3	17,000
	9/17/02	1245	290	0.17	350	7	14,000	7.3	15,000	5.2	11,000
YREKA	7/10/02	1645	15	0.35	18	7.3	380	3.8	200	2.1	110
	8/14/02	1340	13	0.34	14	7.9	330	2.5	100	1.6	70
	9/17/02	1515	15	0.27	16	10.6	620	3.4	200	1.7	100
MONTAGUE	7/11/02	1130	15	0.19	18	3.4	300	1.7	200	1.0	100
	8/15/02	0925	9	0.16	9	2.9	200	1.2	100	0.4	0
	9/18/02	1615	13	0.16	13	5.0	400	1.1	100	0.4	0

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Orthophosphate		Phosphorus total		Total organic carbon	Pheophytin-*a* phytoplankton		Chlor-*a* phytoplankton chromoflurom	
			(kg/d as P)	(mg/L as P) [00665]	(kg/d as P)	(mg/L as C) [00680]	(kg/d as C)	(µg/L) [62360]	(g/d)	(µg/L) [70953]	(g/d)
EDGEWOOD	7/11/02	1330	2	0.10	2	4.4	100	4.2	100	2.6	100
	8/15/02	1130	2	0.07	2	3.9	100	4.7	100	6.5	200
	9/19/02	0815	2	0.08	2	4.1	100	8.6	300	6.0	200
IRONGATE	7/11/02	0820	240	0.15	330	6.3	14,000	2	4,400	3.6	7,900
	8/14/02	1610	160	0.17	280	10.3	17,000	2.8	4,600	40.4	65,700
	9/18/02	0845	280	0.16	300	6.4	12,000	5	9,500	8.4	16,000
SHOVEL	7/2/02	1225	130	0.15	150	4.6	4,700	4.5	4,600	2.5	2,500
	8/20/02	1125	120	0.12	130	5.1	5,300	3.6	3,800	2.7	2,800
	9/19/02	1315	210	0.15	260	9.1	16,000	10.4	18,000	6.4	11,000
TULE	8/19/02	1445	11	0.24	89	29.8	11,000	8.3	3,100	37.2	13,700
	9/19/02	1630	11	0.24	130	28.5	15,000	25.9	13,900	45.5	24,400
HATFIELD	7/18/02	1315	31	0.32	41	11.4	1,500	31.6	4,020	22.8	2,900
	8/19/02	1305	74	0.29	89	11.2	3,500	9.3	2,900	5.0	2,000
	9/19/02	1345	130	0.31	160	11.2	5,700	17.3	8,760	27.0	14,000

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Aluminum, dissolved (µg/L) [01106]	Antimony, dissolved (µg /L) [01095]	Arsenic, dissolved (µg /L) [01000]	Barium, dissolved (µg /L) [01005]	Beryllium, dissolved (µg /L) [01010]	Cadmium, dissolved (µg /L) [01025]	Chromium, dissolved (µg /L) [01030]	Cobalt, dissolved (µg /L) [01035]	Copper, dissolved (µg /L) [01040]
KLAMATH	7/15/02	1255	—	—	—	—	—	—	—	—	—
	8/20/02	1400	—	—	—	—	—	—	—	—	—
	9/24/02	1340	<1	<0.05	3	14.0	<0.06	<0.04	<0.8	0.08	0.7
HOOPA	7/9/02	1155	—	—	—	—	—	—	—	—	—
	8/12/02	1350	—	—	—	—	—	—	—	—	—
	9/16/02	1130	1	0.09	2	14.0	0.06	0.04	<0.8	0.04	0.5
ORLEANS	7/9/02	1520	—	—	—	—	—	—	—	—	—
	8/13/02	1055	—	—	—	—	—	—	—	—	—
	9/16/02	1525	1	E0.05	3	14.0	<0.06	<0.04	<0.8	0.1	0.8
SEIAD	7/10/02	0840	—	—	—	—	—	—	—	—	—
	8/13/02	1550	—	—	—	—	—	—	—	—	—
	9/17/02	0800	2	E0.04	4	10.0	<0.06	<0.04	2.4	0.13	1.2
WALKER	7/10/02	1315	—	—	—	—	—	—	—	—	—
	8/14/02	1020	—	—	—	—	—	—	—	—	—
	9/17/02	1245	2	E0.04	5	8.0	<0.06	<0.04	<0.8	0.13	0.6
YREKA	7/10/02	1645	—	—	—	—	—	—	—	—	—
	8/14/02	1340	—	—	—	—	—	—	—	—	—
	9/17/02	1515	1	0.09	6	42.0	<0.06	<0.04	<0.8	0.19	1.0
MONTAGUE	7/11/02	1130	—	—	—	—	—	—	—	—	—
	8/15/02	0925	—	—	—	—	—	—	—	—	—
	9/18/02	1615	<1	E0.04	7	29.0	<0.06	<0.04	<0.8	0.09	0.7

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Aluminum, dissolved (µg/L) [01106]	Antimony, dissolved (µg /L) [01095]	Arsenic, dissolved (µg /L) [01000]	Barium, dissolved (µg /L) [01005]	Beryllium, dissolved (µg /L) [01010]	Cadmium, dissolved (µg /L) [01025]	Chromium, dissolved (µg /L) [01030]	Cobalt, dissolved (µg /L) [01035]	Copper, dissolved (µg /L) [01040]
EDGEWOOD	7/11/02	1330	—	—	—	—	—	—	—	—	—
	8/15/02	1130	—	—	—	—	—	—	—	—	—
	9/19/02	0815	1	0.07	2	7.0	<0.06	<0.04	<0.8	0.09	0.7
IRONGATE	7/11/02	0820	—	—	—	—	—	—	—	—	—
	8/14/02	1610	—	—	—	—	—	—	—	—	—
	9/18/02	0845	2	E0.03	5	7.0	<0.06	<0.04	<0.8	0.11	0.8
SHOVEL	7/2/02	1225	—	—	—	—	—	—	—	—	—
	8/20/02	1125	—	—	—	—	—	—	—	—	—
	9/19/02	1315	2	0.05	6	7.0	<0.06	E0.03	<0.8	0.15	0.8
TULE	8/19/02	1445	—	—	—	—	—	—	—	—	—
	9/19/02	1630	2	0.16	9	11.0	<0.06	E0.02	<0.8	0.2	1.7
HATFIELD	7/18/02	1315	—	0.04	1	0.3	0.2	0.3	11.4	31.6	22.8
	8/19/02	1305	—	0.08	1	0.4	0.2	0.3	11.2	9.3	5.0
	9/19/02	1345	3	0.07	1	0.3	0.3	0.3	11.2	17.3	27.0

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Manganese, dissolved (µg /L) [01056]	Mercury, dissolved (µg /L) [71890]	Mercury, total recoverable (µg /L) [71900]	Molybdenum, dissolved (µg /L) [01060]	Nickel, dissolved (µg /L) [01065]	Selenium, dissolved (µg /L) [01145]	Silver, dissolved (µg /L) [01075]	Zinc, dissolved (µg /L) [01090]	Uranium, dissolved (µg /L) [22703]
KLAMATH	7/15/02	1255	—	—	—	—	—	—	—	—	—
	8/20/02	1400	—	—	—	—	—	—	—	—	—
	9/24/02	1340	3	E0.01	<0.01	0.6	2.43	E1	<1	1	0.07
HOOPA	7/9/02	1155	—	—	—	—	—	—	—	—	—
	8/12/02	1350	—	—	—	—	—	—	—	—	—
	9/16/02	1130	0.9	E0.01	E0.01	0.5	1.55	<2	<1	—	0.06
ORLEANS	7/9/02	1520	—	—	—	—	—	—	—	—	—
	8/13/02	1055	—	—	—	—	—	—	—	—	—
	9/16/02	1525	2.5	<0.01	<0.01	0.8	2.28	<2	<1	—	0.11
SEIAD	7/10/02	0840	—	—	—	—	—	—	—	—	—
	8/13/02	1550	—	—	—	—	—	—	—	—	—
	9/17/02	0800	7.2	0.01	0.02	1.0	1.36	<2	<1	—	0.12
WALKER	7/10/02	1315	—	—	—	—	—	—	—	—	—
	8/14/02	1020	—	—	—	—	—	—	—	—	—
	9/17/02	1245	6.1	E0.01	E0.01	1.0	1.00	<2	<1	—	0.13
YREKA	7/10/02	1645	—	—	—	—	—	—	—	—	—
	8/14/02	1340	—	—	—	—	—	—	—	—	—
	9/17/02	1515	9.7	0.04	0.05	1.0	5.05	<2	<1	—	0.72
MONTAGUE	7/11/02	1130	—	—	—	—	—	—	—	—	—
	8/15/02	0925	—	—	—	—	—	—	—	—	—
	9/18/02	1615	4.7	E0.01	<0.01	0.8	3.13	<2	<1	—	0.72

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Manganese, dissolved (µg /L) [01056]	Mercury, dissolved (µg /L) [71890]	Mercury, total recoverable (µg /L) [71900]	Molybdenum, dissolved (µg /L) [01060]	Nickel, dissolved (µg /L) [01065]	Selenium, dissolved (µg /L) [01145]	Silver, dissolved (µg /L) [01075]	Zinc, dissolved (µg /L) [01090]	Uranium, dissolved (µg /L) [22703]
EDGEWOOD	7/11/02	1330	—	—	—	—	—	—	—	—	—
	8/15/02	1130	—	—	—	—	—	—	—	—	—
	9/19/02	0815	3.7	<0.01	<0.01	0.5	9.28	<2	<1	—	0.07
IRONGATE	7/11/02	0820	—	—	—	—	—	—	—	—	—
	8/14/02	1610	—	—	—	—	—	—	—	—	—
	9/18/02	0845	7.3	E0.01	<0.01	1.0	0.80	<2	<1	—	0.10
SHOVEL	7/2/02	1225	—	—	—	—	—	—	—	—	—
	8/20/02	1125	—	—	—	—	—	—	—	—	—
	9/19/02	1315	4.9	E0.01	<0.01	1.7	0.92	<2	<1	—	0.17
TULE	8/19/02	1445	—	—	—	—	—	—	—	—	—
	9/19/02	1630	2.6	E0.01	E0.01	7.9	2.21	<2	<1	—	0.49
HATFIELD	7/18/02	1315	—	—	—	—	—	—	—	—	—
	8/19/02	1305	—	—	—	—	—	—	—	—	—
	9/19/02	1345	35.5	<0.01	E0.01	1.6	1.46	<2	<1	—	0.22

Streamflow is regulated in all but the smallest subbasins throughout the study area. The effects of regulation are most obvious at IRONGATE on the Klamath River and at HOOPA on the Trinity River (*fig. 7*). The greater short-term variability of flow at MONTAGUE and YREKA on the Shasta River represents a more natural regime. Estimation of natural flow, encompassing both seasonal and daily variations, is beyond the scope of this study but is under investigation by others (Perry and others, 2004). The stations downstream from the Iron Gate Reservoir on the Klamath River show changes in the release rates from the Iron Gate Dam that occurred as a reduction in discharge on July 11 and July 31, 2002, and July 10, 2003, and increased discharge on September 1 and September 27, 2002, and August 1, September 1, and September 21, 2003. *Figure 7* shows the effects of the dam release rates at seven streamflow-gaging stations on the Klamath, Trinity, and Shasta Rivers. Discharge was typically higher at all stations in 2003 than in 2002. Variations in the DO concentration at IRONGATE may be related to reservoir DO conditions that are accentuated by the change in discharge. DO fluctuations were smaller in 2003 than in 2002 for all stations throughout most of the measurement period, probably because of the increased discharge.

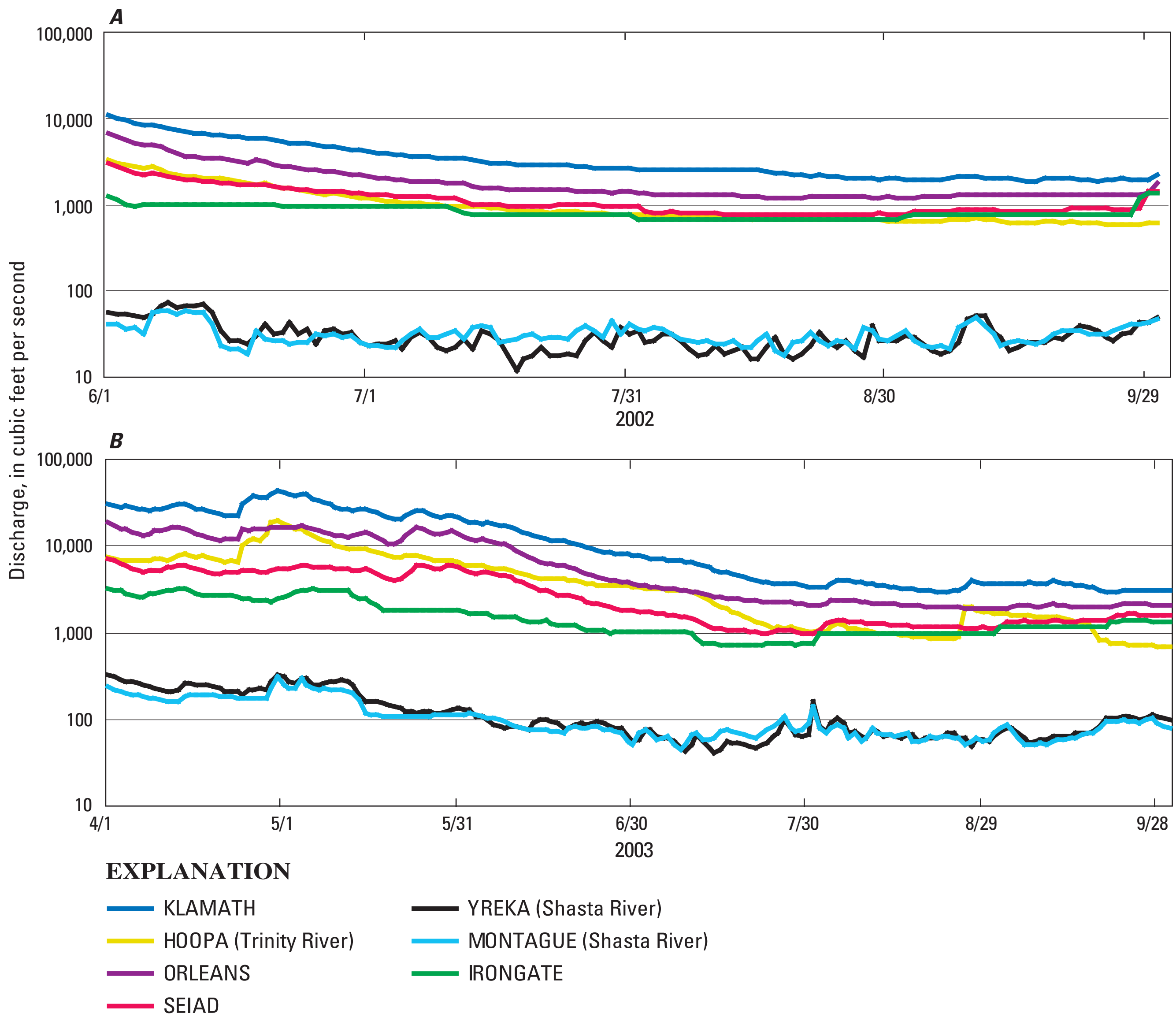

Figure 7. Discharge for seven USGS streamflow gaging stations on the Klamath, Trinity, and Shasta Rivers in the Lower Klamath River Basin, California, 2002 and 2003.

DO at the YREKA station on the Shasta River was low at times, below the chronic minimum of 7 mg/L for salmonids through more than half of July of both 2002 and 2003 (*fig. 4*, *tables 2* and *3*). Although the low DO water from the Shasta River flows into the Klamath River, the flows were too low to greatly affect the DO at the downstream WALKER station, which had DO values above the chronic threshold through July. Few data, however, were available for the WALKER station for August and September 2002. Values for the SEIAD station remain above the chronic minimum threshold for the entire 2002 season but decreased to below the chronic minimum in both July and September 2003. DO at the ORLEANS station never decreased below either minimum threshold. Some of the highs and lows in DO that occurred at the YREKA station were visible in the data from the SEIAD and the ORLEANS stations, yet the patterns do not extend all the way downstream to the KLAMATH station. These patterns may be due partly to climatic patterns that influence algal activity. DO at the HOOPA station was above the minimum thresholds. However, DO at the KLAMATH station was lower than at any other station downstream from the WALKER station for several periods between July and September of 2002, reaching or falling just below the chronic minimum threshold. DO concentration at the KLAMATH station was similar to that at the ORLEANS station in 2003, which was a higher discharge year.

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; mi^2, square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Instantaneous discharge (ft^3/s) [00061]	Drainage area (mi^2)	Turbidity (NTU) [99872]	Dissolved oxygen (mg/L) [00300]	Dissolved oxygen (percent saturation) [00301]	pH, field (standard units) [00400]	Specific conductivity, field (µS/cm)
Shasta River										
Grenada	11516880	6/17/03	0840	103		2.7	6.8	83	8.0	426
Montague	11517000	6/17/03	1150	73	673	5.3	8.7	109	8.3	479
Hwy3	11517015	6/17/03	1435	81	676	2.0	9.9	129	8.4	484
Yreka	11517500	6/17/03	1815	103	793	2.1	8.8	121	8.8	494
Grenada	11516880	8/19/03	0830	83	--	2.1	6.6	77	7.9	426
Montague	11517000	8/19/03	1120	64	673	3.6	8.9	110	8.2	490
Hwy3	11517015	8/19/03	1250	59	676	4.3	10.0	127	8.4	498
Yreka	11517500	8/19/03	1820	62	793	3.7	7.3	97	8.8	530
Klamath River										
Irongate	11516530	7/14/03	0810	747	4,630	1.9	8.6	105	8.2	198
Walker	11517818	7/14/03	1940	933	5,885	2.0	8.4	107	8.8	220
Seiad	11520500	7/15/03	0630	1,110	6,940	1.3	7.8	94	8.3	224
Orleans	11523000	7/16/03	0650	2,510	8,475	2.3	8.6	98	8.2	177
Klamath	11530500	7/17/03	0910	4,680	12,100	1.0	8.5	94	8.2	161
Irongate	11516530	9/15/03	0800	1,190	4,630	4.1	7.0	82	8.4	160
Walker	11517818	9/15/03	1930	1,410	5,885	3.2	8.8	102	8.5	186
Seiad	11520500	9/16/03	0650	1,370	6,940	3.6	8.7	95	8.1	200
Orleans	11523000	9/17/03	0720	1,990	8,475	4.4	9.4	100	8.3	189
Klamath	11530500	9/18/03	0920	3,110	12,100	2.3	9.4	97	8.1	168

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California—***Continued.***

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; mi^2, square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Water temperature (ºC) [00010]	Hardness, unfiltered (mg/L as $CaCO_3$)	Calcium, filtered (mg/L) [00915]	Magnesium, filtered (mg/L) [00935]	Potassium, filtered (mg/L) [00935]	Sodium, filtered (mg/L) [00930]	Sodium, percent in equivalents of major cations [00932]
Shasta River										
Grenada	11516880	6/17/03	0840	19.6	170	21.1	27.6	2.35	27.7	26
Montague	11517000	6/17/03	1150	21.0	180	24.0	30.3	2.78	31.7	27
Hwy3	11517015	6/17/03	1435	23.0	180	23.8	30.0	2.87	31.7	27
Yreka	11517500	6/17/03	1815	26.0	200	28.1	31.8	2.86	31.7	25
Grenada	11516880	8/19/03	0830	18.2	170	22.7	26.8	2.55	27.7	26
Montague	11517000	8/19/03	1120	21.0	190	27.5	29.8	3.10	32.1	26
Hwy3	11517015	8/19/03	1250	22.0	200	28.1	30.4	3.12	33.0	26
Yreka	11517500	8/19/03	1820	25.5	210	31.8	32.8	3.30	34.2	25
Klamath River										
Irongate	11516530	7/14/03	0810	21.5	65	13.4	7.73	3.03	16.3	34
Walker	11517818	7/14/03	1940	24.0		15.3	9.63	2.85	16.6	31
Seiad	11520500	7/15/03	0630	22.0	86	16.9	10.6	2.25	13.4	25
Orleans	11523000	7/16/03	0650	21.5	74	16.0	8.19	1.47	8.18	19
Klamath	11530500	7/17/03	0910	20.0	70	15.5	7.59	.91	5.25	14
Irongate	11516530	9/15/03	0800	19.5	55	11.5	6.43	2.54	13.2	33
Walker	11517818	9/15/03	1930	19.5		12.7	8.21	2.55	14.1	31
Seiad	11520500	9/16/03	0650	17.5	74	14.4	9.22	2.47	13.9	28
Orleans	11523000	9/17/03	0720	18.0	75	15.6	8.69	1.99	11.3	24
Klamath	11530500	9/18/03	0920	17.0	76	15.9	8.77	1.34	7.59	18

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California—***Continued.***

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; mi^2, square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Alkalinity, water, filtered, field (mg/L as $CaCO_3$) [39086]	Bicarbonate, water, filtered, field (mg/L) [00453]	Carbonate, water, filtered, field (mg/L) [00452]	Chloride, water, filtered (mg/L) [00940]	Fluoride, water, filtered (mg/L) [00950]	Silica, water, filtered (mg/L) [00945]	Sulfate, water, filtered (mg/L) [00945]
Shasta River										
Grenada	11516880	6/17/03	0840	194	231	2	15.1	0.2	54.8	5.6
Montague	11517000	6/17/03	1150	263	314	3	18.3	.2	53.7	6.5
Hwy3	11517015	6/17/03	1435	227	268	4	18.4	.3	53.8	6.5
Yreka	11517500	6/17/03	1815	238	269	10	18.3	.3	49.0	7.6
Grenada	11516880	8/19/03	0830	188	227	<1	15.8	.3	57.7	5.8
Montague	11517000	8/19/03	1120	216	260	2	19.2	.3	57.3	6.2
Hwy3	11517015	8/19/03	1250	238	286	2	20.6	.3	57.3	6.4
Yreka	11517500	8/19/03	1820	240	280	6	21.6	.3	51.0	7.7
Klamath River										
Irongate	11516530	7/14/03	0810	100	122	<1	4.25	<0.2	28.1	13.3
Walker	11517818	7/14/03	1940	88	104	2	5.37	<.2	27.2	11.9
Seiad	11520500	7/15/03	0630	94	114	1	5.48	<.2	23.9	10.5
Orleans	11523000	7/16/03	0650	86	104	<1	3.78	<.2	19.8	7.0
Klamath	11530500	7/17/03	0910	72	87	<1	2.87	<.2	16.2	5.7
Irongate	11516530	9/15/03	0800	76	92	1	3.88	<.2	37.5	6.3
Walker	11517818	9/15/03	1930	78	94	1	5.21	<.2	36.1	6.4
Seiad	11520500	9/16/03	0650	76	92	1	5.65	<.2	34.4	6.5
Orleans	11523000	9/17/03	0720	90	109	<1	5.23	<.2	29.2	5.9
Klamath	11530500	9/18/03	0920	78	95	<1	3.87	<.2	21.4	5.4

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California—***Continued.***

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; mi^2, square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Residue on evaporation, dried at 180 C, water, filtered (mg/L) [70300]	Ammonia plus organic nitrogen, water, filtered (mg/L as N) [00608]	Ammonia, water, filtered (mg/L as N)	Nitrite plus nitrate, water, filtered (mg/L as N) [00631]	Orthophosphate, water, filtered (mg/L as P) [00671]	Total phosphorus, water, unfiltered (mg/L) [00665]
Shasta River									
Grenada	11516880	6/17/03	0840	275	0.23	<0.015	<0.022	0.14	0.15
Montague	11517000	6/17/03	1150	289	.33	<.015	<.022	.14	.17
Hwy3	11517015	6/17/03	1435	300	.35	<.015	<.022	.15	.17
Yreka	11517500	6/17/03	1815	309	.36	<.015	<.022	.15	.17
Grenada	11516880	8/19/03	0830	270	.20	<.015	<.022	.15	.17
Montague	11517000	8/19/03	1120	302	.30	<.015	<.022	.17	.19
Hwy3	11517015	8/19/03	1250	317	.38	<.015	<.022	.14	.17
Yreka	11517500	8/19/03	1820	335	.41	<.015	<.022	.16	.19
Klamath River									
Irongate	11516530	7/14/03	0810	150	0.53	0.014	0.125	0.1	0.12
Walker	11517818	7/14/03	1940	139	.49	<.015	.013	.1	.11
Seiad	11520500	7/15/03	0630	140	.35	<.015	.038	.07	.08
Orleans	11523000	7/16/03	0650	120	.16	<.015	<.022	.03	.04
Klamath	11530500	7/17/03	0910	100	.10	<.015	<.022	.01	.02
Irongate	11516530	9/15/03	0800	130	.61	.009	.317	.12	.16
Walker	11517818	9/15/03	1930	147	.58	.010	.285	.12	.16
Seiad	11520500	9/16/03	0650	141	.55	.008	.257	.11	.16
Orleans	11523000	9/17/03	0720	136	.36	<.015	.018	.06	.11
Klamath	11530500	9/18/03	0920	122	.17	<.015	<.022	.03	.06

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California—***Continued.***

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; mi^2, square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Total nitrogen, water, filtered (mg/L) [00602]	Organic carbon, water, unfiltered (mg/L) [00680]	Pheophytin-*a*, phytoplankton (µg/L) [62360]	Chlorophyll-*a*, phytoplankton, chromatographic-fluorometric method (µg/L) [70953]	Iron, water, filtered (µg/L) [01046]	Manganese, water, filtered (µg/L) [01056]
Shasta River									
Grenada	11516880	6/17/03	0840		3.7	4.6	1.7	9	3.4
Montague	11517000	6/17/03	1150		5.6	2.9	.9	12	9.2
Hwy3	11517015	6/17/03	1435		4.5	2.1	.7	10	12.4
Yreka	11517500	6/17/03	1815		5.1	1.1	.4	9	3.7
Grenada	11516880	8/19/03	0830		4.1	3.7	1.0	8	2.9
Montague	11517000	8/19/03	1120		5	1.5	.7	12	5.7
Hwy3	11517015	8/19/03	1250		5.7	1.6	.9	11	7.2
Yreka	11517500	8/19/03	1820		6.7	2.7	.9	7	6.6
Klamath River									
Irongate	11516530	7/14/03	0810	0.65	6.9	3.8	5.8	24	3.2
Walker	11517818	7/14/03	1940		6.2	1.6	.8	23	5.4
Seiad	11520500	7/15/03	0630	.39	4.8	2.6	1.2	20	4.5
Orleans	11523000	7/16/03	0650		2.3	1.5	.8	14	1.4
Klamath	11530500	7/17/03	0910		1.5	.6	.9	8	1.1
Irongate	11516530	9/15/03	0800	.93	8.5	3.8	6.8	21	2.4
Walker	11517818	9/15/03	1930		8.8	4.2	5.0	21	4.8
Seiad	11520500	9/16/03	0650	.80	7.6	5.5	5.0	24	4.2
Orleans	11523000	9/17/03	0720		8.1	5.7	9.7	19	1.8
Klamath	11530500	9/18/03	0920		3.2	2.5	6.2	11	1.3

Lost River Locations

Two species of suckers are endangered in the Lost River. These fish require less oxygen than salmonids, but DO concentrations of less than 2.4 mg/L are considered lethal to suckers (Rykbost, 2001). Water temperatures of greater than 31 to 33 °C are considered above the maximum threshold for suckers in the Klamath Basin (National Research Council, 2004). Water-quality constituents are being measured at the HATFIELD station, which is located on the Lost River where it drains into Tule Lake, and at the TULE station, which is located at the exit of the lake where water is pumped from Tule Lake into Lower Klamath Lake.

