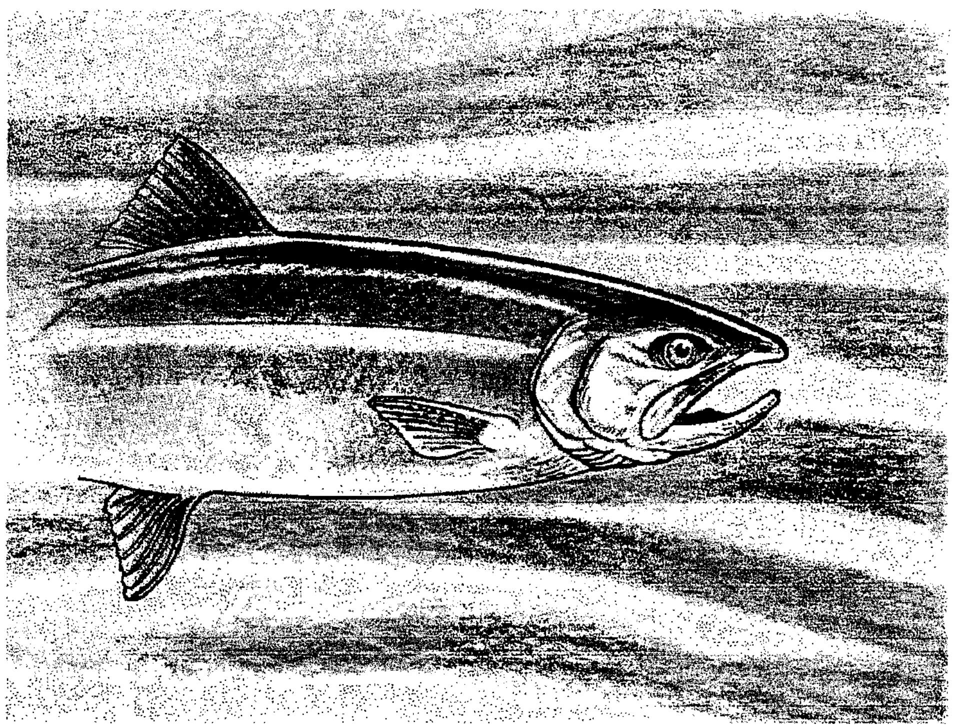
Water Quality and Nutrient Loading in the Klamath River Between Keno, Oregon and Seiad Valley, California From 1996-1998

Open File Report 01-301



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WATER QUALITY AND NUTRIENT LOADING IN THE KLAMATH RIVER BETWEEN KENO, OREGON AND SEIAD VALLEY, CALIFORNIA FROM 1996 - 1998

by

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Prepared in Cooperation with:
North Coast Regional Water Quality Control Board,
U.S. Bureau of Reclamation,
U.S. Fish and Wildlife,
PacifiCorp, Inc.,
and University of California - Davis

ABSTRACT

A water quality study was performed in the mainstem Klamath River from Keno, Oregon to Seiad Valley, California during 1996 through 1998. Four sites within the study area were continuously monitored using multiparameter recorders. Water quality sampling was also performed at these four locations in 1996 and 1997. Additional water quality sampling sites were added in 1998 for a total of 8 locations between Keno and Seiad.

Temperature ranged from near zero °C to >25 °C with cooler temperatures in early spring and fall, and maximum temperatures occurring in July and August of each year. Dissolved oxygen concentration ranged from near zero mg/L to >13 mg/L with highest DO occurring in early spring and fall and lowest DO occurring in mid-summer. Air temperature was generally highly correlated with water temperature with r values ranging from 0.8 to 0.9 during the study period from 1996-1998. Water temperature in the study area exceeded chronic (>16°C) and acute (>22°C) criteria for salmonids during the summer months. Although chronic DO (<7 mg/L) criteria were exceeded throughout most of the study area during the summer, in the free-flowing river below Iron Gate Dam the acute DO (<5.5 mg/L) criteria were not exceeded.