Water temperature and DO for the Lost River stations are shown in *figure 8*. Water temperatures were above 21°C for most of July and August, extending above 25°C on several days. Water temperatures at the Lost River stations were nearly always higher than those at the SHOVEL station (*fig. 3A*). Daily concentrations of DO were extremely variable at the HATFIELD station, but were relatively low at the TULE station. Although the record for the HATFIELD station has large gaps, variations in the weekly or bi-weekly concentrations were quite large, indicating the influences of a complex system at this site (*fig. 8*). The DO concentrations at the HATFIELD station were below the lethal limit for suckers on most days during the period of record; the DO concentrations at the TULE station also were problematic for fish health. These wide variations in DO concentrations at the Lost River sites reflect the complex interaction of nutrient and sunlight availability, algal productivity, and biologic and sediment oxygen demand in the Lost River and Tule Lake, where water has a much longer average residence time than in any of the Klamath River reaches. Trends in the DO data for the SHOVEL station (*fig. 4A*), the closest station to receive water flowing from Tule Lake, are similar to those for the stations on the Klamath River, indicating very different influences of flow and other factors on DO between the stations in the two river systems. Information on water-quality conditions in the stretch of river between the Upper Klamath Lake and the SHOVEL station would help clarify the relative importance of the processes affecting DO in the reach upstream of the SHOVEL station.

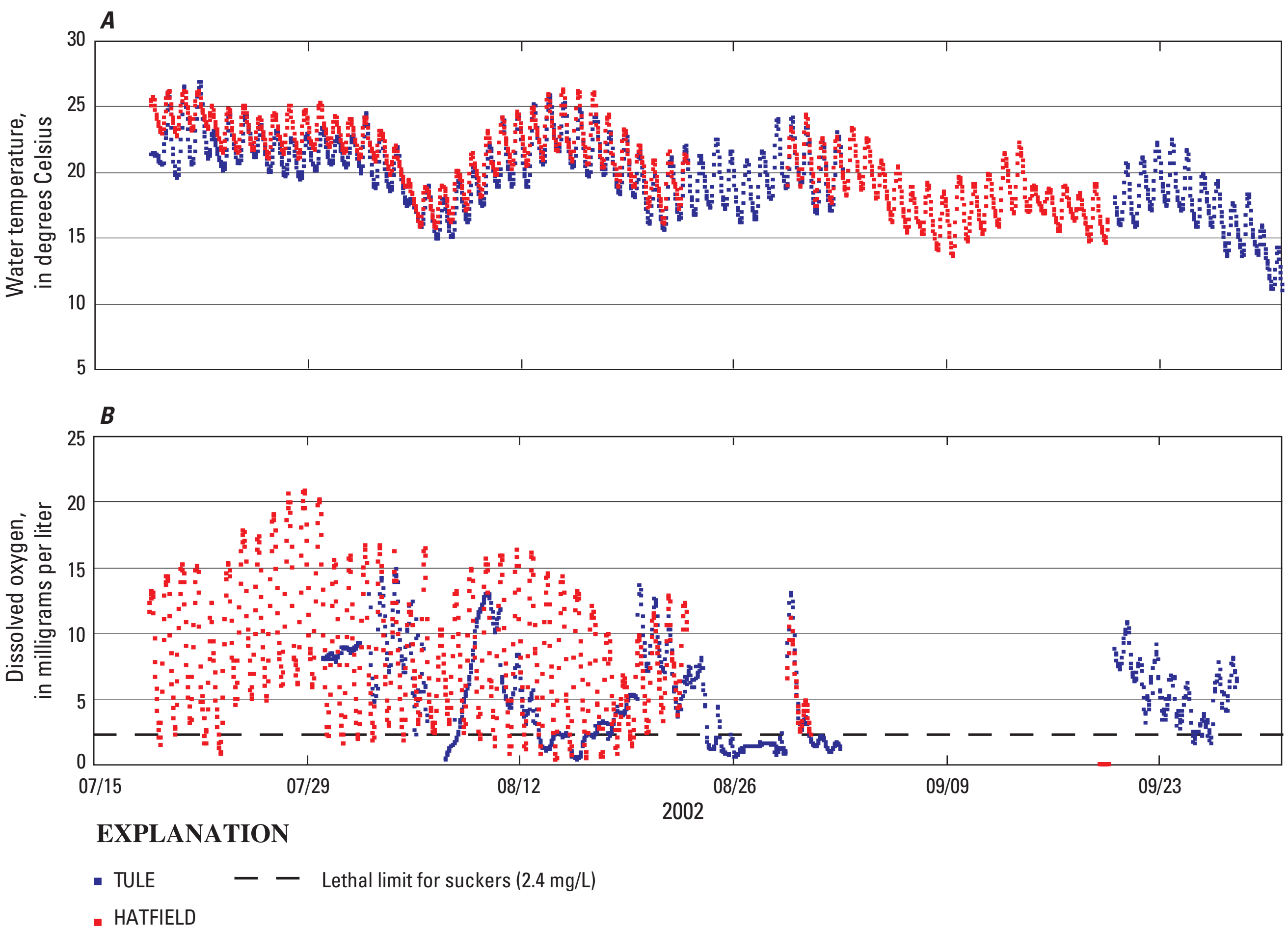

Figure 8. (***A***) Water temperature and (***B***) dissolved oxygen at continuous water-quality monitoring stations at TULE and HATFIELD on the Lost River in the Lower Klamath River Basin, California, 2002.

Monthly Water-Quality Sampling

Water-quality samples were collected at 12 stations each month from July through September 2002 using an equal-discharge increment depth-integrated method at five centroids across the stream cross section; all data that were collected and analyzed are given in *table 2* according to standard USGS procedures and quality-control protocols used at the USGS National Water Quality Laboratory. In 2003, the data-collection approach was changed to a parcel-tracking study to determine physical and chemical changes to a “parcel” of water as it moved downstream (the Lagrangian approach) from IRONGATE to the estuary at the mouth of the Klamath River at the KLAMATH station and from the GRENADA station to the YREKA station on the Shasta River.

The existing Water Quality Control Plan for the North Coast Region (North Coast Regional Water Quality Control Plan, accessed April 2002) includes no direct guidelines for nutrient concentrations, except that “waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.” The range in allowable pH is 7.0 to 8.5 for the Klamath, Trinity, and Shasta Rivers and 7.0 to 9.0 for Tule Lake and the Lost River. The U.S. Environmental Protection Agency (USEPA) has a “desired goal,” rather than a criterion, of 0.1 mg/L for total phosphorus for the prevention of plant nuisances in streams (U.S. Environmental Protection Agency, 1986). Furthermore, the USEPA’s desired goal for total phosphorus should not exceed 0.05 mg/L in any stream at the point where it enters any lake or reservoir nor 0.025 mg/L within the lake or reservoir.

In 2001, the USEPA developed recommended nutrient criteria for rivers and streams of 13 aggregate ecoregions in the United States (U.S. Environmental Protection Agency, 2002). The USEPA’s recommended ecoregional nutrient criteria represent conditions of surface waters that have minimal impacts caused by human activities. The criteria are suggested baselines. California and the Regional Technical Advisory Group: National Nutrient Development, Region 9, are in the process of refining these ecoregional criteria. The USEPA’s recommended total phosphorus and total nitrogen criteria for ecoregion II, which includes the Klamath and Lost Rivers, are 0.01 and 0.12 mg/L, respectively (U.S. Environmental Protection Agency, 2002), as well as a recommended level of chlorophyll-*a* of no more than 1.08 µg/L. The interpretation of the measured nutrient data for the Lower Klamath River Basin is based on these recommendations, as well as on our experience and observations of conditions that likely may cause nuisance levels of algae or that may adversely affect beneficial uses of the water.

2002 Sampling Program

Klamath River Locations

Selected data from the monthly water-quality sampling that occurred in July, August, and September 2002, are shown in *figures 9*, *10*, and *11*. All the hourly data for which quality-assurance checks were completed are shown in the figures. The complete data set is archived in the California District NWIS database. *Figure 9* shows discharge, DO, turbidity, conductivity, alkalinity, water temperature, and pH. The data are presented in groups of three with each bar representing the data for each month for that station. Turbidity was somewhat elevated in August at the IRONGATE, YREKA, and WALKER stations, but diminished downstream. Conductance and alkalinity were very high at the YREKA station for all 3 months (consistent with the continuously monitored data for that station, see *appendix 1*), confirming the relative hardness of the water in the Shasta River compared with that in the rest of the Klamath River drainage, which may be related to the effects of irrigation and evaporation, as well as the geology of the Shasta River Basin. The hardness of the water provides a buffering capacity for specific conductivity in the Shasta River that doesn’t extend downstream in the Klamath River because of the small contribution of water from the Shasta River. The pH was high at all stations, but reached a peak in August at the SEIAD station at pH 9.8, which is above the recommended maximum of pH 8.5. There is no apparent relation between this high value of pH with any other constituents, and although it had the potential to influence ammonia toxicity, the filtered ammonia levels at this location were very low. These values are not inconsistent with the continuously collected data for these sites, many of which exceeded the 8.5 maximum on the Klamath River at many times throughout the 2002 season (*appendix 1*).

Concentrations of nitrogen constituents were low at all the stations measured, with the possible exception of the those at WALKER, IRONGATE, SHOVEL, and HATFIELD stations (*fig. 10*; *table 2*). The total nitrogen concentrations for the SHOVEL and HATFIELD stations could be considered a concern. Concentrations of orthophosphate were high enough to promote a nuisance level of algae at most sites, and concentrations at the SEIAD, WALKER, YREKA, MONTAGUE, IRONGATE, SHOVEL, and HATFIELD stations were high enough to be considered “excessive.” Levels of in-stream soluble phosphate greater than 0.025 mg/L contribute to a saturation of algal growth (Bothwell, 1989), levels at these sites approached or exceeded this concentration for the sampling dates in 2002. Concentrations of orthophosphate at the upstream stations, particularly concentrations at the HATFIELD station on the Lost River and at the YREKA station on the Shasta River, were large enough to be considered hypereutrophic, similar to concentrations in Upper Klamath Lake where hypereutrophic conditions occurred at these levels (Boyd and others, 2002), whereas concentrations at the KLAMATH, HOOPA, ORLEANS, and TULE stations

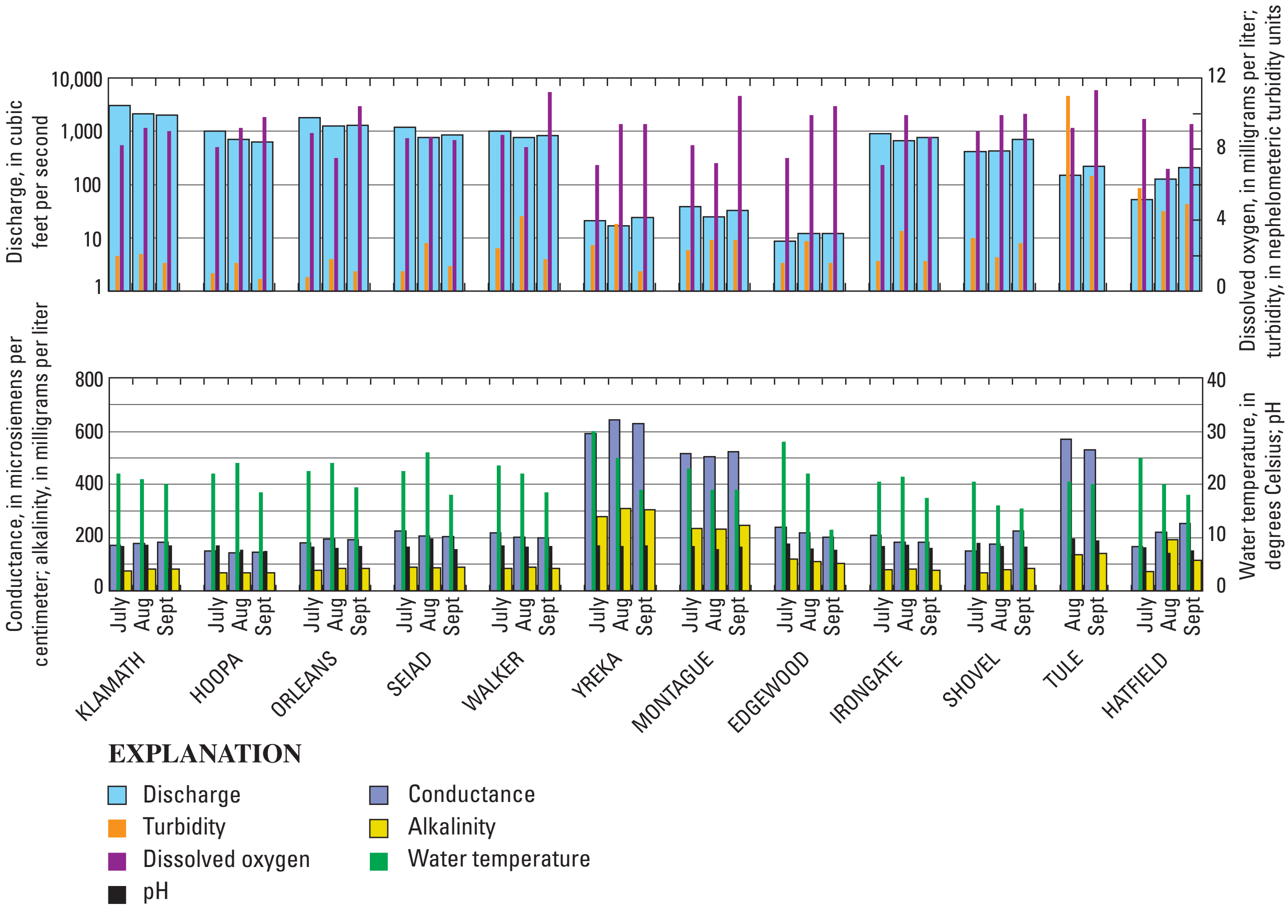

Figure 9. Monthly water-quality sampling data for July, August, and September 2002 for six sites on the Klamath River, one site on the Trinity River, three sites on the Shasta River, and two sites on the Lost River in the Lower Klamath River Basin, Califonia. ***A.*** Instantaneous discharge, dissolved oxygen (DO), and turbidity, and ***B.*** Specific conductance, alkalinity, water temperature, and pH.

probably were low enough to limit further algal growth. Concentrations of total phosphorus exceeded the recommended level of 0.01 mg/L for Ecoregion II, the Klamath River Basin, at all stations.

Loads were calculated using measured discharge (*table 2*) and concentrations for the nitrogen and phosphorus species, total organic carbon, chlorophyll-*a,* and pheophytin-*a,* and are presented in *figure 11* along with the nitrogen:phosphorus ratio. The mass ratio of total inorganic nitrogen to orthophosphorus in algae is about 7, much higher than the maximum 3.7 and median 1.0 measured in the 2002 monthly samples. Thus it is clear there is no P limitation on phytoplankton/algal growth. This is not necessarily true for blue-green algae such as *Aphanizomenon flos-aquae* which are fixed to atmospheric nitrogen and are predominant in the Iron Gate and Copco Reservoirs. Benthic algae such as *Cladophora spp*. reside throughout the mainstem Klamath River. Reducing phosphorus inputs would affect algal biomass only under conditions where sufficient reduction takes place to make phosphorus a growth-limiting constituent (Lee and Jones, 1991). The required reduction of phosphorus to restrict algal growth would be difficult given its high concentration in the natural environment of this basin. The concept of using limiting nutrients to manage eutrophication in the Klamath River Basin is questionable.

The Iron Gate Reservoir has more than twice the load of ammonia + organic nitrogen, although less nitrates and nitrites, as that at the SHOVEL station (*fig. 11*). This is also reflected at the WALKER station on the Shasta River, which contributes very little nutrient load. Indicators of phytoplankton biomass, chlorophyll-*a* and pheophytin-*a* in the Shasta and Trinity Rivers suggest that these constituents did not

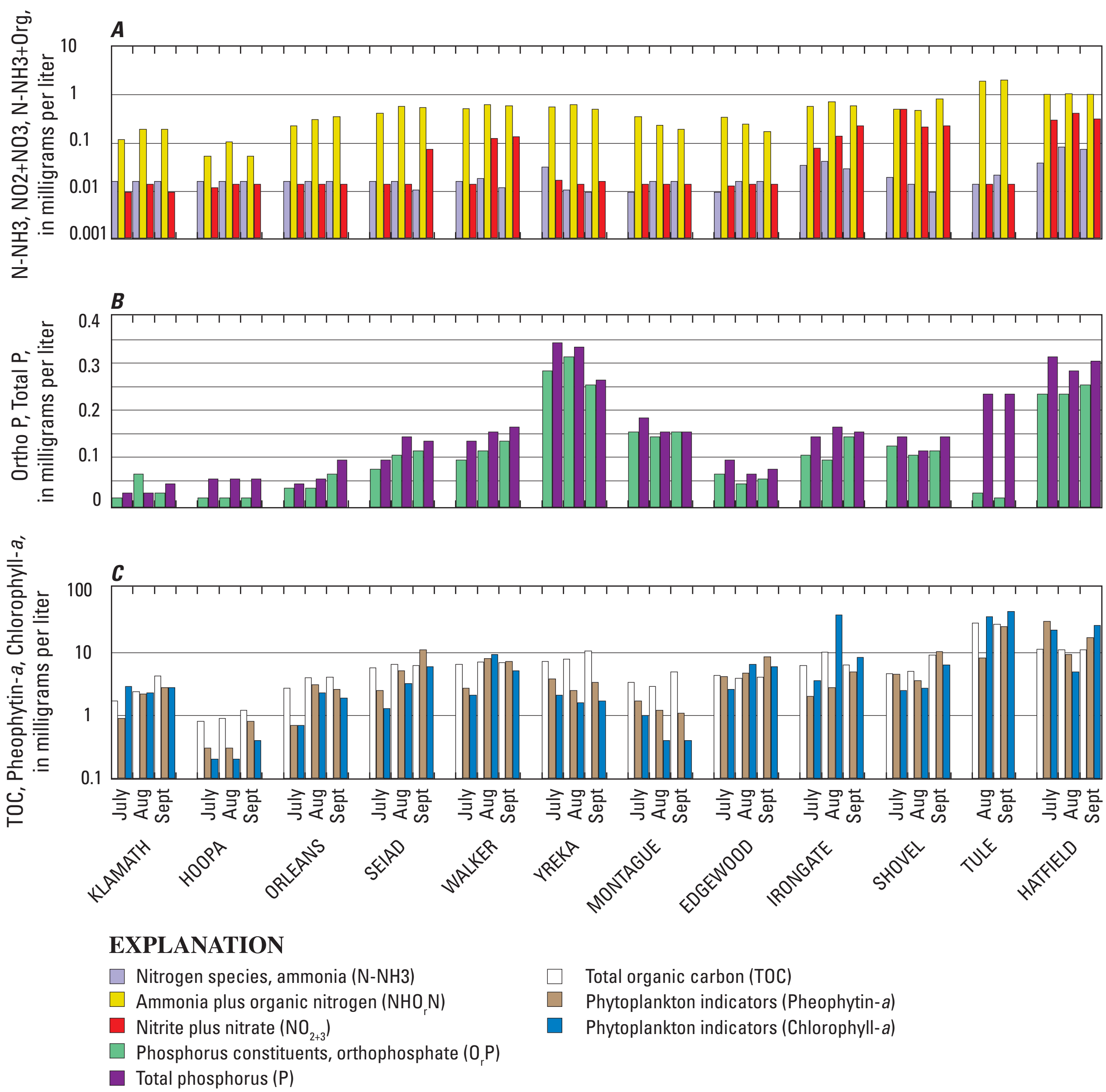

Figure 10. Monthly water-quality sampling data for July, August, and September 2002 for six sites on the Klamath River, one site on the Trinity River, three sites on the Shasta River, and two sites on the Lost River in the Lower Klamath River Basin, California. ***A.*** Nitrogen, ***B.*** Phosphorus constituents, and ***C.*** Total organic carbon (TOC), and phytoplankton indicators pheophytin-***a*** and chlorophyll-***a***, calculated as concentrations.

contribute appreciably to the loads in the Klamath River. Biomass loads of chlorophyll-*a* and pheophytin-*a* were somewhat higher at the SHOVEL station in September as was ammonia + organic nitrogen. There was a peak in chlorophyll-*a* (40.4 µg/L, 65,700 g/day; *table 2*) at the IRONGATE station in August and a relatively high value (9.3 µg/L, 17,000 g/day; *table 2*) at the WALKER station, but it is not clear if this would have been partially responsible for the elevated pH at the SEIAD station that month. There were somewhat high loads of phytoplankton indicators present at the KLAMATH station in July and September, with low values being transmitted from upstream. The high phytoplankton loads could have contributed to the low DO concentration in the water during this time. Further analysis and modeling would be needed to integrate all factors responsible for phytoplankton growth and DO into the interpretation of cause or source, and to evaluate other possible sources between the ORLEANS and the KLAMATH stations.

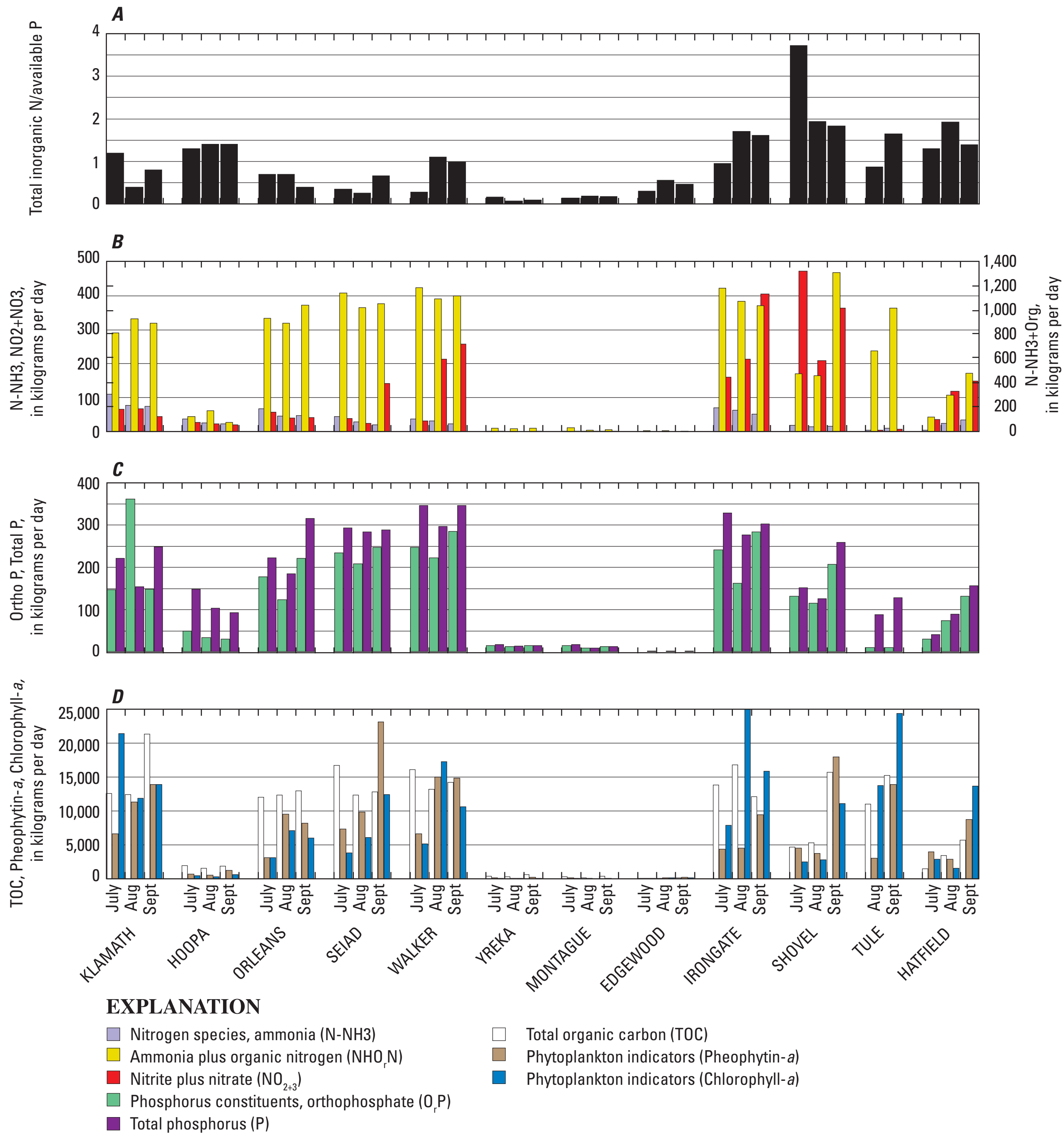

Figure 11. Monthly water-quality sampling data for July, August, and September of 2002 for six sites on the Klamath River, one site on the Trinity River, three sites on the Shasta River, and two sites on the Lost River in the Lower Klamath River Basin, California.
A. Nitrogen phosphorus ratio, ***B.*** Nitrogen and ***C.*** Phosphorus constituents, and ***D.*** Total organic carbon (TOC), and phytoplankton indicators pheophytin-***a*** and chlorophyll-***a***, calculated as loads.

Lost River Locations

Figures 9, *10*, and *11* and *table 2* show selected water-quality data for August and September for the TULE station and for July, August, and September for the HATFIELD station. The HATFIELD station represents water input from the upper Lost River system into Tule Lake, and the TULE station represents water that has moved through Tule Lake to be pumped westward into Lower Klamath Lake. Turbidity and conductivity were particularly high at the TULE station, as was pH, which exceeded 9.5 both months; this is verified in the continuous monitor data. A pH of 9.0 is the maximum pH standard for these sites; the measured pH of >9.5 is considered lethal to suckers, as is the measured DO concentration of < 2.4 mg/L (K. Rykbost, Oregon State University, written commun., 2001). Both of these conditions existed for a good portion of the summer at TULE. The HATFIELD station typically contributes water with low DO (*appendix 1*), which is not apparent from the monthly sampling data because of the large diurnal variations. Ammonia + organic nitrogen was greater than 1 mg/L at the TULE station and was just below that at the HATFIELD station, although the other nitrogen constituents were low (*table 2*). Phosphorus values were high at the HATFIELD station, and total organic carbon was quite elevated at the TULE station, nearly 30 mg/L, which was one-third higher than that at the HATFIELD station (*fig. 10*). Very large concentrations of the phytoplankton indicators were found at both sites, although total loads were higher at the TULE station than at the HATFIELD station. The evidence of algal communities is supported by the concentrations of orthophosphate (ortho P) and total phosphorus (P) at the TULE station, which indicates that an abundance of algae grow in Tule Lake, using up most of the available phosphorus in the process. On the other hand, the concentration of total P at the HATFIELD station indicates that streamflow at this station delivers a large amount of orthophosphate to Tule Lake (orthophosphate concentration was 80 percent of the total P). Data for the TULE station show that orthophosphate was only 10 percent of the total P, again indicating that the phosphorus has been incorporated into algal biomass in Tule Lake. *Table 2* also shows the trace elements and metals for all stations; concentrations of beryllium, cadmium, chromium, cobalt, copper, and manganese are notably high at the HATFIELD station.

2003: Parcel-Tracking Study on the Klamath and Shasta Rivers

In 2003, the NCRWQCB requested that the data collection approach be changed from the fixed interval (Eulerian) sampling used in 2002 to a parcel-tracking (Lagrangian) method in 2003. By using a parcel-tracking approach, a particular “parcel” of water can be followed downstream, and the changes in the physical, chemical, and hydrologic characteristics with location can be evaluated. This approach can provide information regarding the locations or reaches that have conditions contributing to the changes in measured constituents. Lagrangian sample sets can be more useful than Eulerian data for identifying in-stream processes and, thus, for constructing transport models (Battaglin and others, 2001).

The request for parcel-tracking sampling came from the NCRWQB in the spring of 2003. Because the data were needed in 2003, there was not ample time to perform a tracer study to estimate time of travel. Estimates of time of travel from the release at Iron Gate Dam to the mouth of the Klamath River were instead based on analyses of the changes in the stage height caused by a change in release flows in 2002 recorded at the IRONGATE station. Abrupt changes in discharge recorded at IRONGATE can be seen in the downstream discharge records. For example, the decrease in flow at IRONGATE on July 10, 2002, is seen at SEIAD 23 hours later, at ORLEANS 47 hours later and at KLAMATH 73 hours later. The monitoring site at WALKER has no flow gage, so the travel time was estimated as half the travel time between IRONGATE and SEIAD, as it is approximately half way between the two gage sites. Average times of travel were estimated using the decreases in flow on July 10 and July 31 and the increases on August 31 and September 27, 2002, the months that sampling would be done in 2003.

Similarly, time of travel on the Shasta River was estimated using the timing of the change in stage height due to operations at Dwinnell Dam, and the travel time to the HWY3 sampling site estimated as half the time from the MONTAGUE gage to the YREKA gage. Average times of travel were estimated using the decreases in flow on June 12 and August 16, and the increases on June 5 and August 26, 2002, the months that sampling would be done in 2003.

This method gives only rough estimates of travel times in the rivers. As flow increases, so does the velocity of the water, and therefore, travel times are reduced, but this was not accounted for in the estimates of travel times for this study. This was the case in the Klamath River where there was significantly more water in the system in 2003 than in 2002. For most of 2003, the release from Iron Gate Dam was 40 to 60 percent higher than in 2002. In July the 2003 release fell below that of 2002, but in August the release was increased to around 1,190 ft^3/s, so that the 2003 release was again around 50 percent greater than the 2002 release. For most of 2003, discharge at Klamath ranged from 180 to 220 percent of the discharge recorded in 2002. During the third week of July through the third week of August, the flow dropped to around 130 percent. During the third week of August, the Iron Gate Dam release was increased; releases from Lewiston Dam on the Trinity River also were increased for the specific purposes of helping maintain flow and lowering water temperatures for the fall run of salmon in the Klamath and Trinity Rivers, and for the Hoopa Valley Tribe's White Dear Skin Boat Dance. The increase in flow in the Trinity River resulted in an increase in discharge of about 180 percent of that in 2002 at the KLAMATH station on the Klamath River; the increase lasted through the middle of September when it then decreased to about 130 percent of that in 2002. This change in flow regime could not be anticipated, therefore, no compensation could be made for the shorter travel times than those estimated from the 2002 data.

A comparison of the monthly data collected in 2002 with the data collected during the 2003 parcel-tracking study in the Klamath and Shasta Rivers (*table 3*) indicates that most constituents were at comparable levels in 2002 and 2003 at all sites. Notable exceptions include flow, as discussed above, and nitrate + nitrite. Nitrate + nitrite concentrations in September 2003 were more than twice those measured in September 2002 for all five stations on the Klamath River.

Klamath River Parcel Tracking

Figure 12 shows selected data from the parcel-tracking sampling on the Klamath River. In July 2003, the concentrations of most of the constituents decreased as the water moved downstream. In general, it is hard to infer processes underlying changes in temperature and dissolved oxygen since they fluctuate diurnally. Owing to the travel time in the Klamath River, IRONGATE, SEIAD, and ORLEANS were sampled before 8:00 a.m., when one would expect the coolest water temperatures and lower dissolved oxygen, while KLAMATH was sampled after 9:00 a.m., when water temperature and photosynthesis were increasing. WALKER was sampled at 7:30 p.m., when even higher water temperatures and dissolved oxygen were expected. In addition, the Shasta River, which usually has warmer, more alkaline water, discharges just above the WALKER sampling site, which complicates the interpretation of the changes in the various constituents between IRONGATE and WALKER beyond that of the diurnal fluctuations. However, because there is no data from the Shasta River at the time of the Klamath River sampling, its relative contribution could not be determined.

Results of the parcel-tracking sampling does lend credence to the inference made in the prior discussion of the 2002 data that the discharge of the Shasta River has a noticeable effect on the water quality at WALKER, but that the effect does not extend downstream. Nitrate + nitrite, pheophytin-*a,* and chlorophyll-*a* concentrations decreased appreciably from the concentrations at IRONGATE, increased at SEIAD, and then decreased as the water moved downstream. The water temperature leaving IRONGATE was 21.5°C. The temperature rose to 24°C at WALKER, and then decreased steadily until it reached 20°C at KLAMATH. Also specific conductivity, carbonate, and pH also were higher at WALKER than at IRONGATE.

Specific conductivity, carbonate, bicarbonate, and alkalinity all remained high or increased at SEIAD (*fig. 12*) indicating that the Scott River may also contribute to the buffering capacity of the Klamath River. The temperature dropped 2°C between WALKER and SEIAD, indicative of the lower water temperature contributed by the Scott River and (or) cool ground-water accretion between those sampling points. The SEIAD site had the highest concentrations of pheophytin-*a* and chlorophyll-*a* below IRONGATE. This and the large fluctuations of DO (6.4–11.5 mg/L; *fig. 4B*) shown in the continuous record during this time indicate a good amount of algae at this site.

The water-quality comparison for September 2003 was quite different. Specific conductivity, carbonate, bicarbonate, and alkalinity concentrations were lower at IRONGATE, but they increased as the water moved downstream, until the confluence of the Trinity. Total organic carbon, ammonia + organic nitrogen, nitrate + nitrite, DO, pheophytin-*a,* and chlorophyll-*a* were higher in 2003 than in 2002, and remained higher, and in some cases, increased as the water moved downstream. The nutrients obviously supported an increased biomass downstream; chlorophyll-*a* increased from about 5 to 6 µg/L to 9.7 µg/L at ORLEANS. Pheophytin-*a* increased from 3.8 µg/L at IRONGATE to 5.7 µg/L at ORLEANS.

The addition of Trinity River water between ORLEANS and KLAMATH is apparent in many ways besides flow: total organic carbon, pheophytin-*a*, chlorophyll-*a*, orthophosphate, phosphorus, and ammonia + organic nitrogen were all notably less at KLAMATH than at ORLEANS. In addition, pH, temperature, and turbidity also decreased, which improved the habitat for salmonids.

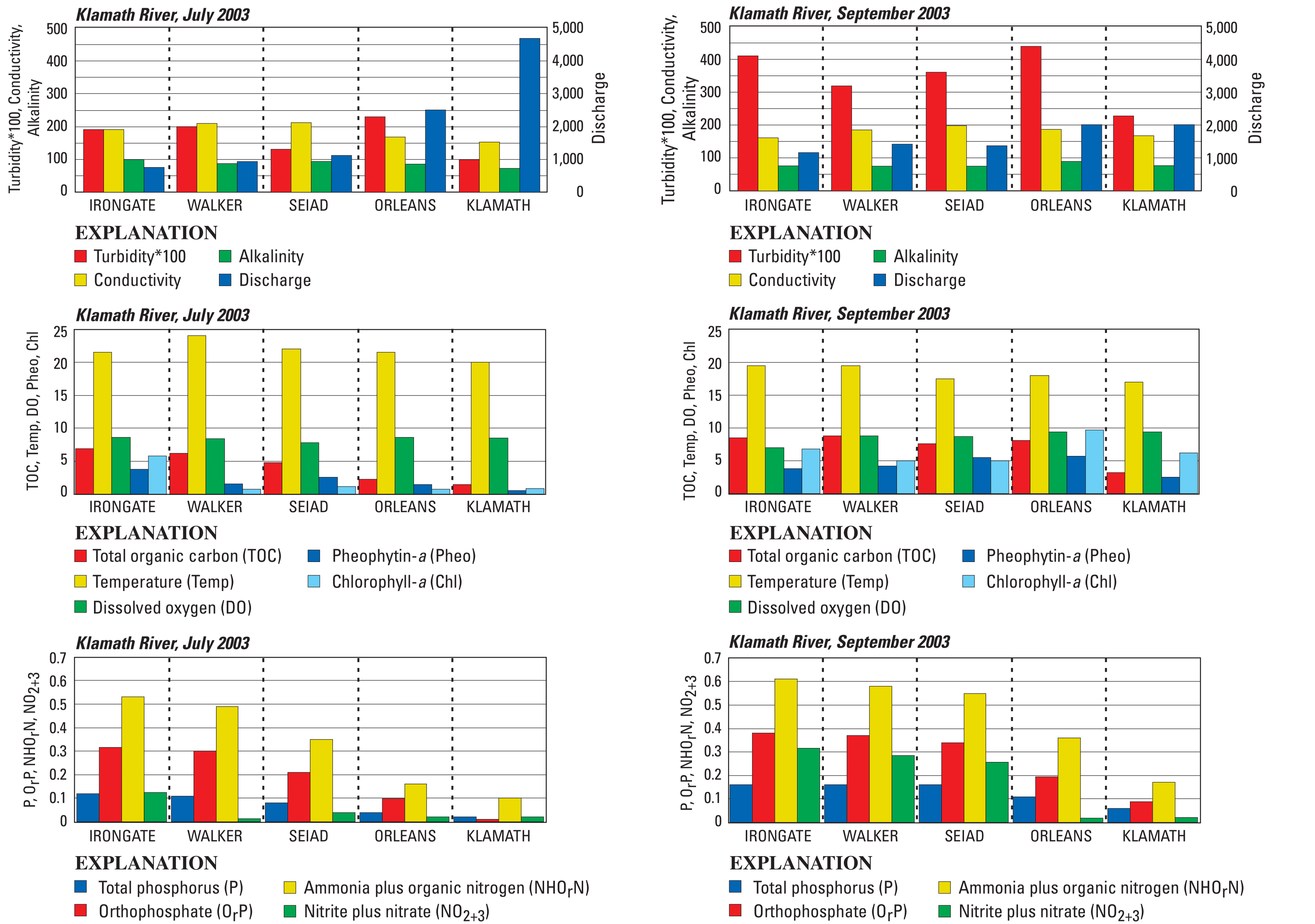

Figure 12. Data from parcel-tracking study on the Klamath River, California. ***A.*** July 2003, and ***B.*** September 2003 for various constituents. Turbidity is in nephalometric turbidity units, conductivity is in microsiemens per second, discharge is in cubic feet per second, water temperature (Temp) is in degrees Celsius, pheophytin-***a*** (Pheo) and chlorophyll-***a*** (Chl) are in micrograms per liter, alkalinity, total organic carbon (TOC), dissolved oxygen (DO), total phosphorus (P), orthophosphate (OrP), ammonia plus organic nitrogen (NHOrN), and nitrite plus nitrate (NO2+3) are in milligrams per liter.

Shasta River Parcel Tracking

Figure 13 shows selected data from the parcel-tracking sampling on the Shasta River. The timing of the sampling on the Shasta River caused more difficulty with respect to interpretation of temperature and dissolved oxygen data than it did for the Klamath River. GRENADA was sampled at 8:40 a.m., MONTAGUE at 11:50 a.m., HWY3 at 2:35 p.m., and YREKA at 6:15 p.m. for both sampling runs. The results of the June sampling discharge measurements show that the flows at GRENADA and YREKA were the same, but that flow between these two stations was considerably less. Alkalinity, turbidity, pH, conductance, total organic carbon, and ammonia + organic nitrogen increased significantly between GRENADA and MONTAGUE. Conductance, ammonia + organic nitrogen, and water temperature continued to increase as the water moved downstream, but the pheophytin-*a* and chlorophyll-*a* decreased. This pattern of changes in constituents, as well as the increase in concentration of nitrogen and carbon constituents, is consistent with the incidence of agricultural diversions and lower quality return flows. The considerably higher conductance, pH, and concentrations of nitrogen and carbon constituents were maintained in August, although the discharge at all sites was lower.

On the basis of this parcel-tracking study alone, it is difficult to draw specific conclusions about the changes in chemistry, water temperature, and biomass without additional information. Some general statements can be made, however. The water quality in the Shasta River is noticeably different from that of the Klamath River. The water quality of the Shasta River, however, does not account for all of the changes in the Klamath River between IRONGATE and WALKER; the concentration of DO in the water at IRONGATE in September 2003 was 7.0 mg/L, the concentration at WALKER was 8.8 mg/L, but the continuous monitoring indicates that the concentration in the Shasta River at about that time was around 9.0 mg/L. The increase in flow between IRONGATE and WALKER is only 15 percent, so it seems unlikely that a DO concentration of 9.0 mg/L could cause such an increase. Likewise, the decrease in temperature between WALKER and SEIAD probably cannot be explained by the small contribution of flow from the Scott River. The significant variability in DO at SEIAD also points to the need for further investigation in that area of the river. The decreases in nitrogen and phosphorus from WALKER to KLAMATH suggest a significant amount of uptake by a population of attached algae. In order to increase understanding of the changes in water quality in the Klamath River from Iron Gate Dam to the mouth, it would be necessary to conduct a much more rigorous study of parcel tracking that would include the effects of diurnal fluctuations and changes in flow between sampling sites. Such a study would include implementing dye or tracer tests to accurately determine the travel times between sites, and thus sampling the tributaries at the appropriate time to accurately represent travel time, and initiating the sampling at several times during the day to characterize the diurnal effects.

A comparison of the 2002 data collected during monthly sampling with data collected during the 2003 parcel-tracking study in the Klamath and Shasta Rivers (*table 3*) indicates that most of the constituents were at comparable levels for the 2 years for all sites. Notable exceptions include discharge and nitrate. Discharge at the IRONGATE station in July 2003 was 747 ft^3/s, which was lower than the 2002 discharge of 897 ft^3/s, but it was higher between the SEIAD and the ORLEANS stations (1,400 ft^3/s) and between the ORLEANS and the KLAMATH stations (2,170 ft^3/s) resulting in a discharge of 4,680 ft^3/s at the KLAMATH, which was 150 percent of that in July 2002. In September 2003, discharge at the IRONGATE station was 1,190 ft^3/s, much higher than 773 ft^3/s in 2002. In 2003, the reach between the WALKER and the SEIAD stations had reduced flows indicating a losing reach; nevertheless, discharge at the KLAMATH station was again 150 percent of that in 2002 (3,110 ft^3/s compared with 2,030 ft^3/s) because of the relatively large increases between the SEIAD, ORLEANS, and KLAMATH stations. Nitrate concentrations in September 2003 were more than twice those measured in September of 2002 for all five stations on the Klamath River.

Sediment Oxygen Demand Study on the Shasta River

Sediment oxygen demand (SOD) is the rate of DO loss from a water body through its uptake and consumption by biotic or abiotic reactions in surficial sediments. In most river systems, such oxygen consumption is dominated by microbially mediated decomposition processes. In other words, organic materials in the water body's sediments decompose; that process requires oxygen to proceed, and the oxygen is supplied from the overlying water. In streams with an abundance of sedimentary organic material from soil erosion or an accumulation of plant and algal detritus, SOD can be an important part of the stream's DO budget. Field observations of sediment accumulation and low DO levels measured by the authors indicate that some reaches of the Shasta River may have a significant SOD; as a result, an investigation was initiated to measure that rate.

The rate of SOD was measured at six sites in two reaches of the Shasta River (*table 4*). These sites were chosen because they are located in a reach of the Shasta River with measured low DO (*appendix 2*) and observed accumulation of fine sediment and plant detritus. Other considerations for site selection included access, type of stream substrate, and the amount of macrophyte (aquatic plant) growth.

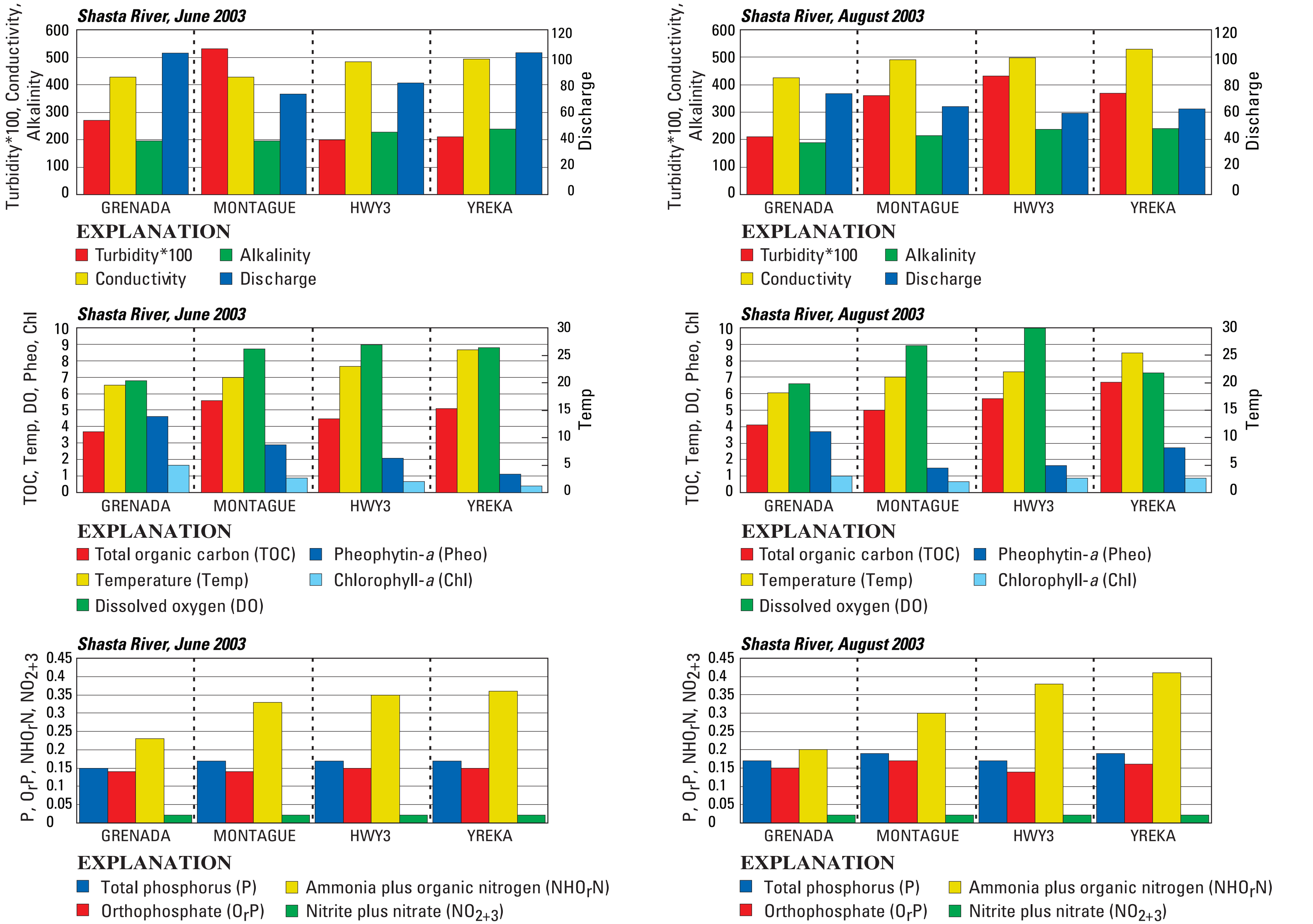

Figure 13. Data from parcel-tracking study on the Shasta River in lower Klamath River Basin, California. ***A***. June 2003, and ***B***. August 2003 for various constituents. Turbidity is in nephalometric turbidity units, conductivity is in microsiemens per second, discharge is in cubic feet per second, water temperature (Temp) is in degrees Celsius, pheophytin-***a*** (Pheo) and chlorophyll-***a*** (Chl) are in micrograms per liter, alkalinity, total organic carbon (TOC), dissolved oxygen (DO), total phosphorus (P), orthophosphate (OrP), ammonia plus organic nitrogen (NHOrN), and nitrite plus nitrate (NO2+3) are in milligrams per liter.

Table 4. Locations of sites used to measure sediment oxygen demand on the Shasta River in the Lower Klamath River Basin, California.

[Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Site Name	Latitude	Longitude	Location description
Shasta River upstream of Montague–Grenada Road	41.7081 N	–122.5378 W	100–200 meters upstream of bridge
Shasta River downstream of Montague–Grenada Road	41.7114 N	–122.5422 W	Approximately 400 meters downstream from bridge
Shasta River near Hwy 3—site A	41.7183 N	–122.5533 W	Approximately 1 kilometer upstream of bridge; 200–300 meters upstream of pump house on right bank
Shasta River near Hwy 3—site B	41.7158 N	–122.5517 W	50–100 meters upstream of site A, at bend in river
Shasta River near Hwy 3—site C	41.7272 N	–122.5569 W	100–200 meters downstream from bridge
Shasta River near Hwy 3—site D	41.7269 N	–122.5578 W	25–50 meters upstream of site C

Procedure

Sediment oxygen demand rates were measured with in-situ chambers, as previously described by Murphy and Hicks (1986), Caldwell and Doyle (1995), Rounds and Doyle (1997), and Doyle and Rounds (2003). These chambers allow a known volume of water to be isolated above a known area of stream sediment. The DO concentration in that isolated water then is monitored over the course of at least 2 hours. Measurements typically are performed with three such chambers at each site to assess the variability of the site's SOD. In addition, a fourth chamber with a sealed bottom to exclude interaction with stream sediments is used to assess the level of oxygen loss owing to biochemical oxygen demand (BOD) in the water column. The measured oxygen loss rate in each of the three SOD chambers, once corrected for the effects of BOD, is a direct measurement of the site's SOD rate. Final SOD rates are corrected to 20°C (SOD_{20}) and reported as a loss rate in grams of oxygen per square meter per day ($g/m^2/d$). Details of the procedures were documented previously by Rounds and Doyle (1997). An estimate of the SOD rate at any temperature is then given by

$$SOD_T = SOD_{20} \times 1.065^{(T-20)}$$

where SOD_T is the SOD rate at temperature T (°C).

To measure SOD rates with this type of in-situ chamber, (1) the stream must be deep enough (> 0.4 meters) to submerge the chamber, (2) the sediments must be fine enough to allow the chamber's cutting edge to seat and seal to the stream bottom, and (3) the stream's DO concentration must be high enough (> 4 mg/L, approximate) to provide a measurable loss rate and a stable aerobic environment for the sediment's microbial community.

Those reaches of the Shasta River where the SOD rate was measured had a productive population of attached algae and an abundance of rooted aquatic plants (macrophytes). Both the algae and the macrophytes produce DO through photosynthesis. In order to measure the effects of only SOD (and BOD), it was important to exclude these oxygen producers from the SOD measuring chambers, either by prudent site selection or by physical removal of these plants prior to chamber deployment.

At the two sites near the Montague-Grenada Road, macrophytes were less abundant which allowed suitable sites for chamber deployment without having to remove any plant material. At all sites near Highway 3, however, macrophytes were abundant and had to be removed from the site before each chamber was deployed. The tops of the plants were removed by cutting them off near their base, taking care not to disturb the plants' roots or the site's sediments. In this manner, the plant's production of DO was eliminated without disturbing the sediments or any respiration processes in the plant's roots. Such measures may introduce additional uncertainty into the SOD measurement, but it was the only way to collect such a measurement in areas dominated by macrophytes.

At each SOD measuring site, samples also were collected to roughly characterize the organic content and particle size of the stream sediments. Samples were analyzed for percent organic content (loss on ignition [Fishman and Friedman, 1989]) and for the size fraction finer than 63 microns (Guy, 1969) by the USGS Cascades Volcano Observatory sediment laboratory.

SOD Results

DO loss rates were measured in the SOD chambers. The loss rates were corrected for the effects of BOD ("blank corrected") and adjusted to a rate at 20°C. These rates, as well as the results from the sediment analyses, are shown in *table 5*. The measured SOD_{20} rates range from 0.1 to 2.3 $g/m^2/d$ with a median of 1.5 $g/m^2/d$. The organic-matter content and particle size analyses don't appear to correlate well with the measured SOD rate; the lack of such a correlation was also observed by Caldwell and Doyle (1995) for the lower Willamette River in Oregon and by Wood (2001) for the Upper Klamath and the Agency Lakes in Oregon. Knowing the amount of organic material present is useful, but that information does not provide insight into how fast that material might decompose. The SOD measurement is necessary to provide that rate.

Table 5. Measured sediment oxygen demand rates and sediment characteristics at sites on the Shasta River in the Lower Klamath River Basin, California.

[m, meters; SOD, sediment oxygen demand, blank-corrected; SOD_{20}, sediment oxygen demand corrected to a temperature of 20°C; $g/m^2/d$, grams per square meter per day; %, percent; —, no measurement]

Site	Date	Replicate	Water depth (m)	SOD rate at 20°C (SOD_{20}, $g/m^2/d$)	Sediment characteristics: Organic content (loss on ignition) (percent)	Sediment characteristics: Percent finer than 63 microns (percent)
Shasta River upstream of Montague–Grenada Road	8/12/03	1	0.9	2.0	2.3	5.7
		2	0.8	—	1.4	3.2
		3	0.7	1.0	1.7	3.3
Shasta River downstream from Montague–Grenada Road	8/12/03					
		1	0.7	1.6	4.8	5.0
		2	0.6	0.5	7.5	54.3
		3	0.5	1.0	4.1	2.4
Shasta River near Hwy 3—site A	8/13/03					
		1	0.9	1.5	2.6	2.1
		2	0.9	0.7	1.0	0.8
		3	0.8	0.1	1.5	1.6
Shasta River near Hwy 3—site B	8/13/03					
		1	0.9	1.3	1.4	3.3
		2	0.9	1.4	1.2	1.3
		3	0.8	1.7	1.5	2.9
Shasta River near Hwy 3—site C	8/14/03					
		1	0.4	2.1	0.9	0.7
		2	0.5	—	1.2	8.9
		3	0.4	2.3	0.8	2.3
Shasta River near Hwy 3—site D	8/14/03					
		1	0.6	1.8	6.5	29.9
		2	0.7	—	3.4	48.9
		3	0.7	2.3	6.3	44.4

A SOD rate of 1 to 2 $g/m^2/d$ is indicative of a system with organic material that is decomposing at a moderate rate. Similar rates have been measured in many other stream systems having a moderate amount of organic material in silty sediments that are not heavily affected by pollution (Murphy and Hicks, 1986; Rounds and Doyle, 1997). A moderate SOD rate indicates that the decomposing organic matter is neither extremely labile nor extremely refractory.

Some reaches of the Shasta River do not accumulate sediment; those reaches may have a gravelly or cobbly bottom and little to no SOD. For those reaches that do accumulate sediment, however, an SOD of 1.5 $g/m^2/d$ can represent a significant loss mechanism for DO. This is especially true for streams that are relatively shallow. The amount of DO that can be consumed by SOD over the course of a day is a function of stream depth and is calculated as the SOD rate in $g/m^2/d$ divided by the stream depth in meters. So, a stream having an SOD rate of 1.5 $g/m^2/d$ can reduce stream concentrations by 1.5 mg/L of DO to SOD over the course of 1 day if the SOD is acting on a water column that is 1 meter deep. The concentration reduction increases to 3.0 mg/L if the stream is only 0.5 meters deep. Many of the sites where SOD was measured in the Shasta River are relatively shallow (*table 5*) and SOD is therefore more likely to overwhelm other processes and to be a significant loss mechanism for DO in those reaches.

A complete assessment of the factors affecting DO in the Shasta River, though, needs to include more than just a measurement of SOD. Judging from the abundant levels of attached algae and rooted plants in the Shasta River, the effects of photosynthetic production and plant respiration also will contribute a lot to the DO budget. The effects of plant photosynthesis and respiration can be estimated using the SOD rate, estimates of BOD and the rate of oxygen exchange between the river and the atmosphere, and the analysis of continuous DO measurements from one or more locations. Such an analysis would be a logical next step in any assessment of DO in the Shasta River.

Relevance of Water-Quality Observations to 2002 Fish Kill on the Klamath River

Conclusions made by the California Department of Fish and Game in a preliminary analysis of the cause of the September 2002 fish kill near the mouth of the Klamath River (State of California, 2003) noted that the kill was the result of a combination of high densities of adult fish (due to low flows and possibly inadequate fish passage) and warm water-temperature conditions typical at that time of year. These conclusions were supported by an analysis of hydrologic conditions in the Klamath River Basin prior to the die-off (Lynch and Risley, 2003); the conclusions indicate that low streamflow and high water temperature contributed to the pathogenic infections that killed the fish. The September 2002 flow releases from the Iron Gate Dam were among the four lowest flows recorded since 1960, and the numbers of returning fall Chinook salmon were at average or above average levels. The September 2002 flows also were the lowest since the major storm events in 1997 and 1998 that may have caused aggraded channel conditions that threaten fish passage.

On the basis of an analysis of long-term water temperatures in the nearby Rogue River Basin and air temperatures within the Klamath River Basin, it was concluded that the water temperatures in September 2002 in the Lower Klamath River were probably above average (Lynch and Risley, 2003). Indeed, daily minimum water temperatures at ORLEANS, upstream of the fish die-off reach, remained above 18°C between September 1 and 24, 2002, which was a level at which disease rates in salmonids can be severe (Lynch and Risley, 2003). Measurements of DO were not analyzed in reports by either the State of California (2003) or Lynch and Risley (2003), but it is likely that the extended period of low DO measured in August and September of 2002 for this crrent study contributed to the fish kill by increasing the stress that could result in disease in salmonids. Given these results, it seems as though a combination of factors, including elevated temperature and phytoplankton indicators, contributed to the low DO values.

Model Code Selection and Analysis

The step following data collection and analysis in the iterative conceptual and numerical model development process is to use the available data to continue the development of the conceptual model of the Klamath River system (*fig. 2*). There have been many investigations over the years to evaluate water quality and fish habitat in this basin. These studies have contributed to the development of conceptual models of the system from various perspectives and levels of detail and scale. At least two different mathematical models (Deas, 2000; Campbell and others, 2001) have been used to simulate many of the interacting processes in the Klamath River. Results of these efforts and of future studies should be used to complete the conceptual model of processes and will require additional information and data and a variety of experts who can look at different parts of the river system (physics, chemistry, and biology).

The evaluation, testing, and implementation of a conceptual model using a mathematical model are the next steps in characterizing a natural river system. Several mathematical codes have been used to develop existing mathematical models of the rivers in the Klamath Basin, some of which were evaluated by the Oregon Department of Environmental Quality (Wells, 1995) for the Klamath River. Three model codes were analyzed for this current study of the Klamath River to aid in determining where there are gaps in data and where data are inadequate for developing TMDLs. The codes are from existing mathematical models of the Klamath River: the SIAM model suite (Bartholow and others, 2003), the WQRRS, RMA2, and RMA11 models (Deas, 2000), and the CE-QUAL-W2 (Cole and Wells, 2002). The model using SIAM and the model used by Deas (2000) were calibrated for the Klamath River. PacifiCorp, the firm responsible for operation of the Iron Gate Reservoir, is using the CE-QUAL-W2 model code for their analysis for Federal Energy Regulatory Commission (FERC) relicensing; this model code also was selected by the Oregon Department of Environmental Quality to model the Klamath River between the Link River and the Keno Dam (Scott Wells, Portland State University, written commun., 1995). Most recently, Deas completed work using two model codes: the CE-QUAL-W2 model for the Iron Gate Reservoir, and the RMA2 and RMA11 models for the Klamath River below the reservoir (Matt St. John, North Coast Regional Water Quality Control Board, written commun., 2003). It is important to match up the data needs of the model intended for use with the available data.

Model Description: SIAM

SIAM is a management interface to several underlying models. Campbell and others (2001) and Hanna and Campbell (2000) applied SIAM to MODSIM, a network water-quantity simulation program (John W. Labadie, MODSIM-DSS; accessed August 3, 2004) to simulate streamflow, and to HEC-5Q, a one-dimensional U.S. Army Corps of Engineers (Corps) program (Environmental Software and Services, accessed August 3, 2004) to simulate water quality. The work concentrated on temperature and DO as calibration variables.

MODSIM was used to simulate monthly mean streamflows through the river system. For dam operations and long-term simulations (many seasons), a monthly time step can meet most needs for the purposes of modeling water supply. However, simulating monthly flow data when the time frame for water-quality problems is hourly to weekly may not be the best practice. It is unclear whether this resulted in any major problems in model calibration or performance.

HEC-5Q is a one-dimensional water-quality model that utilizes the flow simulation capabilities of HEC-5. HEC-5 simulates multiple purpose, multiple reservoir systems in essentially any stream tributary configuration using a variable computational interval. It can simulate the longitudinal dimension in riverine reaches, or the vertical dimension in reservoirs where it is necessary to capture the effects of stratification on water quality. The model simulates one or the other dimension, not both. So, in a long reservoir where the retention time is long relative to the time scale of water-quality problems, HEC-5Q does not simulate any important longitudinal processes in the reservoir and will introduce some numerical dispersion in the longitudinal dimension. Water entering the head of the reservoir is immediately mixed into the appropriate model layer in the reservoir, and those layers extend from the head of the reservoir to the dam. So, if the time-varying nature of the inputs to the head of the reservoir is important, the simulations will smear signals in the reservoir and result in longitudinal numerical dispersion. Numerical dispersion also can be significant if the residence time is longer than the model time-step. HEC-5Q was run by Campbell and others (2001) using a daily time step, and outputs were stated to represent daily means. If the water-quality standards are written for daily maximum water temperatures or for daily minimum DO concentration, the model needs to be able to produce information on time scales of less than 1 day. In addition, if the reservoir residence times are less than 1 day, it is possible to induce significant numerical dispersion in the model results. HEC-5Q cannot simulate or use information regarding the amount of topographic or riparian shading of the stream channel. Shading was not considered, yet increased or restored riparian shading on stream-water temperature is often an important effect that must be evaluated by regulatory agencies when setting a TMDL for water temperature. If a mathematical model is used to help understand the dynamics and spatial variations in water temperature in the Klamath River, it will be necessary for the model to address the effects of shading. In general, the algorithms used to simulate heat exchange processes in the HEC-5Q model are sufficient for basic applications, but many of these processes are not simulated explicitly.

Dissolved oxygen can be simulated in HEC-5Q as a balance among inflows, outflows, reaeration (exchange with the atmosphere), biochemical oxygen demand (BOD decomposition of organic materials in the water column), sediment oxygen demand (SOD—decomposition of organic materials in the surficial sediments), photosynthesis (primary production by algae and (or) aquatic plants), respiration (by algae, plants, and bacteria), and ammonia nitrification (microbially facilitated conversion to nitrate). These typically are the most important components of the DO budget for most rivers and reservoirs. DO solubility is a strong function of water temperature; that effect appears in the implementation of reaeration algorithms in the model. Field verification of reaeration coefficients generally is advised if this appears to be a dominant process. The HEC-5Q model appears to include all the necessary processes for simulating DO. Use of the HEC-5Q model to improve understanding of the water quality of the Klamath River may not be the best overall choice though because of its limitation to one dimension in the reservoirs in this system, reservoirs that have the potential to influence the water quality in the streams.

Considering the difficulty of simulating a complex system with less than a full complement of simulated processes, USGS researchers (Hanna and Campbell, 2000; Campbell, 2001; Bartholow and others, 2003) were able to use SIAM to simulate daily mean water temperature over a several year period for the Seiad Valley with an average error of about 1.5 to 2°C and corresponding errors in predictions of lows in DO concentrations in flows below Iron Gate Dam of approximately ± 4 to 5 mg/L. Any failure in their efforts to simulate DO is indicative of a lack of data and a lack of quantification of those processes affecting DO.

Model Description: WQRRS; RMA2; RMA11

The Water Quality for River-Reservoir System (WQRRS), a Corps of Engineers computer package preceding HEC-5Q, simulates the water quality in a reservoir and the hydraulics of a river and the water quality of that river (Environmental Software and Services, accessed August 3, 2004). The WQRRS package consists of the programs Stream Hydraulics Package (SHP), WQRRSQ, and Reservoir Water Quality (WQRRSR) that interface with each other. The SHP and the Stream Water Quality (WQRRSQ) programs simulate flow and water-quality conditions for stream networks that can include branching channels and islands. The WQRRSR program is a one-dimensional model used to evaluate the vertical stratification of physical, chemical, and biological parameters in a reservoir. The SHP provides a range of optional methods for computing discharges, velocities, and depths as a function of time and location in a stream system. The hydraulic computations can be performed using either input stage-discharge relations, hydrologic routing, kinematic routing, steady-flow equations, or the full unsteady-flow St. Venant equations (finite-element method). The WQRRSR and the WQRRSQ programs provide capabilities for analyzing temperature and more than a dozen chemical, physical, biological, and organic constituents. WQRRS simulates the vertical distribution of thermal energy and chemical and biological materials in a reservoir through time. A reservoir is conceptualized as a vertical sequence of horizontal layers with thermal energy and materials uniformly distributed in each layer. The distribution of inflows among the horizontal layers is based on density differences. The model simulates the dynamics of more than a dozen water-quality variables, computing both in-pool and downstream release magnitudes.

RMA2 is a two-dimensional, depth-averaged, finite-element hydrodynamic numerical model (Boss, International; accessed August 3, 2004). Water-surface elevations and horizontal velocity components are computed for subcritical and turbulent flows. Both steady and transient (dynamic) problems can be analyzed.

RMA11 is a finite-element water-quality model for simulation of three-dimensional estuaries, bays, lakes, and rivers (Boss, International; accessed August 3, 2004). It can simulate one- and two-dimensional applications and is designed to accept input of velocities and depths either from text files or from output files produced by the two-dimensional hydrodynamic model RMA2 or by the three-dimensional stratified flow model RMA10.

Deas (2000) used the WQRRS model to simulate temperature, DO, pH, alkalinity, conductivity, pollutants, and nutrients in the Iron Gate Reservoir. He modeled the Klamath River from the Iron Gate Dam to the USGS gage at SEIAD using the RMA2 model to simulate the hydrodynamics of the river, and the RMA11 model to simulate water quality. The details of the modeling efforts are described in Deas (2000).

These three components of a river system, hydrodynamics, water quality, and reservoir dynamics, may also be simulated separately, as was done by Deas (2000) in his Klamath River application. This model assumes a one-dimensional system, which when applied to a reservoir is prone to numerical dispersion in the longitudinal direction, as is the HEC-5Q model. It takes into account the effects of mass transport owing to outflow, and it can model many different water-quality constituents.

Model Description: CE-QUAL-W2

CE-QUAL-W2 (W2) is a water-quality and hydrodynamic model in two dimensions (longitudinal-vertical) for rivers, estuaries, lakes, reservoirs, and river basin systems (Cole and Wells, 2002). W2 simulates basic eutrophication processes, such as temperature-nutrient-algae-DO-organic matter and sediment relations. This model is supported by the Corps of Engineers, Waterways Experiments Station, Vicksburg, Mississippi. The current model release (v3.1) enhancements were developed under research contracts between the Corps and researchers at Portland State University.

W2 simulates longitudinal-vertical hydrodynamics and water quality in stratified and non-stratified systems. It includes the simulation of nutrient and DO dynamics and biomass, and sedimentation of multiple algal groups, epiphyton/periphyton, in addition to carbonaceous biochemical oxygen demand (CBOD), nutrients, DO, pH, general water-quality constituents, internal dynamic pipe/culvert flow, hydraulic structures (weirs, spillways), and a dynamic shading algorithm based on topographic and vegetative cover. These more complex functions mean that W2 requires more computer power and is more difficult to use in optimization.

In contrast to the other models, W2 requires much more input data. Basic data needs for W2 include stream and reservoir geometric data, initial conditions, inflows, outflows, meteorological and water-quality data, as well as a substantial number of hydraulic and kinetic rates and parameters. A detailed list is available in the model's user manual (Cole and Wells, 2002).

Model Application and Data Gaps

To better understand DO in the Klamath River and its reservoirs, it is important to understand which parts of the DO budget are most important in each part of the basin. Certainly inputs, outputs, reaeration, and BOD must be included, and BOD appears to be large and important in the reaches just downstream from Upper Klamath Lake. The relative importance of algae and SOD, however, are not known specifically yet, but, on the basis of the data included in this report, are suspected to be significant. To adequately evaluate the effects of algae, an effort should be made to collect additional data to simulate these effects in a model. Note, however, that if the algae in the Klamath River downstream from IRONGATE are predominantly the attached varieties (periphyton)—growing in riverine reaches attached to the stream's rocky substrate rather than floating downstream with the water—then any simulation of those algae-related processes will be a difficult task. Few models address the effects of attached algae directly; among the models described here, only W2 has a simple set of algorithms that can be used to estimate the dynamics of periphyton. It is a much easier task to simulate the types of algae that float downstream with the water, as model calibration can rely on measurements of chlorophyll-*a* and other indicators present in the water. Coastal rivers almost always have a measurable community of attached algae in the summer. Decomposing algae (periphyton and phytoplankton combined) is likely a large component of any BOD other than that contributed from agricultural drain sources.

USGS researchers (Hanna and Campbell, 2000; Campbell, 2001; Campbell and others, 2001) indicate that water temperature in many streams is largely a result of climatic and streamflow conditions. Human-related factors that appear to be important are the presence of dams, the operation of those dams, and any disturbances to the stream's riparian vegetation. Those human-related factors are small (but measurable), however, compared to the effects of climate and streamflow.

In terms of DO, model simulations indicate that the large BOD loads from the Upper Klamath Lake and from the various agricultural return flows in Oregon are major influences on DO in the upper reaches of the Klamath River, extending to the Iron Gate Dam. Preliminary SOD data from stations on the Klamath River downstream from the Upper Klamath Lake support the conclusions from the model simulations, showing the rates to be significant, though potentially less important than those for BOD. Ammonia nitrification does not appear to have much influence in most of the Klamath River downstream from Keno, although some high concentrations have been recorded at Keno, which probably were due to high concentrations present just downstream from Upper Klamath Lake.

The effects of photosynthesis and respiration on DO in the reservoirs and the riverine reaches of the Klamath River, although evident qualitatively in the data presented in this report, have yet to be quantified numerically. Certainly, the nitrogen and phosphorus concentrations appear to be high enough to support a significant population of algae. Depending on the health of the *Aphanizomenon* population swept downstream from Upper Klamath Lake to the reservoirs, these algal-related processes could have impacts on the processes occurring in those reservoirs. A substantial population of attached algae also may thrive in parts of the river downstream from the IRONGATE station and needs to be investigated. Reaeration is always an important process; at times, it can be a significant part of the DO budget for both the reservoirs and the riverine reaches.

Some obvious gaps in data that need to be filled in order to better understand the relative importance of the various processes that affect DO in the reservoirs and in the riverine reaches include

- BOD data—It is imperative to measure BOD at various locations in the river system and at important inflow boundaries. If possible, the CBOD rate also should also be measured.

- Algae data—A better understanding is needed of the types and populations of algae (periphyton and phytoplankton) in the reservoirs and in the riverine reaches, unless another source of data is available, to determine if the *Aphanizomenon* in the reservoirs are thriving or slowly dying as they are swept downstream from Upper Klamath Lake. It also is necessary to determine if algal growth is limited by the nitrogen or phosphorus levels, to measure primary productivity, and to assess the adequacy of available nutrient data.

- SOD data—SOD can be a dominant process. The USGS Oregon District measured SOD rates in the Klamath River downstream from Upper Klamath Lake in March 2003. The data, which were provisional at the time of this study, are available at *http://oregon.usgs.gov/projs_dir/lake_ewauna_sod/rate_table.html* (accessed on February 6, 2004). The Upper Klamath Lake study supported the importance of the SOD process and is also shown to be important in the Shasta River study discussed in this report. The prevalence of the SOD process needs to be evaluated throughout the Klamath River system, but most importantly in reaches with lower levels of DO.

Additional data needs, beyond those mentioned above, include

- Meteorological data: air temperature, dew point temperature (or relative humidity), wind speed, wind direction, cloud cover, and solar radiation. These data are needed on an hourly basis from both coastal and inland areas if models require that these data to be used on time intervals of less than 1 day.

- Shading data for stream channels: Topographic-shading data are easily derived from digital elevation model (DEM) data. Riparian-shading data can be estimated or collected in the field. Some field data will be necessary to evaluate current shading conditions.

- Vertical reservoir profiles: The balance among processes in the Copco and Iron Gate Reservoirs is almost certainly different than that in the flowing reaches of the Klamath River, and understanding that balance is important to understanding the downstream effects of the reservoirs. Even for simple models, water temperature and DO profiles are necessary. PacifiCorp, the company operating the Iron Gate and Copco Dams for electricity generation, may have collected these profiles to support modeling they did to be relicensed by the Federal Energy Regulatory Commission (FERC). If profiles are not available, then at the minimum, monthly or twice-monthly water-temperature and DO profiles are needed; obtaining profiles throughout the year would result in a more complete understanding of the seasonal processes. Such profiles are useful for calibrating models of reservoirs that are stratified. For more complex models, vertical profiles of pH, conductivity, chlorophyll-*a*, total organic carbon, soluble reactive phosphorus, total phosphorus, nitrate + nitrite nitrogen, and ammonia nitrogen would be useful, particularly if CE-QUAL-W2 is used to model the reservoir/river system.

Potential Data Sources

Meteorological Data

The meteorological data necessary for any water-quality model are available from a variety of sources for many stations in the Klamath River Basin (*fig. 14*). For this current study, all relevant current and historical data (through 2001) were compiled from the National Climate Data Center (NCDC) for multiple locations and multiple datasets in and around the Klamath River Basin (station locations are shown in *fig. 14*; *appendix 3*, *tables A3-1*, *A3-2*, and *A3-3*). The NCDC data include precipitation, snowfall, maximum and minimum daily air temperature, wind speed, wind direction, dew point temperature, and total sky cover.

Hourly data for Tule Lake are available from the California Department of Water Resources and from the University of California, Davis (station locations are shown in *fig. 14*; *appendix 3*, *table A3-4*). These data, from the California Irrigation Management Information System (CIMIS; California Department of Water Resources, accessed February 6, 2004), include hourly measurements of potential evapotranspiration,

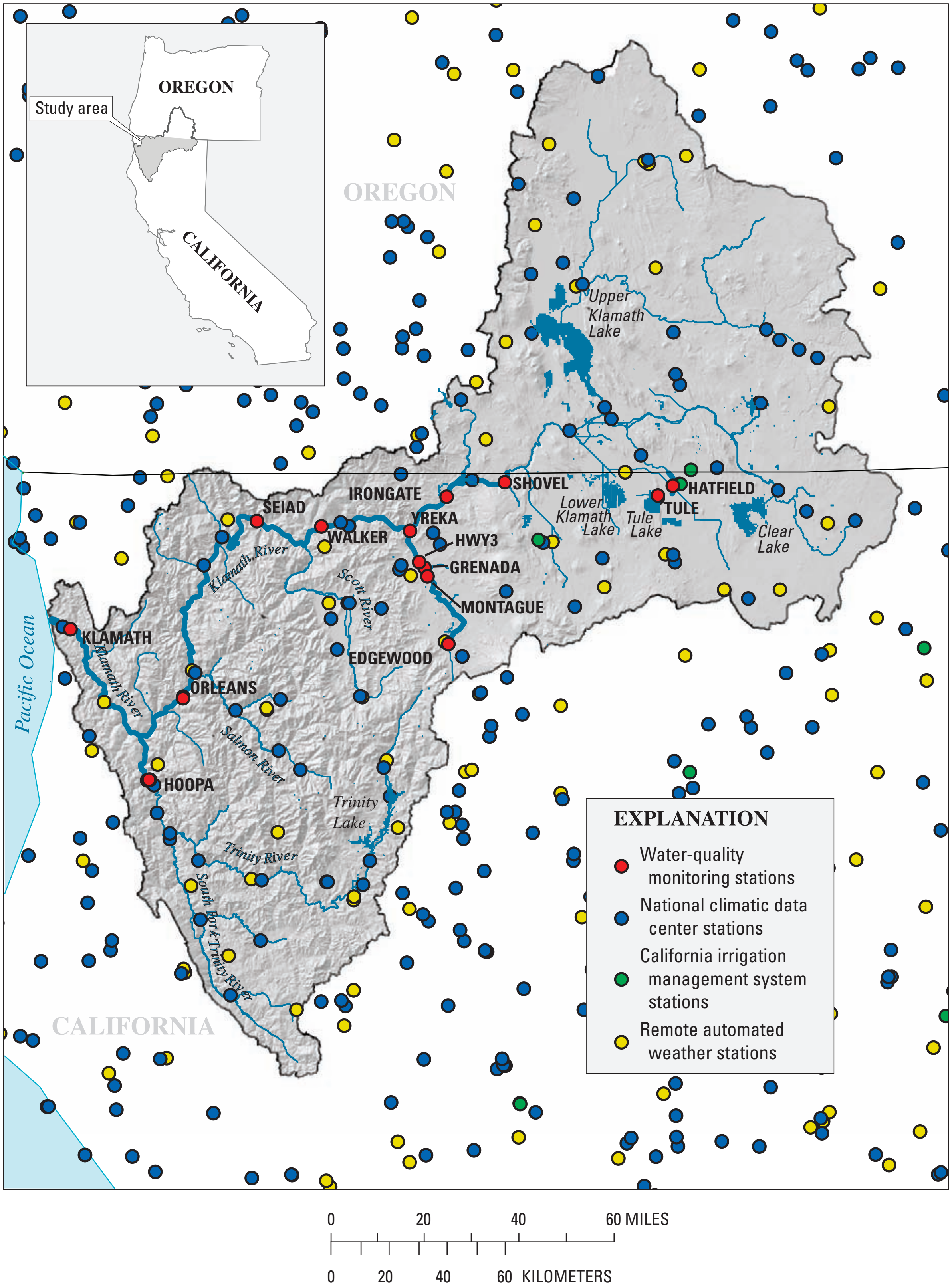

Figure 14. Meteorological stations in and around the Klamath River Basin in Oregon and California.

precipitation, solar radiation, vapor pressure, air temperature, wind speed, and wind direction, as well as daily measurements of potential evapotranspiration, solar radiation, minimum and maximum air temperature, and average vapor pressure.

Data were also compiled from the Solar and Meteorological Surface Observation Network, 1961–90 (National Renewable Energy Laboratory, U.S. Department of Energy) (station locations are shown on *fig. 14*; *appendix 3*, *table A3-5*). These data were used to develop a detailed solar radiation model, SOLRAD (Flint and Childs, 1987) that includes a calibrated equation to relate minimum and maximum air temperature to percent cloud cover (Bristow and Campbell, 1984) (there is much more air temperature data for the study area than there is cloud cover data, which makes the air temperature/cloud-cover relation useful for modeling the water temperatures in the basin). NREL data include hourly solar radiation, dew-point temperature, air temperature, and cloud cover, as well as monthly measurements of ozone, precipitable water, and Ångstrom's turbidity coefficient.

In addition, hourly data are available from a network of Remote Automated Weather Stations (RAWS) managed by the Western Regional Climate Center (WRCC) (station locations are shown on *fig. 14*; *appendix 3*, *table A3-6*). RAWS data include hourly measurements of air temperature, dew-point temperature (relative humidity), barometric pressure, precipitation, wind speed, and wind direction.

Another potential source of relevant meteorological data include Snotel weather stations managed by the WRCC. Data from all the sources described above should be evaluated before looking much further for additional sources.

Stream Shading

The most recent 30-m digital elevation models (DEM) for California and Oregon, which were used for calculations of topographic shading, are the Elevation Derivatives for National Applications (EDNA) data sets developed by the USGS. Some modeling packages include their own algorithms to calculate shading, but the USGS computer program, SKYVIEW, calculates topographic shading and blocking ridges around each pixel in the DEM. This program also can be used to calculate the shading effects of riparian vegetation. The resultant analysis is used in the program SOLRAD to calculate solar radiation loads for each pixel in the DEM at any time step required. The program SOLRAD incorporates the most significant atmospheric parameters for calculating solar radiation (ozone, precipitable water, and Ångstrom's Turbidity Coefficient). Minimum and maximum air temperatures are used in SOLRAD to estimate percent cloud cover when those data are not directly available for the site being modeled. SKYVIEW and SOLRAD model at point scales, river scales, or basin scales. When combined with air-temperature data, the model SOLRAD is converted to NETRAD to calculate the net radiation. This stand-alone analysis can be used to locate areas in the Klamath River Basin that would be most likely to cause increases in stream temperature owing to radiation loads.

Vertical Reservoir Profiles

Some profiles of temperature and DO already exist for the reservoirs in the study area, and have been used to calibrate existing reservoir models (Deas, 2000). PacifiCorp currently (2004) is in the process of collecting additional profiles, which may be available to others for TMDL model development.

Summary

The USGS investigated the water quality of the Lower Klamath River Basin in 2002 and 2003 in partnership with the California North Coast Regional Water Quality Control Board. In an attempt to identify and fill data gaps and to better understand water-quality processes in the river system of this basin, several investigations were undertaken. Water-quality constituents were measured using continuous monitors, and monthly water-quality samples were collected and analyzed. Sediment oxygen demand rates were measured. Lastly, existing models were assessed, gaps in data were identified, and directions for future research were suggested for the purpose of developing TMDLs for the rivers in the Lower Klamath River Basin.

The USGS deployed 12 continuous water-quality monitors in the Lower Klamath River Basin between June and November 2002 to collect hourly measurements of water temperature, DO, pH, and specific conductance. Six stations were on the Klamath River, one station on the Trinity River, three stations on the Shasta River, and two stations on the lower Lost River. Similar data were collected at 10 locations between April and September 2003; 3 of the 12 monitoring stations were discontinued (stations on the Trinity and Lost Rivers) and one station was added on the Shasta River. Data from these stations indicated that water temperatures were higher than that desired for the protection of Chinook salmon at most stations during mid summer. Low DO concentrations, were shown to be problematic in the lower Lost River. Low dissolved-oxygen concentrations that were likely to be stressful to Chinook salmon also were measured at stations in the Shasta and Klamath Rivers. Dissolved-oxygen concentrations varied greatly over the course of a day at most sites. Measured pH values exceeded water-quality standards at many of the stations; the highest recorded values were in the Lost River.

Monthly water-quality samples were collected at 12 sites in July, August, and September of 2002 and analyzed for selected nutrients, organic carbon, chlorophyll-*a*, and trace metals. Ammonia concentrations were low at all the sites, and nitrate + nitrate concentrations were low downstream from the WALKER station and moderate upstream. Phosphorus concentrations at most sites upstream of the ORLEANS station, however, were typically greater than 0.1 mg/L—large enough for the system to be classified as hypereutrophic with respect to phosphorus. Large populations of algae or aquatic plants could be supported in the Shasta River system and in the upper concentrations of phosphorus tended to decrease between the IRONGATE station and the KLAMATH station, the most downstream site, which may indicate the existence of a population of periphyton in that reach.

Two Lagrangian parcel-tracking studies were done on the Klamath (July, September) and Shasta (June, August) Rivers in 2003. Data from these studies were similar to that collected during the monthly sampling study in 2002, although the levels of nitrate in the Klamath River were markedly higher in the reach extending from the IRONGATE station to the SEIAD station than during any of the previous sampling periods. Similar trends of decreasing nitrogen and phosphorus concentrations were measured in the reach extending from the IRONGATE station to the most downstream KLAMATH station, again indicating potentially significant uptake by periphyton.

Sediment oxygen-demand rates were measured at six locations in two reaches on the Shasta River during the summer of 2003. The rates of SOD at these sites were moderate (median rate of 1.5 $g/m^2/d$); however, they were large enough for SOD to be a significant contributor in the loss of DO in the Shasta River, particularly for those shallow reaches that accumulate sediment and algal and plant detritus.

The process of determining and evaluating gaps in data using conceptual and mathematical models are discussed in this report. Several recent efforts to simulate water quality in the Klamath River also are discussed and evaluated. Learning from existing models is a good beginning to start understanding the most important influences on the water quality of a river system. Those models can be used to help identify gaps in both data and in the understanding of water-quality processes. Of the models evaluated, CE-QUAL-W2 may be best suited for further evaluations of the river systems in the Lower Klamath River Basin.

The appropriate and targeted use of modeling tools is one good method that can be used to lay the foundation for TMDL development, but additional data will likely be required before sufficiently robust and accurate predictive models can be constructed. Some data gaps are already known and are discussed in this report. Perhaps the largest data gap centers on algae both in the reservoirs and in the river downstream from the IRONGATE monitoring station. The gap in algae data includes unknowns regarding the types of algae present, the size, timing, and spatial distribution of algal communities, as well as their primary productivity and respiration rates. Additional data detailing the vertical water-quality profiles of DO and temperature for reservoirs in the Lower Klamath River Basin would be useful. More data are needed to define the BOD and SOD in the reservoirs and in the lower Klamath River. Information on the extent and importance of riparian shading is needed. These data gaps can be used to define additional studies needed to advance the understanding of water quality in the Klamath River, as well as to build tools that can be used to create a scientifically defensible framework for resource management and water-quality improvement.

Selected References

Bartholoma, S.D., 1997, User's manual for the National Water Information System of the U.S. Geological Survey, chap. 3, Automated data processing system: U.S. Geological Survey Open-File Report 97-635, 219 p.

Bartholow, J.M., J. Heasley, R.B. Hanna, J. Sandelin, M. Flug, S. Campbell, J. Henriksen, and A. Douglas, 2003, Evaluating water management strategies with the Systems Impact Assessment Model: SIAM, version 3: U.S. Geological Survey, Fort Collins Science Center Open File Report 03-82, 127 p.

Battaglin, W.A., Kendall, C., Chang, C.C.Y., Silva, S.R., Campbell, D.H., 2001, Chemical and isotopic evidence of nitrogen transformation in the Mississippi River, 1997-98: Hydrological Processes, v. 15, no. 7, p. 1285–1300.

Boss International, Enhanced RMA Models accessed August 3, 2004, at http://*hc-2.com/html/rma11.html*.

Boyd, M., Kirk, S., Wiltsey, M., and Kasper, B., 2002, Upper Klamath Lake Drainage Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP): Portland, Ore., Oregon Department of Environmental Quality, 188 p.

Bothwell, M.L., 1989, Phosphorus-limited growth dynamics of lotic periphyton diatom communities: areal biomass and cellular growth rate response: Canadian Journal of Fisheries and Aquatic Sciences, v. 46, p. 1291–1301.

Bristow, K.L. and Campbell, G.S., 1984, On the relationship between incoming solar radiation and daily maximum and minimum temperature: Journal of Agriculture and Forest Meteorology 31:159–166.

Caldwell, J.M., and Doyle, M.C., 1995, Sediment oxygen demand in the lower Willamette River, Oregon, 1994: U.S. Geological Survey Water-Resources Investigations Report 95-4196, 14 p.

California Environmental Protection Agency, 2003, State Water Resources Control Board, Final, 2002 Clean Water Act Section 303(d) List of Water Quality Limited Segments: Region, accessed April 2004 at http://*www.swrcb.ca.gov/tmdl/303d_lists.html*

California Department of Water ResourcesFinal 2002 Cleas Water Act Section 303(d) List of Water Quality Limited Sigments, accessed April 2004, at http://*www.swrcb.ca.gov/tmdl/303d_lists.html*

Campbell, S.G., 1995, Klamath River Basin flow-related scooping study – Phase I, water quality: Study status report: Denver, Colo., National Biological Service.

Campbell, S.G., 2001, Water quality and nutrient loading in the Klamath River between Keno, Oregon and Seiad Valley, California from 1996–1998: U.S. Geological Survey Open-File Report 01-301, 55 p. + diskette.

Campbell, S.G., Hanna, R.B., Flug, M., Scott, J.F., 2001, Modeling Klamath River system operations for quantity and quality: J. Water Resources Planning and Management, Sept/Oct, p. 284–294.

Cole, T.M., and Wells, S.A., 2002, CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic water-quality model, version 3.1. Instruction Report EL-02-1: Washington, DC, U.S. Army Corps of Engineers, 615 p.

Davis, J.C., 1975, Minimal DO requirements of aquatic life with emphasis on Cadagian species: a review: Journal of Fisheries Research Board Canada, v. 32, no. 12, p. 2295–2332.

Deas, M.L., 2000, Application of numerical water quality models in ecological assessment: Davis, Calif., University of California, Ph.D. dissertation, 400 p.

Doyle, M.C., and Caldwell, J.M., 1996, Water-quality, streamflow, and meteorological data for the Tualatin River Basin, Oregon, 1991–93: U.S. Geological Survey Open File Report 96-173, 49 p., CD ROM in pocket.

Doyle, M.C., and Rounds, S.A., 2003, The effect of chamber mixing velocity on bias in measurement of sediment oxygen demand rates in the Tualatin River Basin, Oregon: U.S. Geological Survey Water-Resources Investigations Report 03-4097, 16 p.

Environmental Software and Services, GAIA Model base: Accessed August 3, 2004, at http://*www.ess.co.at/GAIA/models/idro.htm*

Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediments (3rd ed.): U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, p. 451.

Flint, A.L., and Childs, S.W., 1987, Calculation of solar radiation in mountainous terrain: Journal of Agricultural and Forest Meteorology, v. 40, p. 233–249.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, p. 18–30.

Hanna, R.B., and Campbell, S.G., 2000, Water quality modeling in the Systems Impact Assessment Model for the Klamath River Basin–Keno, Oregon, to Seiad Valley, California: U.S. Geological Survey Open-File Report 99-113, 82 p.

Hem, J.D., 1989, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 264 p.

Hsieh, P.A., Bahr, J.M., Doe, T.W., Flint, A.L., Gee, G.W., Gelhar, Solomon, D.K, van Genuchten, M. Th., and Wheatcraft, S.W., eds., 2001, Conceptual Models of Flow and Transport in the Fractured Vadose Zone: Washington DC, National Academy Press, 374 p.

Karuk Tribe of California, 2003, Water year 2002 water quality monitoring report: Orleans, Calif., Department of Natural Resources.

Kelly, V.J., 1997, Dissolved oxygen in the Tualatin River, Oregon, during winter flow conditions, 1991 and 1992: U.S. Geological Survey Water-Supply Paper 2465-A, 68 p.

Labadie, J.W., MODSIM-DSS: Water Resources and Water Rights Planning and Operations Decision Support System; Accessed August 3, 2004 http://*modsim.engr.colostate.edu*

Lee, G.F., and Jones, R.A., 1991, Regulating drinking water quality at the source: Presented at the University of California Water Resources Center Conference, Sacramento, Calif., April 3–4, handout.

Leidy, R.A., and Leidy, G.R., 1984, Life stage periodicities of anadromous salmonids in the Klamath River Basin northwest California: U.S. Fish and Wildlife Service, Division of Ecological Services, Sacramento, Calif., April.

Lynch, D.D., and Risley, J.C., 2003, Klamath River Basin hydrologic conditions prior to the September 2002 die-off of salmon and steelhead: U.S. Geological Survey Water-Resources Investigation Report 03-4099, 10 p.

Murphy, P.J. and Hicks, D.B., 1986, In-situ method for measuring sediment oxygen demand, *in* Hatcher, K.J., ed., Sediment oxygen demand—Processes, modeling, and measurement: Athens, Georgia, Institute of Natural Resources, University of Georgia, p. 307–322.

National Research Council, 2004, Endangered and threatened fishes in the Klamath River Basin: Causes of decline and strategies for recovery: Washington DC, National Academies Press, 384 p.

North Coast Regional Water Quality Control Board, 2001, Water Quality Control Plan for the North Coast Region accessed April 2002 at *http://www.krisweb.com/biblio/ncc_swrcb_ ncrwqcb_ 2001_ wqcontrolplan.pdf*

Perry, T., Mull, T., Lieb, A., Harrison, A., Cohen, E., Rasmussen, J., and Hicks, J., 2004, Natural inflow to, natural losses from, and natural outfall of Upper Klamath Lake to the Link River and of Lower Klamath Lake to the Klamath River at Keno: Denver, Colo., Bureau of Reclamation BOR Technical Service Center, 151 p.

Radtke, D.B., White, A.F., Davis, J.V., and Wilde, F.D., 1998, Dissolved oxygen, *in* Wilde, F.D., and Radtke, D.B., eds., 1998, Field measurements, *in* National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6.2, 38 p.

Rounds, S.A., and Doyle, M.C., 1997, Sediment oxygen demand in the Tualatin River Basin, Oregon, 1992–1996: U.S. Geological Survey Water-Resources Investigations Report 97-4103, 19 p.

Rounds, S.A., Wood, T.M., and Lynch, D.D., 1999, Modeling discharge, temperature, and water quality in the Tualatin River, Oregon: U.S. Geological Survey Water-Supply Paper 2465-B, 121 p.

Stanley, D.L., Boozer, T.M., and Schroder, L.J., 1998, Summary of the U.S. Geological Survey National Field Quality-Assurance Program from 1979 through 1997: U.S. Geological Survey Open-File Report 98-392, 11 p.

State of California, Department of Fish and Game, 2003, September 2002 Klamath River Fish Kill: Preliminary analysis of contributing factors, January.

U.S. Environmental Protection Agency, 1986, Quality Criteria for Water: Washington, DC, EPA 440/5-86-001, 398 p.

U.S. Environmental Protection Agency, 2002, National recommended water quality criteria: 2002: EPA-822-R-02-047, 33 p.

U.S. Geological Survey, Water-quality data for the Nation, accessed March 14, 2003, at http://*waterdata.usgs.gov/nwis/qw*

U.S. Geological Survey, Tualatin River at Oswego Diversion Dam (14207200), accessed April 2004 at http://*or.water.usgs.gov/cgi-bin/grapher/graph_setup.pl?site_id=14207200*

Wagner, R.J., Mattraw, H.C., Ritz, G.F., and Smith, B.A., 2000, Guidelines and standard procedures for continuous water-quality monitors: Site selection, field operation, calibration, record computation, and reporting: U.S. Geological Survey Water-Resources Investigations Report 00-4252, 53 p.

Weiss, R.F., 1970, The solubility of nitrogen, oxygen, and argon in water and seawater: Deep Sea Research, v. 17, no. 4, p. 721–735.

Wilde, F.D., and Radtke, D.B., eds., 1998, Field measurements, *in* National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6 [variously paged].

Wood, T.M., 2001, Sediment oxygen demand in Upper Klamath and Agency Lakes, Oregon, 1999: U.S. Geological Survey Water-Resources Investigations Report 01-4080, 13 p.

Wood, T.M., and Rounds, S.A., 1998, Using CE-QUAL-W2 to assess the effect of reduced phosphorus loads on chlorophyll-*a* and dissolved oxygen in the Tualatin River, Oregon: *In* Proceedings of the First Federal Interagency Hydrologic Modeling Conference: U.S. Geological Survey, April 19–23, Las Vegas, Nevada, p. 2-149–2-156.

Appendix 1. Continuous dissolved oxygen, water temperature, ph, and specific conductance data measured at USGS sites in 2002 and 2003.

Continuously measured water-quality data are presented graphically for all USGS water-quality sites on the Klamath, Trinity, Shasta, and Lost Rivers in the Lower Klamath River Basin for the 2002 and 2003 field seasons. Data include dissolved oxygen, water temperature, pH, and specific conductance. All the hourly data that completed quality-assurance checks are shown in *figures A1-1a-h*. The complete data set is archived in the California District NWIS database.

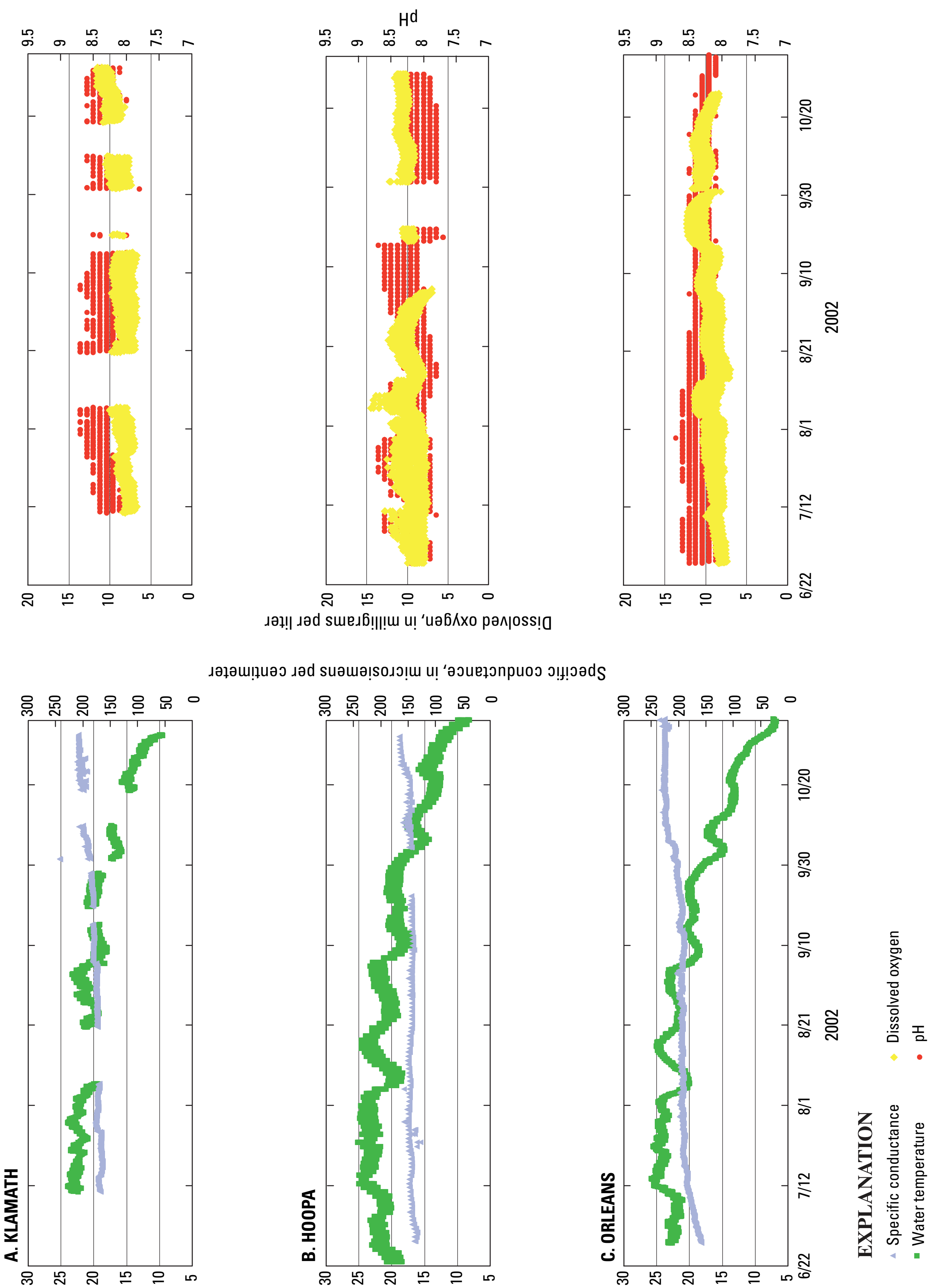

Figure A1-1. Measured continuous data of water temperature and specific conductance in left column, and dissolved oxygen and pH in right column for 2002 and 2003 for stations at (***A***) KLAMATH, (***B***) HOOPA, (***C***) ORLEANS, (***D***) SEIAD, (***E***) WALKER, (***F***) EDGEWOOD, (***G***) MONTAGUE, (***H***) HWY3, (***I***) YREKA, (***J***) IRONGATE, (***K***) SHOVEL, (***L***) TULE, and (***M***) HATFIELD.

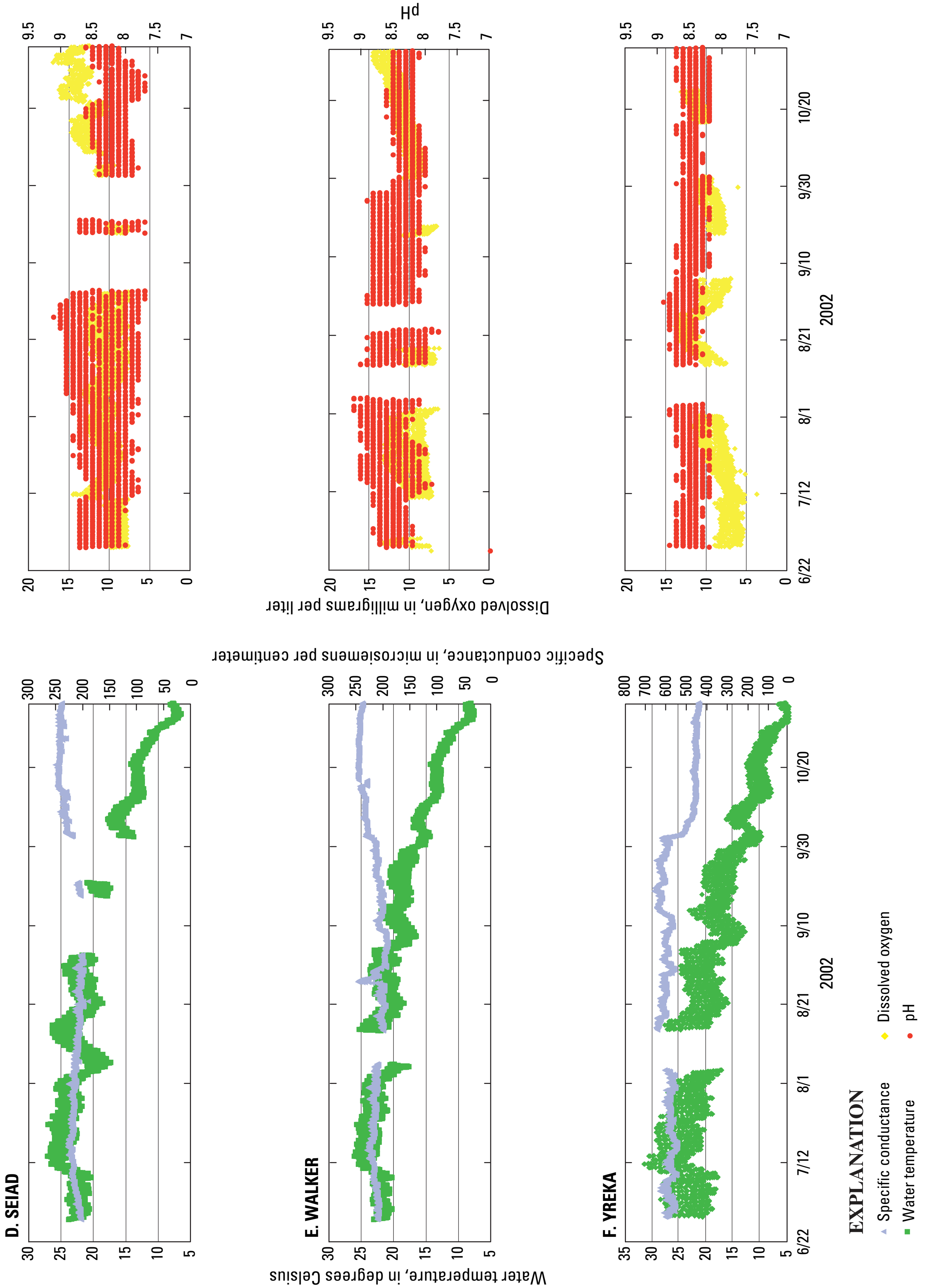

Figure A1-1.—*Continued.*

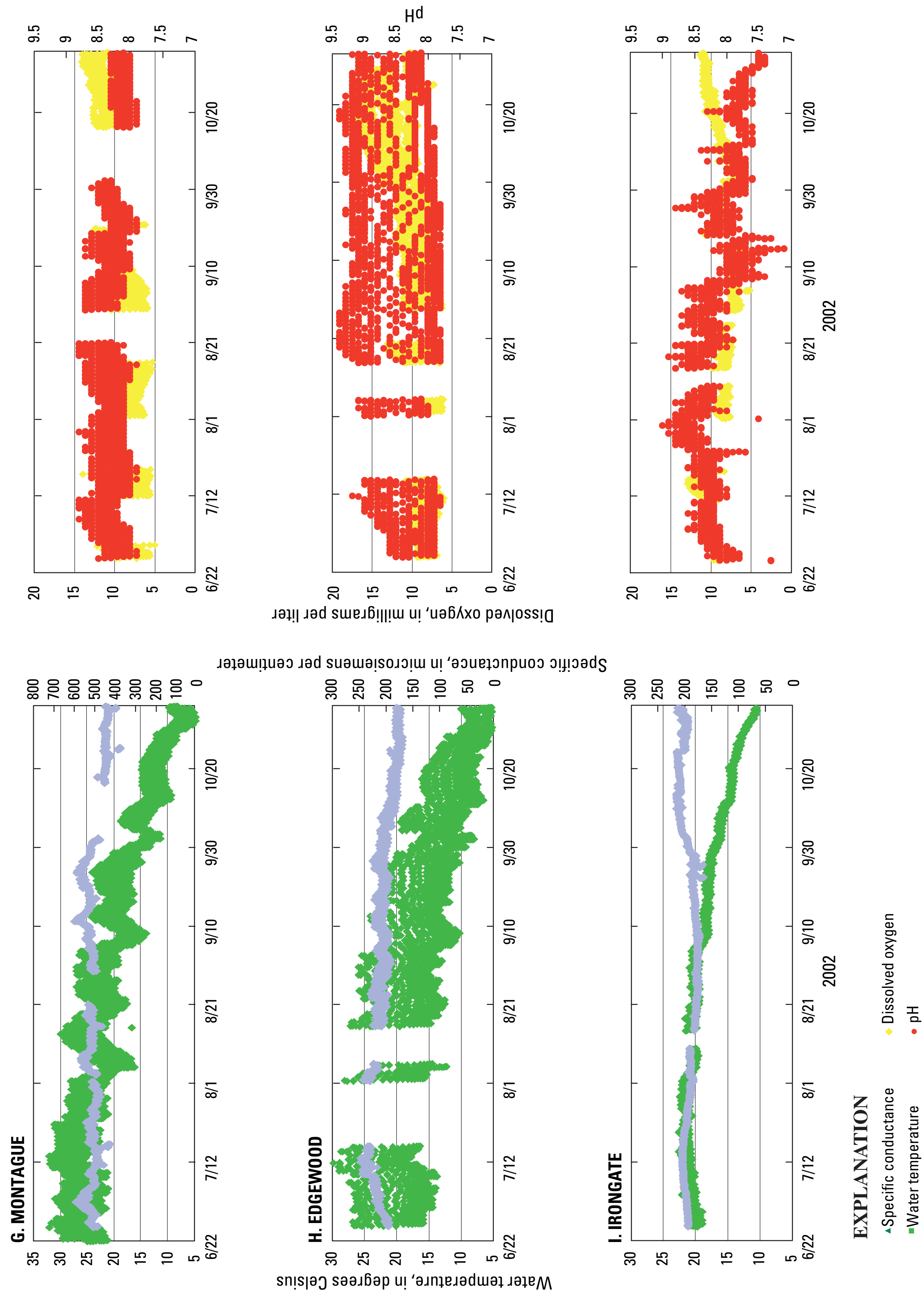

Figure A1-1.—*Continued.*

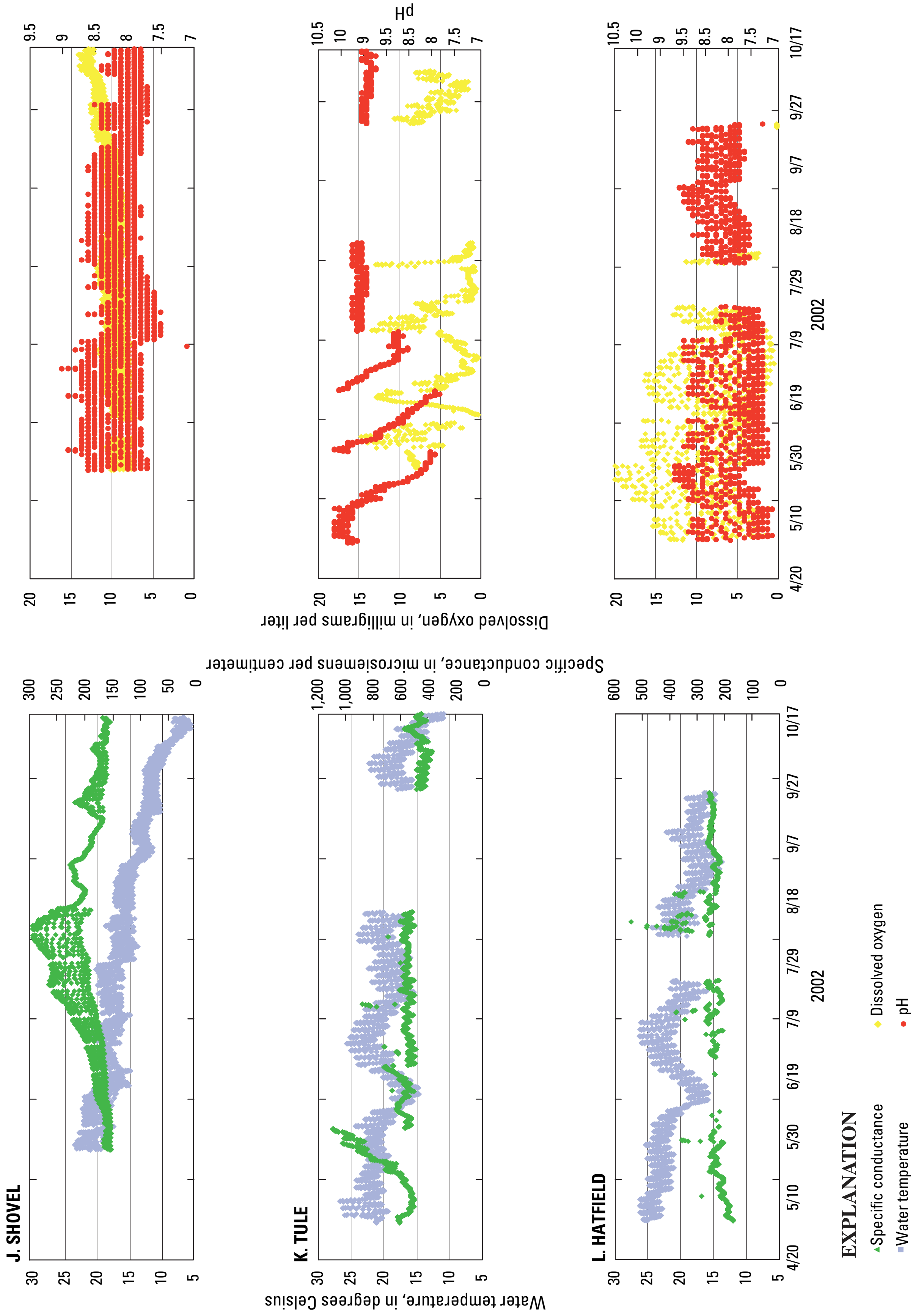

Figure A1-1.—***Continued.***

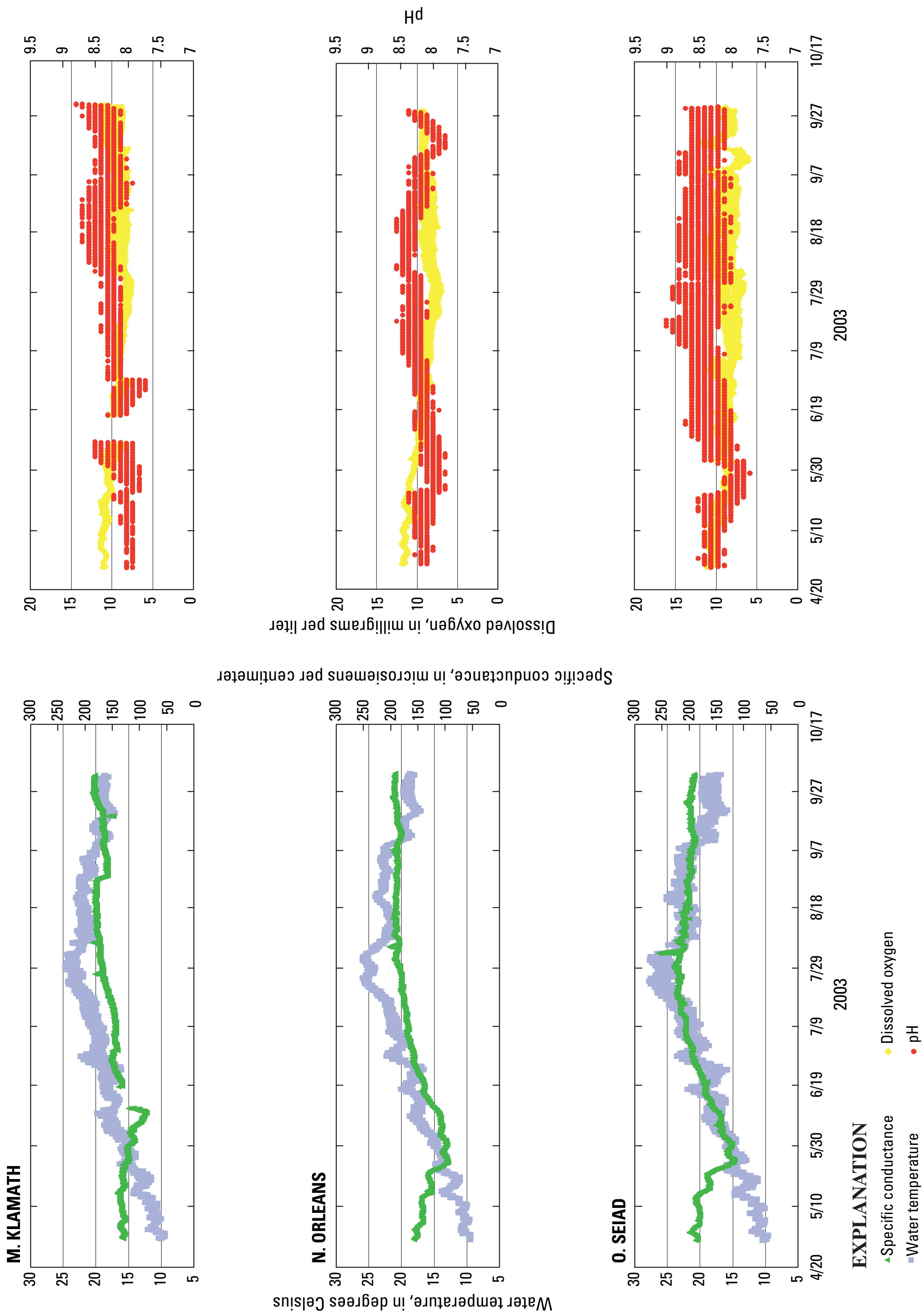

Figure A1-1—*Continued.*

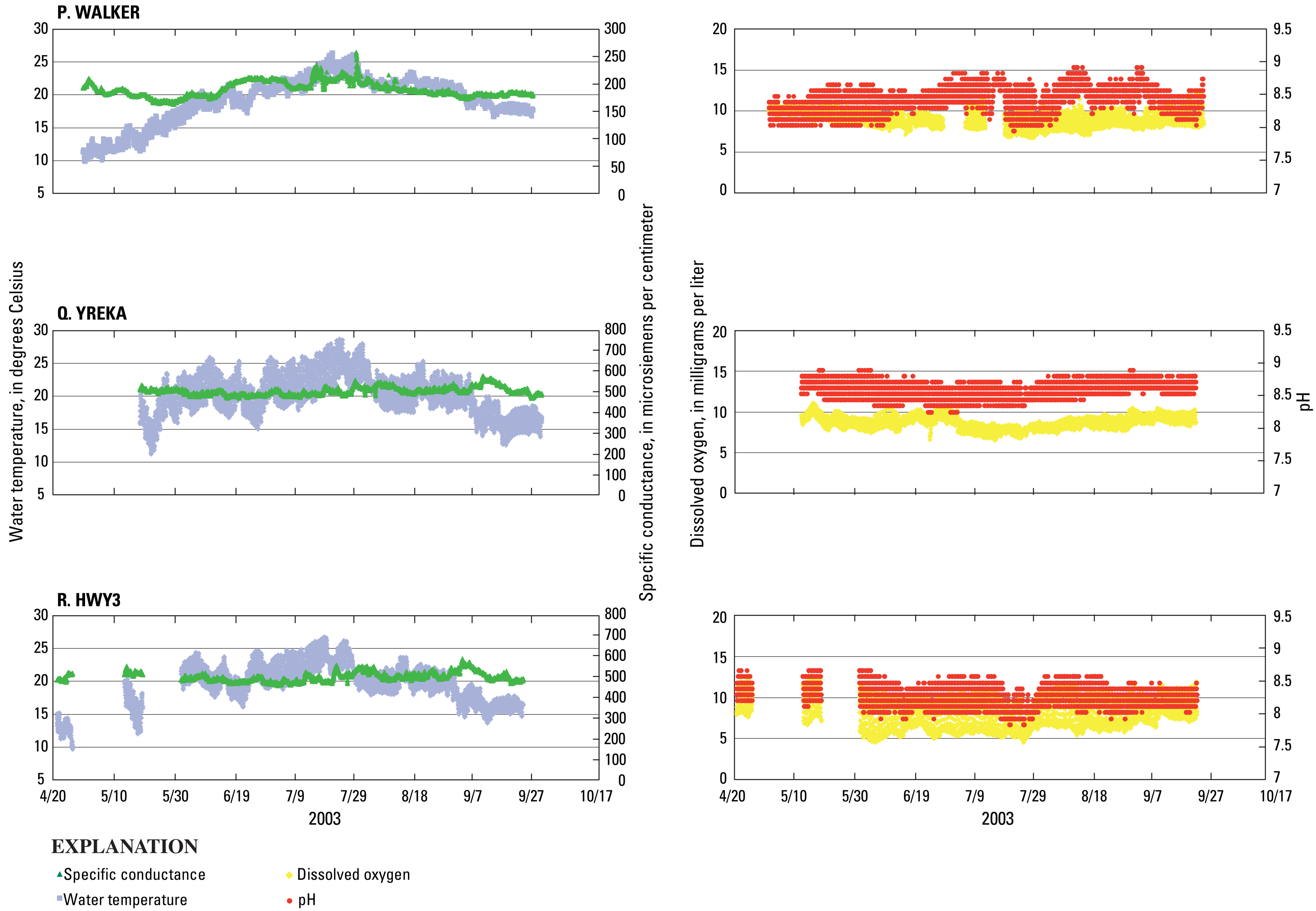

Figure A1-1.—***Continued.***

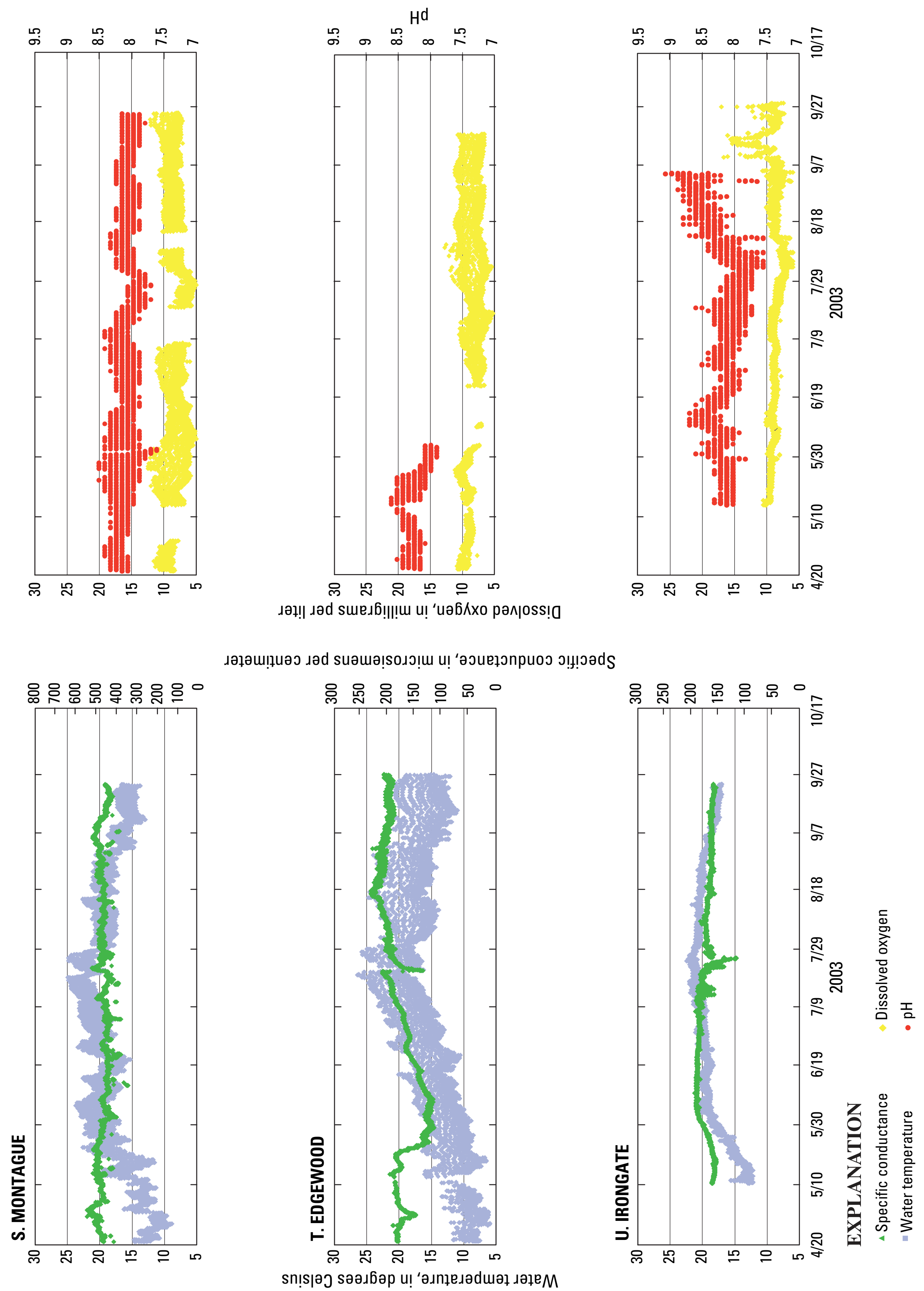

Figure A1-1.—*Continued.*

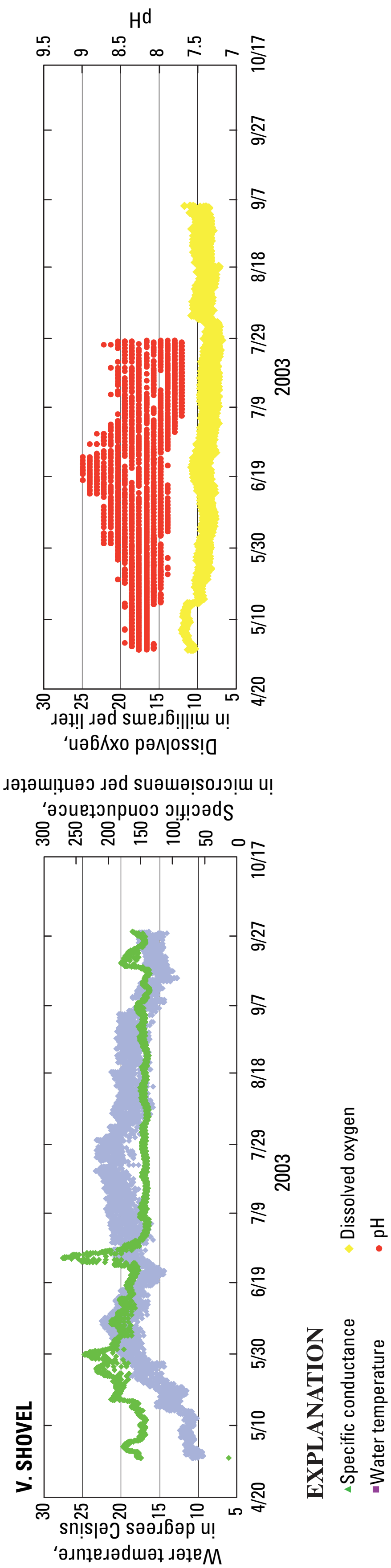

Figure A1-1.—*Continued.*

Appendix 2. Methodology for correcting continuous dissolved oxygen data from USGS datasonde sensors and associated data uncertainty.

Continuous field measurement of dissoved oxygen (DO) is difficult because it requires frequent site visits to maintain and clean the probes (to remove biofouling) and to recalibrate the probes (to correct the sensor drift). Data, therefore, must be corrected to maintain the best accuracy according to field calibrations. The theory for measuring DO and the inherent errors associated with the measurements are discussed in the following section to illustrate the reliability of the DO data collected by the USGS and the accuracy of that data. USGS protocols for deploying and maintaining the probes and for processing the data and reporting it are briefly described with information excerpted from Wagner and others (2000). For further details on USGS protocols, see Wagner and others (2000), as well as publications by Radtke and others (1998) and Wilde and Radtke (1998). For information regarding supersaturated DO conditions, refer to studies of Oregon lakes and rivers by Doyle and Caldwell (1996), Kelly (1997), Rounds and others (1999), and Wood and Rounds (1998). Examples of data collected on the Shasta River for 2002 and 2003 are used in this appendix to illustrate data uncertainty for the Lower Klamath River Basin.

Theory and Measurement of Dissolved Oxygen

The DO concentration in surface water is related primarily to atmospheric reaeration and photosynthetic activity of aquatic plants (Radtke and others, 1998). The range of observed DO in surface waters typically is from 2 to 10 milligrams per liter (mg/L) at 20°C. The value for 100-percent saturation of DO decreases with increased temperature and salinity, and increases with increased atmospheric pressure. Occasions of excess oxygen (supersaturation) are related to extreme photosynthetic production of oxygen by aquatic plants as a result of nutrient (nitrogen and phosphorus) enrichment, sunlight, and low-flow conditions. Occasions of saturated oxygen commonly are related to cascading flow conditions, both natural and artificial. DO may be depleted by inorganic oxidation reactions or by biological and chemical processes that consume dissolved, suspended, or precipitated organic matter (Hem, 1989).

The most commonly used technique for measuring DO concentrations with continuous water-quality sensors is the amperometric method, which measures DO with a temperature-compensated polarographic membrane-type sensor. Although polarographic membrane-type sensors generally provide accurate results, they commonly are sensitive to water temperature and water velocity and are prone to fouling. Because the permeability of the membrane and the solubility of oxygen in water change as functions of water temperature, barometric pressure, and salinity, it is critical that the DO sensors be calibrated. DO sensors are prone to inaccuracies from algal fouling, sedimentation, low velocity, and very high velocities. They also undergo drift in the electronics, and can be subjected to leakage of the membrane. For a complete discussion of DO sensor calibration, DO measurement, and instrument and data limitations, refer to Radtke and others (1998).

USGS Protocols for Collecting, Processing, and Reporting Continuous Dissolved Oxygen Data

YSI 6920 multiparameter datasondes were used to collect continuous DO measurements for this current study of the Lower Klamath River Basin. Standard USGS protocols were followed for the collection of continuous DO data, calibration of probes, and correction and reporting of data (Wilde and Radtke, 1998).

Collecting Field Measurements of Dissolved Oxygen

Maintenance frequency of DO sensors generally is governed by the fouling rate, and this rate varies by sensor type, hydrologic environment, and season. In addition to fouling problems, physical disruptions (such as pump failure, recording equipment malfunction, sedimentation, electrical disruption, debris, or vandalism), or battery failure may cause additional site visits.

During a site visit the sensor is inspected to provide the final quality control for the interval of water-quality record since the last service visit and the initial quality control for the next interval of water-quality record and to verify that the sensor is working properly. This is accomplished by recording the initial sensor readings, servicing the sensors, recording the cleaned-sensor readings, performing a calibration check of sensors at 100 percent oxygen saturation in air saturated with water vapor, and, if the readings of the DO sensor are outside the range of acceptable difference of ± 0.3 mg/L, recalibrating the sensor. The difference between the initial sensor reading and the cleaned sensor reading is the sensor error resulting from fouling during the preceding interval; the difference between the calibration-check reading and calibrated-sensor reading is a result of electronic drift. The tasks during a site visit are performed in sequence so as to properly distinguish errors in sensor measurement that are due to fouling from those that are due to electronic drift.

Data-Processing Procedures

The initial data evaluation serves as a check of the success of the transfer of raw data collected in the field (instrument readings) to the database at the office and provides the opportunity to evaluate obviously erroneous data, such as data recorded while the sensor was out of the water during a site visit. The data are then corrected, if necessary, for changes that occurred in the sensor during the service interval as a result of biofouling or electronic drift. Corrections to compensate for both of these types of measurement error are applied independently and are based on the quality-control information collected in the field during site visits, as described previously. In general, both types of corrections are applied when the measurement errors exceed ± 0.3 mg/L.

The degree of fouling is determined from the difference between sensor measurements before and after the sensors are cleaned in the field and is assumed to occur linearly with time between the sensor checks. A second calibrated instrument is brought into the field to measure any simultaneous changes in conditions so that an environmental change during servicing is not mistakenly attributed to fouling. A calibration drift is an electronic drift in the equipment from the last time it was calibrated and is determined by the difference between what the cleaned sensor reads in air saturated with water vapor and the 100 percent saturation concentration of oxygen in water at the ambient temperature and barometric pressure. If the deviation from calibration is within the manufacturer's calibration criteria for the sensor, then no sensor drift is indicated. Electronic drift is assumed to occur at a constant rate across the service interval. If the sensor readings exceed the shift criteria of 0.3 mg/L, then the correction is linearly interpolated over the time between calibration checks.

Systematic adoption of a standardized final data-evaluation process, including maximum allowable limits and publication criteria, are used by USGS District offices and have established quality-control limits to be used when shifting data. These commonly are referred to as "maximum allowable limits." If the sum of the absolute value of the fouling and calibration shifts is greater than the maximum allowable limit, the data are not published. For DO, the maximum allowable limit is 2.0 mg/L; this is considered a minimum standard for quality. USGS Districts are encouraged to establish stricter requirements. Even with the establishment of maximum allowable limits, professional judgment is required by a hydrographer when processing data.

Uncertainty in Dissolved Oxygen Data

Although DO probes are designed to operate linearly, biofouling with time may not be a linear function. To the best of our knowledge, few studies have been conducted to measure rates of biofouling and (or) instrument drift, and it is not clear exactly how a biofilm growing on the DO sensor affects DO levels, although it likely varies depending on numerous factors, including photo-intensity, time of day, temperature, etc. Given the uncertainties in the effect of biofouling on DO data, it is the practice of the USGS to apply a time-prorated linear data correction to DO data that show biofouling and instrument drift and to report the recorded levels of DO with a qualitative rating of the data. Various arguments can be made to support a nonlinear variation with time. Unfortunately, the only way to select among the many possible approaches to correcting DO data for biofouling is to make an additional measurement in the middle of the time interval. That measurement would require an additional site visit, but the incremental cost of the site visit would be small. The record would be processed as two intervals with linear corrections.

Dissolved Oxygen Data for the Shasta River, 2002–2003

Dissolved oxygen concentrations were measured continuously at three locations on the Shasta River between June and November 2002 and at four locations between April and September 2003 (*table A2-1*). To illustrate the methods used to process the data, the following data and calculations are shown (*fig. A2-1*): (1) field data from the initial data evaluation, which were used to check the success of the transfer of raw field data (instrument readings) to the office database and to provide an initial check for evaluating and correcting erroneous data; (2) computed data following corrections for biofouling and instrument drift; and (3) DO at saturation calculated from measured water temperature and atmospheric pressure (average values were based on measurements during site visits) (*fig. A2-1*). Generally, corrections for biofouling and drift are evident as decreases in the computed data, but occasionally it is evident as increases. There generally are large diurnal fluctuations in the data in mid to late summer, especially at the three upstream sites, EDGEWOOD, MONTAGUE, and HWY3 where the water is shallower and more slowly moving.

For purposes of example, the site at EDGEWOOD was chosen as providing the dataset with the most uncertainty, as this site has the slowest moving water and, therefore, generally has the most occurrences of extreme conditions of high or low DO, and the most biofouling. EDGEWOOD has site visits noted on *figure A2-1*. The probe deployed at that station in 2002 was at the bottom of an approximately 50-m long riffle. In 2003, the monitor was relocated to above the riffle. Corrections were made following site visits owing to biofouling in 2002, and to biofouling and drift in 2003, as noted in *table A2-1*. Calibrations and field checks with a hand-held meter were performed monthly in 2002, and at every site visit in 2003, with the exception of one visit in October when a hand-held meter was not used. Corresponding corrections and shifts to the data can be seen as linear prorated changes.

Although the measured DO values commonly exceed the solubility of DO, indicating supersaturated conditions, the entire diurnal cycle was supersaturated only three times during 24-hour periods: in August (possibly owing to periphyton bloom/die off) and in October 2002 at the YREKA station and in October 2002 at the EDGEWOOD station. The record for the EDGEWOOD station in October 2002 is of particular interest because the diurnal fluctuations in DO exceeded saturated conditions on a 24-hour basis for nearly a month. A comparison of this occurrence with occurrences at other sites where DO has been studied indicates that supersaturated conditions for extended periods of time do occur occasionally. Studies of the Tualatin River and of the Upper Klamath Lake in Oregon (Wood and Rounds, 1998; Rounds and others, 1999; U.S. Geological Survey, Upper Klamath Lake data, accessed March 26, 2004) indicate it is not unusual for this to occur, particularly in a system with little turbulence, few waterfalls or riffles, and an abundance of algae. These conditions are prevalent in the Shasta River which has an abundance of rooted aquatic plants in addition to a substantial population of attached algae. As long as conditions are favorable for the continued growth of the algae and aquatic plants, they can easily produce sufficient DO by photosynthesis to offset any consumptive processes and any losses to the atmosphere.

Studies show that supersaturation is an annual occurrence in many systems in Oregon. For example, the continuous DO record for a station on the Tualatin River (established in 1991) (Doyle and Caldwell, 1996; U.S. Geological Survey, Tualatin River data, accessed April 2004) shows that supersaturated conditions occurred annually at this station for 24-hour periods extending from 1 to 6 weeks. In 1992, supersaturated conditions persisted for a month at a time for several periods, and at saturations as high as 250 percent, even though that river has a TMDL meant to protect it from low DO conditions. Dissolved oxygen at shallow locations in the Upper Klamath Lake often exceeded 100 percent saturation values throughout the diel cycle for several days at a time between May and October of 2002 and 2003 (U.S. Geological Survey, Upper Klamath Lake data, accessed April 2004).

These comparisons give some credence to the data collected at the EDGEWOOD site; however, the site visit record, which was carefully scrutinized, indicates that although the meter was calibrated during the October visit, the only visit during the extended supersaturated period, there was no independent check of the meter for DO using a hand-held meter. This increases the uncertainty of this data for that period by not providing a means for defense; therefore, the computed data for EDGEWOOD for the period September 19, 2002, through November 6, 2002, have been removed from the dataset, although the original edited data remains. This is also true, but to a lesser degree, for the data from the YREKA site during August and September 2002, when there coincidentally was no independent check of the meter for DO during the field visit, and the subsequent visit indicated a failed sensor. As a result, the computed data for YREKA for the period of August 14, 2002, to September 17, 2002, have been removed from the dataset, while the original edited data remain.

There are many uncertainties associated with the DO data particularly the DO data for the Shasta River in particular. At the beginning of the 2002 field season, field crews unfamiliar with the collection of continuous DO data were trained in the USGS procedures decribed by Wagner and others (2000). In 2002, YSI 6920 multiparameter sondes having probes for measuring DO, pH, and specific conductance/water temperature were rented from the USGS Hydrologic Instrumentation Facility. There were numerous battery failures and other problems with the probes, in addition to the expected biofouling. Drift corrections were not made in 2002, but field calibrations were done and sensors were replaced as necessary (approximately monthly). In 2003, new instruments were obtained and more frequent field visits were made (*table A2-1*). In addition to corrections for biofouling, drift corrections were made and DO sensors were replaced as needed following inspections and calibrations in 2003 (approximately every 2 weeks).

Uncertainties in the DO data collected continuously in the field can be exemplified by the data collected in the Shasta River in 2002 and 2003. USGS field protocols were followed more rigorously in 2003 than in 2002, with more frequent site visits, field calibrations, and sensor replacements, thus providing more certainty in the data between visits. In addition, both biofouling and drift corrections were made in 2003. Data obtained during obvious probe failure, membrane leakage, or battery failure were removed in the initial data review, but more frequent site visits and probe inspections in 2002 could have provided more confidence in the data collected between site visits and in the field calibrations. In general, uncertainties governed by probe behavior due to biofouling and drift were consistently corrected for when deviations from the field calibrated values exceeded 0.3 mg/L but no more than 2.0 mg/L, except for the values collected at the EDGEWOOD station on August 18, 2003, and September 30, 2003, which were corrected by −2.2 and −2.4 mg/L, respectively. Careful inspection of other constituents, including coincident water temperature, pH, and specific conductance, as well as discharge, although not necessarily at the identical location, and specific consideration of individual site characteristics, weather conditions, nutrients, and the presence of algal and macrophyte populations would assist in the interpretation of the adequacy and uncertainty of the DO data at these sites.

Locations of active and inactive meteorological stations, type of data, and period of record are given in *table A3-1* Locations of active and inactive meterorological stations type of data, and period ofrecord are given in *table A3-1* through *A3-3* for the National Climatic Data Center (NCDC) stations, in *table A3-4* for the California Irrigation Management Information System (CIMIS) stations, and in *table A3-5* for the National Renewable Energy Laboratory (NREL) stations, and in *table A3-6* for the Remote Automated Weather Station (RAWS) sites.

Table A2-1. Corrections and shifts made to dissolved oxygen data, and comments on site visits to the EDGEWOOD station on the Shasta River in the Lower Klamath River Basin, California, 2002-2003.

[mg/L, milligrams per liter]

Date	Correction due to biofouling (mg/L)	Correction due to drift (mg/L)	Total correction	Comments
6/25/2002				Sonde deployed
7/11/2002	–8.6			Heavy algal growth on probe, fouling correction beyond allowable limit.
8/1/2002				7/16/02–8/1/02 battery failure
8/2/2002			0.0	
8/15/2002	–0.9		–0.9	8/4/02–8/15/02 battery failure
8/29/2002			0.0	8/18/02–8/29/02 faulty probe
9/19/2002	0.4		0.4	
10/2/2002	–0.4		–0.4	
10/16/2002			0.0	Cleaning visit only, no fouling correction needed
11/6/2002	0.7		0.7	Sonde removed for season
4/9/2003			0.0	Sonde deployed
4/25/2003			0.0	4/24/03–4/25/03 battery failure
5/13/2003			0.0	4/24/03 and 5/9/03–5/12/03 battery failure, new Sonde deployed
5/30/2003		–0.9	–0.9	
6/16/2003		0.5	0.5	
6/27/2003			0.0	no site visit
7/3/2003		2.0	2.0	no site visit
7/9/2003			0.0	hole found in membrane, replaced probe. Drift correction applied 6/27/03–7/3/03. 7/3/03–7/9/03 drift correction beyond allowable limit
7/23/2003			0.0	7/9/03 – 7/10/03 new probe questionable, 7/23/03 hole found in membrane, no data published 7/3/03–7/22/03
8/5/2003		–0.5	–0.5	
8/18/2003	–2.0	–0.2	–2.2	
9/11/2003		–1.8	–1.8	
10/1/2003	–0.2	–2.2	–2.4	
10/23/2003	–0.1	–1.4	–1.5	
11/14/2003		–0.9	–0.9	
12/1/2003	–0.1	–1.6	–1.7	Sonde removed for season

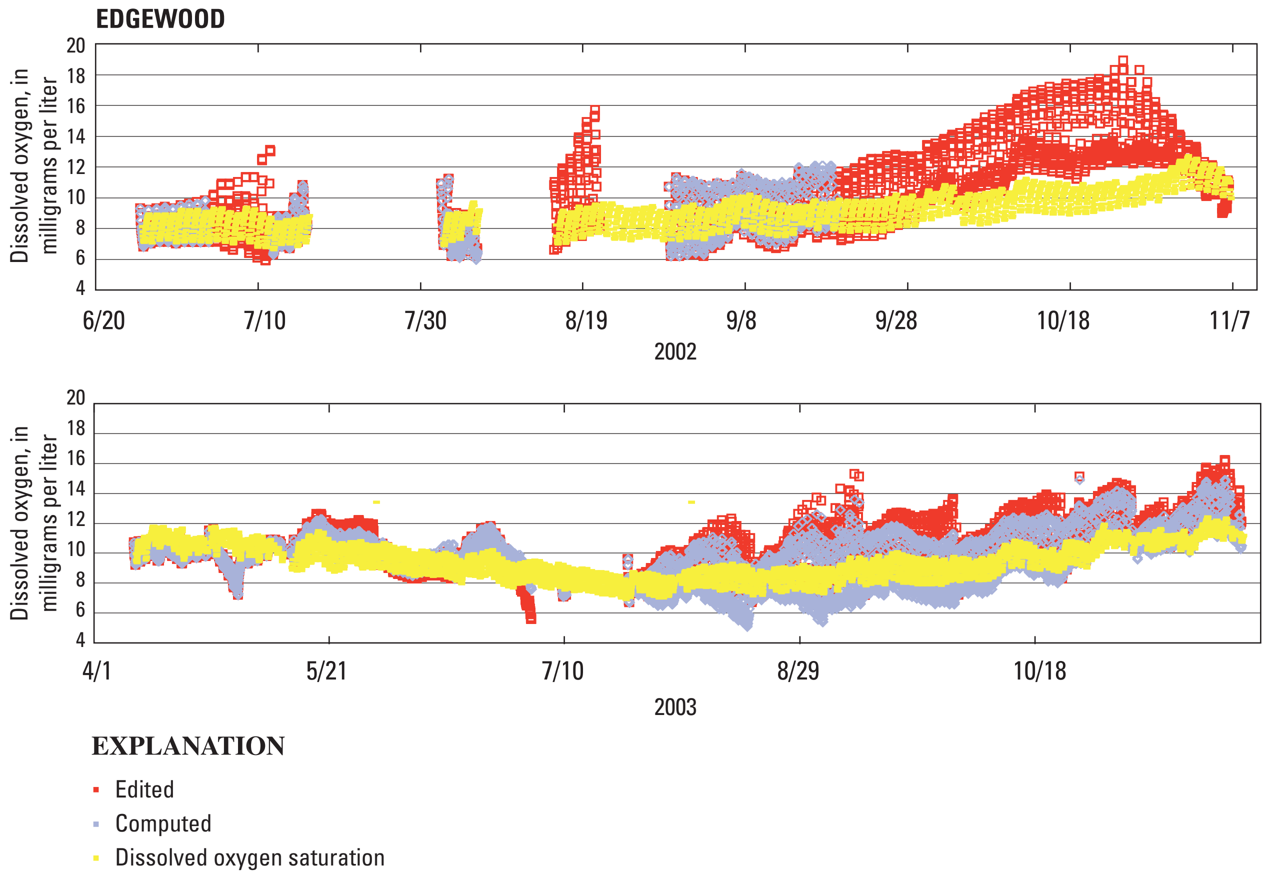

Figure A2-1. Measured continuous data of dissolved oxygen with initial edited record, computed record, and saturated values for 2002 and 2003 for USGS sites on the Shasta River, (***A***) EDGEWOOD, (***B***) MONTAGUE, (***C***) HWY3, and (***D***) YREKA.

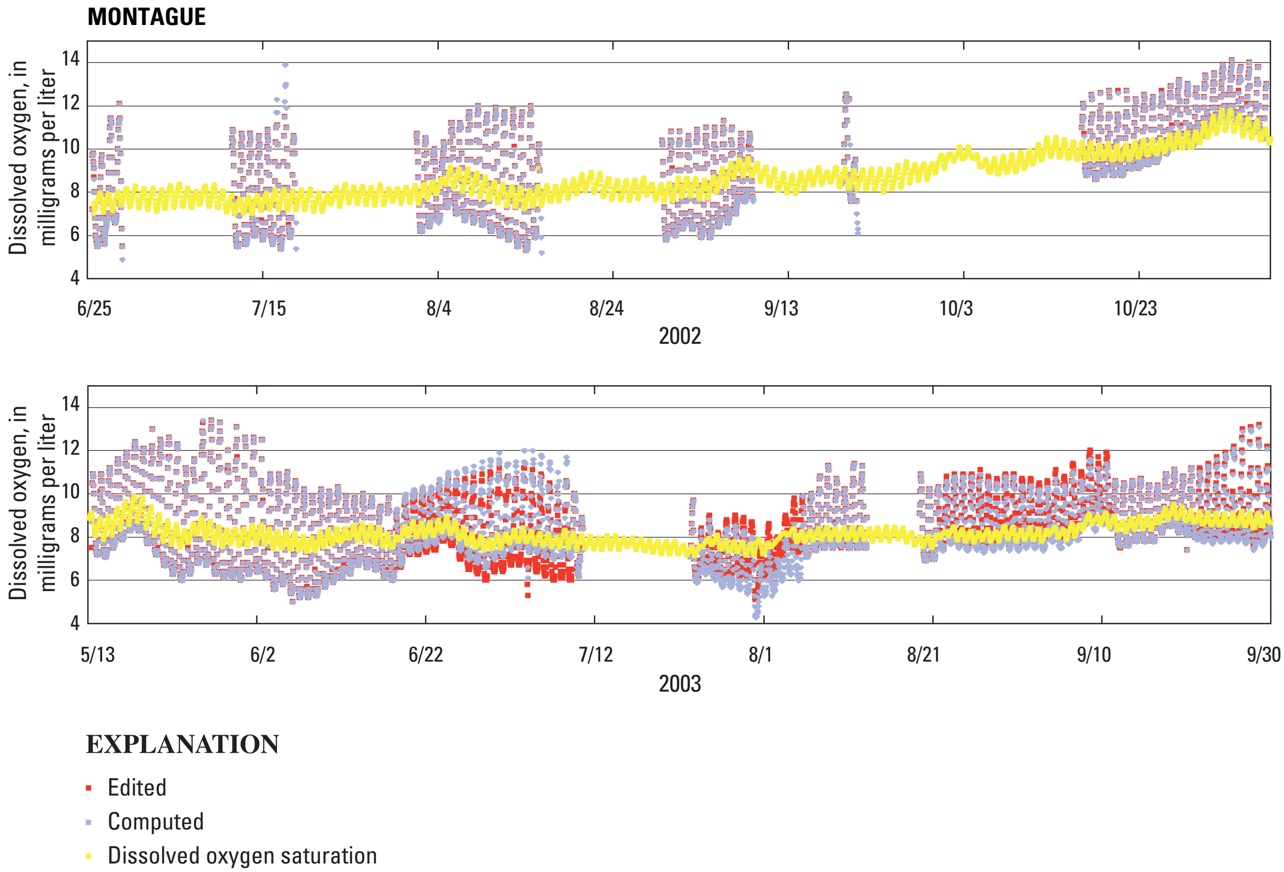

Figure A2-1.—***Continued***.

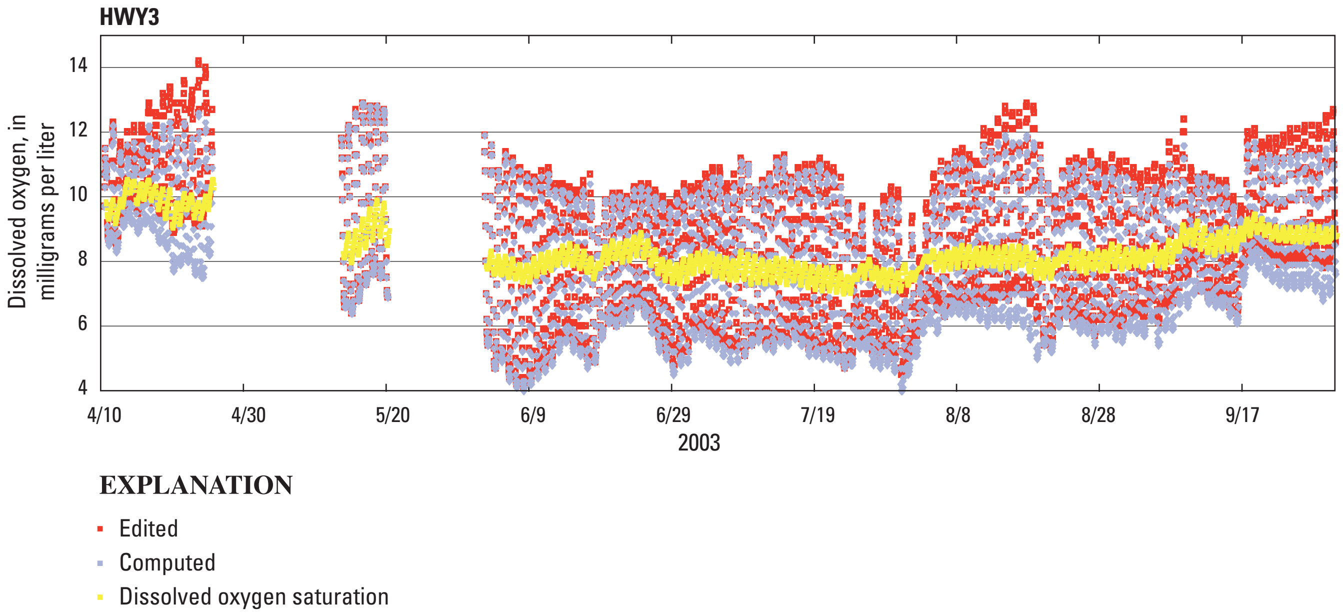

Figure A2-1.—***Continued***.

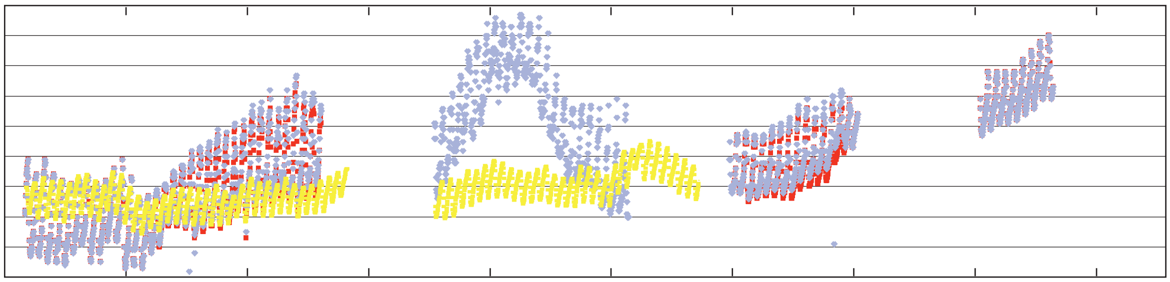

Figure A2-1.—***Continued***.

Appendix 3. Sources of meteorological data and locations of active and inactive stations in and around the Lower Klamath River Basin.

Locations of active and inactive meteorological stations, type of data, and period of record are given in *table A3-1* Locations of active and inactive meterorological stations type of data, and period ofrecord are given in *table A3-1* through *A3-3* for the National Climatic Data Center (NCDC) stations, in *table A3-4* for the California Irrigation Management Information System (CIMIS) stations, and in *table A3-5* for the National Renewable Energy Laboratory (NREL) stations, and in *table A3-6* for the Remote Automated Weather Station (RAWS) sites.

Table A3-1. Active National Climatic Data Center (NCDC) stations recording through 2003 in or around the Lower Klamath River Basin, California.

[Stations measure precipitation, snow, maximum and minimum air temperature. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station Id.	Station name	Elevation (meters)	Latitude	Longitude	Begin date
California					
29	ADIN RS	4,195.0	41.19639	−120.94722	7/1/1948
161	ALTURAS	4,400.0	41.49306	−120.55278	5/11/1931
738	BIG BAR 4 E	1,250.0	40.74028	−123.20806	7/1/1948
1149	BUCKHORN	3,800.0	40.86694	−121.84639	7/1/1948
1159	BUCKS CREEK P H	1,850.0	39.91778	−121.35111	7/2/1959
1214	BURNEY	3,198.0	40.88000	−121.67278	7/1/1948
1316	CALLAHAN	3,185.0	41.31111	−122.80444	7/1/1948
1476	CANBY 3 SW	4,310.0	41.42194	−120.90167	7/1/1948
1497	CANYON DAM	4,560.0	40.17056	−121.08861	7/1/1948
1606	CECILVILLE	2,310.0	41.14167	−123.13917	11/1/1954
1614	CEDARVILLE	4,670.0	41.53361	−120.17361	7/1/1948
1700	CHESTER	4,530.0	40.30333	−121.24222	7/1/1948
1886	COFFEE CREEK R S	2,500.0	41.08944	−122.70861	1/1/1998
1907	COLEMAN FISHERIES STA	420.0	40.40000	−122.14333	7/1/1948
1990	COPCO NO 1 DAM	2,703.0	41.97972	−122.33778	5/1/1959
2081	COVELO	1,410.0	39.81583	−123.24444	7/1/1948
2147	CRESCENT CITY 3 NNW	40.0	41.79583	−124.21472	7/1/1948
2402	DE SABLA	2,710.0	39.87389	−121.61722	7/1/1948
2504	DOYLE	4,240.0	40.02417	−120.10444	7/2/1948
2506	DOYLE 4 SSE	4,390.0	39.97167	−120.08278	7/1/1956
2574	DUNSMUIR TREATMENT PLAN	2,170.0	41.18333	−122.27361	7/1/1978
2910	EUREKA WFO WOODLEY IS	20.0	40.81056	−124.16028	7/1/1948
2964	FALL RIVER MILLS CSD	3,310.0	41.01611	−121.44250	7/1/1948
3157	FORT BIDWELL	4,500.0	41.85944	−120.15139	7/1/1948
3182	FORT JONES RANGER STN	2,725.0	41.60000	−122.84778	7/1/1948
3357	GASQUET RS	384.0	41.84528	−123.96500	7/1/1948
3614	GREENVIEW	2,820.0	41.55194	−122.92361	7/1/1948
3761	HAPPY CAMP RANGER STN	1,120.0	41.80417	−123.37583	1/8/1931
3791	HARRISON GULCH R S	2,750.0	40.36361	−122.96500	7/1/1948
3824	HAT CREEK	3,015.0	40.93167	−121.54333	7/1/1948
3859	HAYFORK 2 W	2,300.0	40.55250	−123.21222	7/1/1948
4374	JESS VALLEY	5,400.0	41.26833	−120.29472	8/1/1948
4577	KLAMATH	25.0	41.52167	−124.03167	7/1/1948
4683	LAKEHEAD	1,260.0	40.91083	−122.38833	6/1/1998
4838	LAVA BEDS NAT MONUMENT	4,770.0	41.74000	−121.50667	10/7/1959
5311	MANZANITA LAKE	5,750.0	40.54194	−121.57639	1/1/1949
5449	MC CLOUD	3,280.0	41.25139	−122.13833	7/1/1948
5941	MOUNT HEBRON RNG STN	4,250.0	41.78361	−122.04472	7/1/1948
5983	MOUNT SHASTA	3,590.0	41.32056	−122.30806	7/1/1948
6328	OAK KNOLL W C	1,980.0	41.83917	−122.85028	7/1/1948
6498	ORICK PRAIRIE CREEK PAR	160.0	41.36194	−124.01917	7/1/1948
6508	ORLEANS	400.0	41.30889	−123.53222	7/1/1948
6946	PIT RIVER P H 5	1,458.0	40.98694	−121.97722	7/1/1948
7085	PORTOLA	4,850.0	39.80528	−120.47194	7/1/1948
7195	QUINCY	3,420.0	39.93667	−120.94750	7/1/1948
7292	RED BLUFF AP	353.0	40.15194	−122.25361	11/1/1933

Table A3-1. Active National Climatic Data Center (NCDC) stations recording through 2003 in or around the Lower Klamath River Basin, California—***Continued***.

[Stations measure precipitation, snow, maximum and minimum air temperature. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station Id.	Station name	Elevation (meters)	Latitude	Longitude	Begin date
7293	RED BLUFF TREATMENT PLA	265.0	40.16222	−122.22028	5/1/2000
7298	REDDING CDF	502.0	40.51944	−122.29889	2/1/1998
7304	REDDING MUNICIPAL AP	497.0	40.51750	−122.29861	11/1/1986
7404	RICHARDSON GR ST PK	500.0	40.02556	−123.79194	11/9/1961
8045	SCOTIA	133.0	40.48333	−124.10389	1/9/1931
8135	SHASTA DAM	1,075.0	40.71417	−122.41611	7/1/1948
8163	SHELTER COVE AV	246.0	40.03306	−124.07278	9/1/1974
8490	STANDISH HICKEY ST PK	850.0	39.88028	−123.72639	5/1/1959
9026	TRINITY RIVER HATCHERY	1,860.0	40.72639	122.79472	8/1/1974
9053	TULELAKE	4,035.0	41.96000	−121.47444	1/1/1932
9351	VINTON	4,950.0	39.80556	−120.18583	3/1/1950
9390	VOLTA POWER HOUSE	2,220.0	40.45694	−121.86556	7/1/1948
9490	WEAVERVILLE	2,040.0	40.73500	−122.93917	7/1/1948
9621	WHISKEYTOWN RESERVOIR	1,295.0	40.61167	−122.52806	4/16/1960
9694	WILLOW CREEK 1 NW	461.0	40.94667	−123.63667	9/28/1968
9866	YREKA	2,625.0	41.70361	−122.64083	7/1/1948
Oregon					
36	ADEL	4,583.0	42.17611	−119.89611	3/7/1956
217	APPLEGATE	1,282.0	42.24500	−123.17472	1/1/1979
304	ASHLAND	1,746.0	42.21278	−122.71444	7/1/1948
856	BLY 4 SE	4,560.0	42.36833	−120.96528	2/1/2000
1055	BROOKINGS 2 SE	46.0	42.02833	−124.24528	1/1/1931
1149	BUNCOM 1 NNE	1,949.0	42.19306	−122.99889	8/1/1948
1448	CAVE JUNCTION 1 WNW	1,280.0	42.17694	−123.67528	3/9/1962
1574	CHILOQUIN 7 NW	4155.0	42.65111	−121.94806	8/1/1980
3356	GOLD BEACH RANGER STN	50.0	42.40361	−124.42417	7/1/1948
3509	GREEN SPRINGS POWER PLA	2,435.0	42.12583	−122.54500	9/21/1960
4060	HOWARD PRAIRIE DAM	4,567.0	42.22917	−122.38139	9/21/1960
4133	ILLAHE	348.0	42.62861	−124.05750	7/1/1948
4403	KENO	4,116.0	42.12972	−121.92972	7/1/1948
4511	KLAMATH FALLS AG STA	4,092.0	42.16444	−121.75472	9/1/1949
4634	LAKE CREEK 2 S	1,865.0	42.39028	−122.62583	1/22/1955
4670	LAKEVIEW 2 NNW	4,778.0	42.21389	−120.36361	1/1/1928
5055	LOST CREEK DAM	1,580.0	42.67222	−122.67500	6/1/1970
5174	MALIN 5 E	4,627.0	42.00778	−121.31861	11/1/1968
5424	MEDFORD EXPERIMENT STN	1,457.0	42.29611	−122.87000	9/1/1937
5429	MEDFORD WSO AP	1,300.0	42.38917	−122.87139	1/1/1928
6426	PAISLEY	4,360.0	42.69222	−120.54028	7/1/1948
7391	RUCH	1,550.0	42.22306	−123.04722	4/1/1963
7668	SELMA 4 E	1,460.0	42.27528	−123.52806	2/1/1998
7698	SEXTON SUMMIT	3,832.0	42.60028	−123.36417	7/1/1948
8812	VALLEY FALLS	4,325.0	42.48444	−120.28222	11/1/1948
9390	WILLIAMS 1 NW	1,450.0	42.22833	−123.28583	12/13/1900

Table A3-2. National Climatic Data Center (NCDC) surface airways stations in or around the Lower Klamath River Basin, California.

[When station data collection formats change, the station records are closed and new records begin. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

State	Station name	Elevation (meters)	Latitude	Longitude	Period of record	
					Beginning date	Ending date
Stations with wind data						
California	MOUNT SHASTA	3,535	41.33250	−122.33278	4/1/1948	12/31/1963
California	MOUNT SHASTA	3,535	41.33250	−122.33278	1/1/1964	9/13/1985
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	1/1/1948	12/31/1963
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	1/1/1964	8/24/1986
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	3/1/1999	12/31/2003
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	1/1/1948	12/31/1963
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	1/1/1964	12/31/1997
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	1/1/1998	12/31/2003
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	1/1/1948	12/31/1963
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	1/1/1964	12/31/1988
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	3/1/1999	12/31/2003
California	REDDING MUNICIPAL ARPT	497	40.51750	−122.29861	9/1/1986	6/30/1996
California	REDDING MUNICIPAL ARPT	497	40.51750	−122.29861	7/1/1996	12/31/2003
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	12/1/1949	12/31/1963
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	1/1/1964	1/31/2003
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	2/1/2001	8/31/2003
Stations with cloudiness data						
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	7/1/1996	2/1/2003
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	3/1/1997	12/31/1997
Stations with dew point temperature data						
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	3/1/1999	12/31/2003
California	REDDING MUNICIPAL ARPT	497	40.51750	−122.29861	7/1/1996	12/31/2003
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	7/1/1996	8/31/2003
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	7/1/1996	12/31/2003
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	3/1/1999	12/31/2003
Stations with relative humidity data						
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	1/1/1948	12/31/2003
California	REDDING MUNICIPAL ARPT	497	40.51750	−122.29861	9/1/1986	12/31/2003
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	12/1/1949	8/31/2003
California	MOUNT SHASTA	3,535	41.33250	−122.33278	4/1/1948	9/13/1985
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	1/1/1948	12/31/2003
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	1/1/1948	12/31/2003

Table A3-3. Inactive National Climatic Data Center (NCDC) stations in or around the Lower Klamath River Basin, California.

[Stations measure precipitation, snow, and maximum and minimum air temperature. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station ID	Station name	Elevation (meters)	Latitude	Longitude	Period of record	
					Beginning date	Ending date
California						
88	ALDERPOINT	459	40.18333	−123.61667	8/1/1948	5/31/1980
615	BEEGUM	1,289	40.35000	−122.86667	7/1/1948	7/9/1958
721	BETTS RANCH	2,651	41.81667	−122.50000	7/2/1948	1/31/1950
731	BIEBER	4,125	41.12083	−121.13472	7/1/1948	9/30/1951
870	BLACKS MOUNTAIN RANCH	5,604	40.73333	−121.25000	7/1/1948	7/31/1960
903	BLUE LAKE REDWOOD CREEK	981	40.91667	−123.81667	2/1/1956	8/31/1965
1080	BRIDGEVILLE 4 NNW	2,100	40.51944	−123.82167	6/1/1954	1/31/2001
1082	BRIDGEVILLE HANSON RANCH	2,602	40.55000	−123.81667	7/1/1948	10/31/1952
1161	BUCKS LAKE	5,203	39.90000	−121.20000	7/1/1948	12/31/1970
1215	BURNT RANCH 1 S	2,150	40.80000	−123.46667	11/1/1959	6/30/1989
1233	BUTLER VALLEY RANCH	420	40.76667	−123.90000	5/20/1970	4/30/1975
1420	CAMP LASSEN	4,304	40.10000	−121.53333	11/1/1948	11/15/1949
1475	CANBY 11SW	4,505	41.36667	−121.05000	5/1/1959	4/30/1971
1522	CARIBOU PH	2,992	40.08333	−121.15000	6/1/1959	6/30/1977
1607	CECILVILLE 5 SE	3,002	41.08333	−123.05000	6/1/1950	10/31/1954
1731	CHINA FLAT	600	40.86667	−123.58333	7/1/1948	6/30/1955
1799	CLEAR CREEK	981	41.71667	−123.45000	9/2/1960	6/30/1977
1805	CLEAR LAKE DAM	4,573	41.93333	−121.06667	1/1/1950	9/30/1954
1890	COHASSET	2,523	39.91667	−121.73333	11/2/1960	8/31/1961
1891	COHASSET 1 NNE	3,192	39.93333	−121.71667	1/1/1962	6/30/1977
1953	COLYEAR SPRINGS	3,304	40.05000	−122.68333	9/1/1960	3/31/1962
2027	CORNING HOUGHTON RANCH	487	39.90000	−122.35000	7/1/1948	5/31/1984
2084	COVELO EEL RIVER RS	1,514	39.82611	−123.08500	7/1/1948	9/30/1951
2148	CRESCENT CITY 7 ENE	120	41.79417	−124.08500	12/4/1951	6/30/2001
2149	CRESCENT CITY CAA AIRPO	56	41.78333	−124.23333	4/1/1950	12/31/1954
2150	CRESCENT CITY MNTC STN	49	41.76667	−124.20000	7/1/1948	9/30/1951
2218	CUMMINGS	1,289	39.83333	−123.63333	9/1/1949	6/30/1981
2269	DANA 2 SE	3,323	41.10000	−121.51667	5/1/1959	5/31/1976
2296	DAVIS CREEK	4,754	41.73333	−120.36667	5/1/1959	11/30/1969
2306	DAY	3,650	41.21222	−121.37417	7/1/1948	9/30/1951
2379	DELTA	1,171	40.95000	−122.41667	11/1/1975	5/31/1978
2572	DUNSMUIR	2,421	41.21667	−122.26667	7/1/1948	6/30/1978
2595	EAGLE LAKE STONE RANCH	5,135	40.50000	−120.65000	5/1/1959	3/31/1961
2749	ELK VALLEY	1,705	41.98750	−123.71750	7/1/1948	4/18/1976
2899	ETNA	2,950	41.45556	−122.89833	7/1/1948	9/30/1951
3020	FERGUSON RANCH	801	40.35000	−122.45000	1/1/1952	7/31/1967
3025	FERNDALE 8 SSW	1,450	40.50000	−124.33333	11/23/1959	12/31/1971
3030	FERNDALE 2 NW	10	40.60000	−124.28333	3/17/1963	9/30/1973
3087	FLEMING FISH & GAME	4,003	40.36667	−120.31667	6/1/1959	6/30/1977
3130	FOREST GLEN	2,339	40.38333	−123.33333	7/1/1948	7/18/1985
3151	FORKS OF SALMON	1,240	41.26667	−123.31667	9/1/1960	5/31/1972
3173	FORT DICK	46	41.86667	−124.15000	11/1/1951	12/31/1988
3176	FORT JONES 6 ESE	3,323	41.58333	−122.71667	7/1/1948	9/30/1951
3204	FORWARD MILL	3,304	40.43333	−121.73333	1/1/1952	5/31/1958
3242	FRENCH GULCH	1,102	40.70000	−122.63333	1/1/1952	11/30/1982

Table A3–3. Inactive National Climatic Data Center (NCDC) stations in or around the Lower Klamath River Basin, California—***Continued***.

[Stations measure precipitation, snow, and maximum and minimum air temperature. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station ID	Station name	Elevation (meters)	Latitude	Longitude	Period of record	
					Beginning date	Ending date
3320	GARBERVILLE	340	40.10000	−123.80000	11/1/1948	3/31/1985
3405	GIBSON HIGHWAY MNT STN	1,650	41.01667	−122.40000	4/1/1965	6/30/1977
3510	GOOSE LAKE WEST	4,892	41.86667	−120.50000	5/1/1959	12/31/1962
3564	GRASS LAKE HWY MNTC ST	5,092	41.63333	−122.20000	9/1/1960	11/30/1967
3621	GREENVILLE R S	3,560	40.14056	−120.94278	7/1/1948	12/21/2001
3647	GRIZZLY CREEK STATE PAR	410	40.48611	−123.90917	12/1/1979	9/30/2001
3817	HATCHET MOUNTAIN MNTNC	4,373	40.85000	−121.76667	2/19/1957	6/30/1960
3821	HAT CREEK EXPERIMENT ST	3,353	40.80000	−121.50000	7/1/1948	9/30/1951
3987	HILTS SLASH DISPOSAL	2,904	42.00000	−122.63333	7/1/1948	12/31/1984
4074	HONEYDEW 1 SW	370	40.23750	−124.13222	11/1/1959	9/30/1972
4082	HOOPA	361	41.05000	−123.66667	7/1/1948	12/31/1983
4084	HOOPA 2 SE	322	41.03333	−123.65000	11/1/1954	10/31/1967
4089	HOOPA	333	41.04833	−123.67778	1/1/1984	5/31/1987
4166	HUNTER DISTR GRAVES RC	771	40.18333	−122.55000	9/1/1960	9/30/1970
4191	HYAMPOM	1,275	40.61639	−123.45667	7/1/1948	10/26/2001
4202	IDLEWILD HWY MNTNC STN	1,250	41.90000	−123.76667	5/1/1959	6/30/1977
4255	INDIAN WELL HQS	4,774	41.71667	−121.50000	8/1/1948	12/31/1949
4274	INSKIP INN	4,823	40.00000	−121.53333	8/17/1948	4/30/1954
4544	KILARC PH	2,651	40.68333	−121.86667	5/1/1959	6/30/1977
4586	KNEELAND 2	2,661	40.66667	−123.91667	7/2/1948	9/30/1951
4602	KORBEL	151	40.86667	−123.95000	11/1/1959	12/31/1974
4675	LAKE CITY	4,613	41.63333	−120.21667	7/1/1948	10/11/1960
4690	LAKE MOUNTAIN	3,163	40.01667	−123.40000	7/1/1948	9/30/1951
4709	LAKESHORE 2	1,079	40.86667	−122.38333	7/1/1948	7/31/1972
4988	LITTLE VALLEY	4,173	40.88333	−121.18333	10/1/1960	1/31/1974
5093	LOOKOUT 3 WSW	4,183	41.20000	−121.20000	5/1/1963	5/31/1977
5131	LOS MOLINOS	220	40.01667	−122.10000	7/1/1948	11/30/1948
5231	MADELINE	5,325	41.01667	−120.50000	6/1/1959	2/28/1975
5244	MAD RIVER RANGER STN	2,675	40.45000	−123.53333	7/1/1948	9/30/1988
5623	MILFORD LAUFMAN RS	4,860	40.14139	−120.35333	7/1/1948	9/30/1951
5679	MINERAL	4,875	40.34583	−121.60917	7/1/1948	11/30/2001
5713	MIRANDA SPENGLER RANCH	361	40.20000	−123.76667	7/1/1948	8/31/1966
5785	MONTAGUE 5 NE	2,635	41.78056	−122.47167	7/1/1948	7/17/1952
5809	MONTGOMERY CREEK	2,103	40.81667	−121.93333	7/1/1948	9/30/1951
5940	MOUNT HEBRON 11 ESE	4,383	41.73333	−121.80000	5/1/1952	12/31/1960
5980	MOUNT SHASTA SKI BOWL	7,844	41.36667	−122.20000	12/11/1958	8/31/1964
6173	NEW PINE CREEK 2 E	5,292	41.98333	−120.26667	10/1/1960	5/31/1961
6329	OAK KNOLL R S NO 2	1,700	41.85000	−122.88333	1/1/1972	1/31/1998
6455	ONO	978	40.48333	−122.61667	1/3/1952	3/31/1984
6499	ORICK 10 SE	2,480	41.18333	−123.91667	11/1/1959	5/31/1963
6726	PASKENTA RANGER STN	755	39.88556	−122.54333	7/3/1948	10/31/2001
6761	PAYNES CREEK	1,841	40.33333	−121.90000	1/1/1952	3/31/1984
6944	PIT RIVER P H 1	2,880	41.00000	−121.50000	9/1/1972	8/31/1996
6975	PLATINA	2,260	40.36667	−122.88333	3/24/1962	4/30/1974
7088	PORTOLA 2	4,833	39.80000	−120.48333	7/1/1948	9/30/1951
7106	POTTERS SAWMILL	4,213	41.23333	−121.21667	5/1/1961	11/30/1962

Table A3–3. Inactive National Climatic Data Center (NCDC) stations in or around the Lower Klamath River Basin, California—***Continued***.

[Stations measure precipitation, snow, and maximum and minimum air temperature. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station ID	Station name	Elevation (meters)	Latitude	Longitude	Period of record	
					Beginning date	Ending date
7197	QUINCY USFS HELIPORT	3,652	39.98333	−120.95000	9/1/1979	3/31/1981
7290	RED BLUFF	287	40.18333	−122.23333	7/1/1948	12/31/1948
7294	RED BLUFF NO 2	310	40.16333	−122.22806	2/1/1998	6/30/1999
7296	REDDING FIRE STN 2	581	40.58333	−122.40000	1/11/1931	4/30/1979
7300	REDDING FIRE STN 4	470	40.55000	−122.38333	5/1/1979	4/30/1987
7580	ROUND MOUNTAIN	2,103	40.81667	−121.93333	1/1/1952	6/30/1970
7581	ROUND MOUNTAIN	2,100	40.79556	−121.93500	7/1/1970	8/31/2000
7698	SALYER RANGER STN	620	40.88333	−123.58333	7/1/1948	11/30/1968
8025	SAWYERS BAR RS	2,169	41.30111	−123.13306	7/1/1948	4/30/1988
8074	SECRET VALLEY	4,442	40.50000	−120.26667	9/1/1962	2/28/1977
8075	SECRET VALLEY M S	4,662	40.66667	−120.25000	5/1/1959	3/31/1981
8162	SHELTER COVE	110	40.03333	−124.06667	11/11/1959	4/30/1974
8175	SHINGLETOWN 2 E	3,556	40.50000	−121.85000	11/1/1958	3/31/1984
8292	SLOAT	4,124	39.86667	−120.73333	7/1/1957	5/31/1958
8311	SMITH RIVER 3 WNW	30	41.95000	−124.20000	10/1/1956	11/30/1958
8346	SOMESBAR 1 W	522	41.38333	−123.48333	11/1/1954	10/31/1967
8472	SQUAW CREEK GS	1,302	40.88333	−122.10000	7/1/1948	1/31/1949
8487	STANDISH 1 E	4,032	40.36667	−120.40000	5/1/1961	4/30/1973
8521	STEELE SWAMP	4,554	41.86667	−120.95000	7/1/1948	4/30/1950
8544	STIRLING CITY R S	3520	39.90417	−121.52806	7/1/1948	8/31/1966
8701	SUSANVILLE	4,173	40.41667	−120.65000	6/17/1952	6/30/1964
8702	SUSANVILLE 2 SW	4,184	40.41667	−120.66306	1/10/1931	12/29/2001
8705	SUSANVILLE STATE RNG	4,193	40.40000	−120.66667	6/1/1949	9/30/1951
8860	TENNANT	4,754	41.58333	−121.91667	5/1/1952	8/31/1957
8873	TERMO 1 E	5,300	40.86667	−120.43333	8/1/1948	3/31/1999
8875	TERMO BRIN MARR	5,364	40.91667	−120.26667	3/1/1960	6/30/1963
9023	TRINITY CENTER RANGER S	2,303	41.00000	−122.68333	7/1/1948	9/30/1951
9024	TRINITY DAM VISTA POINT	2,503	40.80000	−122.76667	7/1/1959	12/31/1973
9056	TULELAKE 5 WSW	4,032	41.91667	−121.56667	7/1/1948	10/31/1957
9057	TULELAKE INSPECTION STN	4,413	41.60000	−121.20000	5/1/1959	7/31/1959
9083	TURNTABLE CREEK	1,070	40.76667	−122.30000	7/1/1948	10/31/1969
9177	UPPER MATTOLE	255	40.25000	−124.18333	7/1/1948	4/30/1986
9386	VOLLMERS	1,342	40.95000	−122.45000	7/1/1948	10/31/1975
9498	WEED	3,514	41.43333	−122.38333	7/1/1948	2/28/1957
9499	WEED FIRE DEPT	3,589	41.43333	−122.38333	4/18/1957	7/31/1989
9526	WENDEL 10 SE	4,042	40.26667	−120.06667	5/1/1959	6/30/1977
9540	WEST BRANCH	3,222	39.93333	−121.53333	7/1/1948	9/30/1952
9599	WESTWOOD	5,072	40.30000	−121.00000	7/1/1948	4/12/1953
9600	WESTWOOD 3 WSW	4,993	40.30000	−121.05000	4/16/1953	6/30/1957
9612	WHEELER	49	39.88333	−123.91667	1/1/1950	10/31/1959
9620	WHISKEYTOWN	1,089	40.63333	−122.55000	7/1/1959	4/14/1960
9691	WILLOW CREEK RANCH	5,203	41.83333	−120.75000	7/1/1964	8/31/1966
9867	YREKA RANGER STN	2,631	41.71667	−122.63333	5/21/1957	5/21/1957

Table A3–3. Inactive National Climatic Data Center (NCDC) stations in or around the Lower Klamath River Basin, California—***Continued***.

[Stations measure precipitation, snow, and maximum and minimum air temperature. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station ID	Station name	Elevation (meters)	Latitude	Longitude	Period of record	
					Beginning date	Ending date
Nevada						
7261	SAND PASS	3,904	40.31667	−119.80000	1/1/1928	9/30/1971
8810	VYA	5,663	41.58333	−119.91667	9/1/1959	6/30/1980
Oregon						
853	BLY RANGER STN	4,390	42.40000	−121.04583	2/1/1950	9/30/1951
854	BLY 3 NW	4,378	42.43333	−121.10000	4/1/1988	9/30/1997
1207	BUTTE FALLS 1 SE	2,500	42.53778	−122.55250	2/1/1950	3/31/1986
1571	CHILOQUIN 1 E	4,193	42.58333	−121.86667	7/1/1948	12/31/1979
1826	COPPER	1,903	42.03333	−123.13333	8/1/1948	9/29/1951
2018	DAIRY 4 NNE YONNA	4,154	42.26667	−121.46667	3/1/1949	2/28/1953
2928	FISH LAKE	4,642	42.38333	−122.35000	1/2/1933	11/10/1956
3022	FORT KLAMATH 7 SW	4,163	42.61667	−122.08333	3/3/1953	8/31/1965
3232	GERBER DAM	4,850	42.20500	−121.13139	7/1/1948	10/26/1956
3445	GRANTS PASS	930	42.42444	−123.32361	1/2/1928	11/30/2001
4135	ILLAHE 2 N	488	42.65000	−124.05000	3/6/1963	5/27/1967
4216	JACKSONVILLE	1,640	42.30000	−122.98333	7/2/1948	11/30/1948
4420	KERBY	1,270	42.21667	−123.65000	2/1/1950	9/30/1951
4506	KLAMATH FALLS 2 SSW	4,098	42.20083	−121.78139	1/1/1928	5/31/2001
4633	LAKE CREEK 3 NE	2,400	42.45000	−122.56667	3/1/1978	11/30/1995
4635	LAKE CREEK 6 SE	1,752	42.36667	−122.53333	7/1/1948	3/31/1953
4636	LAKE CREEK 1 E	1,550	42.42583	−122.62306	1/1/1996	5/31/1998
5505	MERRILL 2 NW	4,081	42.05000	−121.63333	6/1/1949	3/31/1968
5656	MODOC ORCHARD	1,220	42.45000	−122.88333	7/1/1948	4/30/1966
6027	NEW PINE CREEK	4,882	42.00000	−120.30000	11/10/1961	6/30/1972
6717	PLUSH 1 N	4,514	42.41667	−119.90000	7/2/1948	8/31/1961
7285	ROCKY POINT 3 S	4,154	42.43333	−122.08333	10/19/1966	10/31/1975
7354	ROUND GROVE	4,888	42.34139	−120.88944	7/1/1948	12/22/1998
7670	SELMA 4 W	1,503	42.28333	−123.70000	11/12/1960	5/31/1961
7850	SISKIYOU SUMMIT	4,485	42.08333	−122.56667	7/1/1948	9/18/1948
8007	SPRAGUE RIVER 2 SE	4,483	42.43056	−121.48917	5/28/1953	2/28/2001
8071	STAR RANGER STN	1,581	42.15000	−123.06667	7/1/1948	7/31/1948
8338	TALENT	1,552	42.25000	−122.80000	7/1/1948	11/10/1960
8818	VALLEY FALLS 3 SSE	4,583	42.45000	−120.25000	4/8/1965	2/28/1983
9604	YONNA	4,183	42.30000	−121.48333	7/1/1948	1/31/1949

Table A3-4. California Irrigation Management Information System (CIMIS) reference evapotranspiration stations locations within or around the Lower Klamath River Basin, California.

[See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station name	Station Id	County	Elevation (meters)	Latitude	Longitude
Gerber	8	Tehama	250	40.0450	–122.1640
McArthur	43	Shasta	3,310	41.0650	–121.4540
MacDoel	46	Siskiyou	4,254	41.7920	–122.0640
Tulelake	48	Siskiyou	4,042	42.0030	–121.4270
Buntingville	57	Lassen	4,005	40.2900	–120.4340
Alturas	90	Modoc	4,405	41.4330	–120.4790
Tulelake FS	91	Siskiyou	4,035	41.9590	–121.4710
Gerber Dryland	108	Tehama	245	40.0430	–122.1620

Table A3-5. National Renewable Energy Laboratory (NREL) weather stations in or around the Lower Klamath River Basin, California.

[Stations measure hourly solar radiation, dewpoint temperature, air temperature, and cloud cover, and monthly ozone, precipitable water, and atmospheric turbidity. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station	Latitude	Longitude	Period of record	
			Beginning date	Ending date
Arcata	40.9833	–124.1000	1/1/1960	12/31/1990
Medford	42.3667	–122.8667	1/1/1960	12/31/1990

Table A3-6. Remote Automated Weather Station (RAWS) locations in and around the Lower Klamath River Basin, California.

State	Station name	Latitude	Longitude
California	COOSKIE M	40.25694	–124.26611
California	GASQUET	41.84583	–123.97917
California	MAPLE CRE	40.79639	–123.93667
California	SCHOOL HO	41.13833	–123.90556
California	YUROK	41.28972	–123.85750
California	EEL RIVER	40.13833	–123.82361
California	SHIP MTN	41.73583	–123.79167
California	HOOPAH	41.04778	–123.67139
California	BIG HILL	41.09750	–123.63583
California	CRAZY PEA	41.99194	–123.60361
California	ALDER POI	40.18667	–123.59028
California	MAD RIVER	40.46333	–123.52389
California	SRF01 POR	40.45222	–123.51778
California	SOMES BAR	41.39000	–123.49583
California	UNDERWOOD	40.72194	–123.49528
California	SLATER BU	41.85861	–123.35250
California	FRIEND MT	40.50500	–123.34167
California	BIG BAR	40.74333	–123.25000
California	BLUE RIDG	41.27333	–123.19000
California	BLUE RIDG	41.26944	–123.18750
California	BACKBONE	40.88917	–123.14222
California	SAWYERS B	41.30028	–123.13222
California	EEL RIVER	39.82528	–123.08250
California	YOLLA BOL	40.33833	–123.06500
California	COLLINS B	41.77500	–122.95028
California	MENDOCINO	39.80750	–122.94500
California	WEAVERVIL	40.73500	–122.94333
California	QUARTZ HI	41.59972	–122.93278
California	PATTYMOCU	40.28833	–122.87167
California	KNF91 POR	41.60000	–122.85556
California	OAK KNOLL	41.83861	–122.84889
California	ARBUCKLE	40.39833	–122.83333
California	ARBUCKLE	40.39833	–122.83333
California	TRINITY C	40.67889	–122.83306
California	LOWDEN	40.68944	–122.83139
California	CALLAHAN	41.30750	–122.79583
California	SCORPION	41.11167	–122.69667
California	EAGLE PEA	39.92778	–122.65694
California	R501 PORT	40.90222	–122.65139
California	THOMES CR	39.86444	–122.60972
California	OAK BOTTO	40.65056	–122.60556
California	BRAZIE RA	41.68528	–122.59417
California	WEED AIRP	41.47889	–122.45389
California	SUGARLOAF	40.91667	–122.43833
California	SIMS	41.07500	–122.37333

Table A3-6. Remote Automated Weather Station (RAWS) locations in and around the Lower Klamath River Basin, California—***Continued***.

[Stations measure hourly air temperature, dewpoint temperature, barometric pressure, precipitation, wind speed, and wind direction. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

State	Station name	Latitude	Longitude
California	SIMS TEST	41.08083	–122.34694
California	MT. SHAST	41.31556	–122.31556
California	REDDING	40.51583	–122.29056
California	CORNING	39.93889	–122.16972
California	JUANITA L	41.78611	–122.00556
California	OAK MOUNT	41.00639	–121.98333
California	ASH CREEK	41.27694	–121.97944
California	WHITMORE	40.62028	–121.90389
California	VAN BREMM	41.64306	–121.79389
California	COHASSET	39.87000	–121.76917
California	LASSEN LO	40.34417	–121.71361
California	LOWER KLA	41.99917	–121.70028
California	zz LOWER	41.99889	–121.70000
California	SOLDIER M	40.92583	–121.58556
California	CARPENTER	40.06861	–121.58250
California	MANZANITA	40.54000	–121.58028
California	INDIAN WE	41.74167	–121.53833
California	ROUND MOU	41.42722	–121.46389
California	SUMMIT	40.50167	–121.42250
California	LNF01 POR	40.69500	–121.35861
California	MDF04 POR	41.62778	–121.29833
California	TIMBER MO	41.62944	–121.29806
California	LADDER BU	40.80722	–121.29667
California	LNF02 POR	40.28333	–121.20000
California	LNF03 POR	40.28333	–121.20000
California	BLACKS MT	40.73139	–121.11833
California	CHESTER	40.28972	–121.08528
California	BOGARD R.	40.59806	–121.08306
California	MDF06 POR	41.62500	–121.06778
California	PNF21 POR	39.95556	–120.99222
California	PNF22 POR	39.97333	–120.94194
California	QUINCY RD	39.97333	–120.94194
California	CASHMAN	40.00167	–120.91500
California	WESTWOOD	40.30667	–120.90000
California	GORDON	40.75861	–120.89611
California	LNF05 POR	40.75861	–120.89611
California	CANBY	41.43417	–120.86778
California	RUSH CREE	41.29444	–120.86389
California	MDF03 POR	41.82778	–120.86389
California	GRASSHOPP	40.78278	–120.78167
California	ASH VALLE	41.05194	–120.68611
California	PNF14 POR	39.83333	–120.68056
California	DEVILS GA	41.53000	–120.67139
California	PIERCE	40.24611	–120.64222

Table A3-6. Remote Automated Weather Station (RAWS) locations in and around the Lower Klamath River Basin, California—***Continued***.

[Stations measure hourly air temperature, dewpoint temperature, barometric pressure, precipitation, wind speed, and wind direction. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

State	Station name	Latitude	Longitude
California	PNF11 POR	39.93417	−120.55111
California	HORSE LAK	40.63056	−120.50278
California	PNF12 POR	40.19306	−120.48778
California	JUNIPER C	41.33222	−120.47250
California	PNF13 POR	39.97611	−120.35611
California	LAUFMAN	40.14167	−120.35333
California	BLUE DOOR	41.05472	−120.33750
California	RAVENDALE	40.73083	−120.31639
California	BULL FLAT	40.48083	−120.11389
California	DOYLE	40.02222	−120.10556
Nevada	BARREL SP	41.91111	−119.93889
Oregon	RED MOUND	42.12333	−124.30056
Oregon	LAWSON	42.41667	−124.13333
Oregon	QUAIL PRA	42.21667	−124.03333
Oregon	BALD KNOB	42.70000	−124.03333
Oregon	AGNESS	42.33028	−124.02222
Oregon	ILLINOIS	42.11667	−123.66667
Oregon	ONION MOU	42.30000	−123.40000
Oregon	MERLIN SE	42.49472	−123.39722
Oregon	PROVOLT S	42.28972	−123.23028
Oregon	EVANS CRE	42.59778	−123.10333
Oregon	STAR	42.15000	−123.06667
Oregon	SQUAW PEA	42.06667	−123.01667
Oregon	BUCKHORN	42.11972	−122.56333
Oregon	ZIM	42.68889	−122.46833
Oregon	DEAD INDI	42.28333	−122.31667
Oregon	PARKER MO	42.10583	−122.27806
Oregon	SELDOM CR	42.40750	−122.19139
Oregon	CHILOQUIN	42.57694	−121.89361
Oregon	CALIMUS	42.63139	−121.55972
Oregon	GERBER RE	42.20556	−121.13889
Oregon	STRAWBERR	42.18944	−120.84639
Oregon	COFFEE PO	42.55000	−120.62000
Oregon	SUMMIT	42.19889	−120.24556