Nonpoint source pollution in the form of agricultural return flows, industrial, or sewage effluent entering the stream may have resulted in higher ammonia and total organic nitrogen concentrations at the upstream locations in the Klamath River study area (Keno and J.C. Boyle Powerplant). Nitrification of ammonia and organic nitrogen seemed to result in higher concentrations of nitrate in the downstream Klamath River (Iron Gate Dam). Total phosphorus concentration stayed relatively stable through the reservoirs in the study area, but decreased in the downstream direction between Iron Gate Dam and Seiad. Ortho-phosphorus concentrations increased longitudinally through the reservoirs, then decreased in the downstream direction between Iron Gate Dam and Seiad. An increase in ortho-phosphorus concentration can indicate internal cycling occurring in the reservoirs as well as photosynthesis.

On an annual basis total phosphorus loading increased longitudinally from up- to downstream between Keno and Seiad. The increase was statistically significant ($p = .03$) indicating that the reservoirs in series in the Klamath River study area do not function as a nutrient sink. However, during the summer there was no statistically significant difference in total P loading when Keno, Iron Gate and Seiad locations were compared, therefore, the reservoirs may act as a nutrient sink seasonally.

The Klamath River study locations were generally nitrogen limited, although at Keno, a regular change from N limitation to P limitation occurred during the fall of all three years of the study. When the Klamath River annual nutrient loading values are compared to other rivers in the vicinity, the Carson, Truckee, and Long Tom Rivers also appear to be nutrient enriched. The Carson and South Yamhill Rivers seem to be N limited systems and the Wood, Long Tom, Snake and Truckee Rivers seem to be P limited systems.

Implementing management strategies for reservoir operations to improve water quality and reduce nutrient concentration or loading in the Klamath River study area to benefit anadromous fisheries may be difficult and expensive. However, improving the thermal regime in spring to benefit YOY salmonids may be possible as is short-term relief in late summer for over-summering species. Decreases in nutrient concentration or loading accomplished through best management practices in the water shed may allow general protection of water resources in the Klamath Basin for future needs.

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INTRODUCTION

Purpose and Objectives

USGS-BRD (U. S. Geological Survey - Biological Resources Division) began studies in the Klamath River in 1995 from Keno, Oregon to Seiad Valley, California in response to requests from the Klamath River Basin Fisheries Task Force and U.S. Fish and Wildlife Service. The Task Force is a 16-member commission chartered by Congress to restore and maintain anadromous fish stocks in the Klamath River basin (Public Law 99-552, October 1, 1986. During it's 13 year history, the Task Force repeatedly attempted to initiate flow studies that would relate flow volume in the Klamath River to suspected habitat limitations that were root causes for declining anadromous fish populations. The anadromous fish species of concern in the Klamath Basin are chinook salmon (*Onchorhynchus tshawtscha*), coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*) (USFWS, 1997). Among the habitat limitations was water quality, and in particular, water temperature, which was generally believed to be too warm during summer in some portions of the river (W.M. Keir Associates, 1991)

USGS-BRD was charged by the Task Force, to examine historical records of water quality to begin an assessment of water quantity and quality conditions throughout the Klamath River Basin. The USEPA STORET data base was queried and resulting water quality related information was summarized for water temperature, dissolved oxygen, pH, and ammonia concentration (NBS, 1995). The overall data record for everything except water temperature was very sparse and even water temperature records were mostly collected at monthly intervals. No systematic effort had been made to record temperature and other water quality parameters continuously over a broad geographic area or over a long period of time.

Beginning in 1996 and continuing in 1997, continuous monitoring of water temperature and dissolved oxygen concentrations were performed by the Bureau of Reclamation and USGS at 4 locations in the study area (Figure 1.1). The daily average temperature and dissolved oxygen data have been used by USGS to calibrate and validate a water quality model application developed for this Klamath River reach (Keno, OR to Seiad Valley, CA). At monthly intervals, water quality samples were also collected at various locations in the study area and analyzed for nitrogen and phosphorus concentrations. The objective of this report was to characterize water quality as it affects anadromous fish production, particularly as a limiting factor for growth or reproductive success. From Keno, Oregon downstream to Iron Gate Dam, it is now possible to determine where, when, and the duration of temperature and dissolved oxygen concentrations that are unfavorable for anadromous fish health. In addition, because nutrient samples were also collected as part of this study, it is also possible to identify the source and magnitude of nutrient loading that can indirectly affect anadromous fish growth and reproduction.

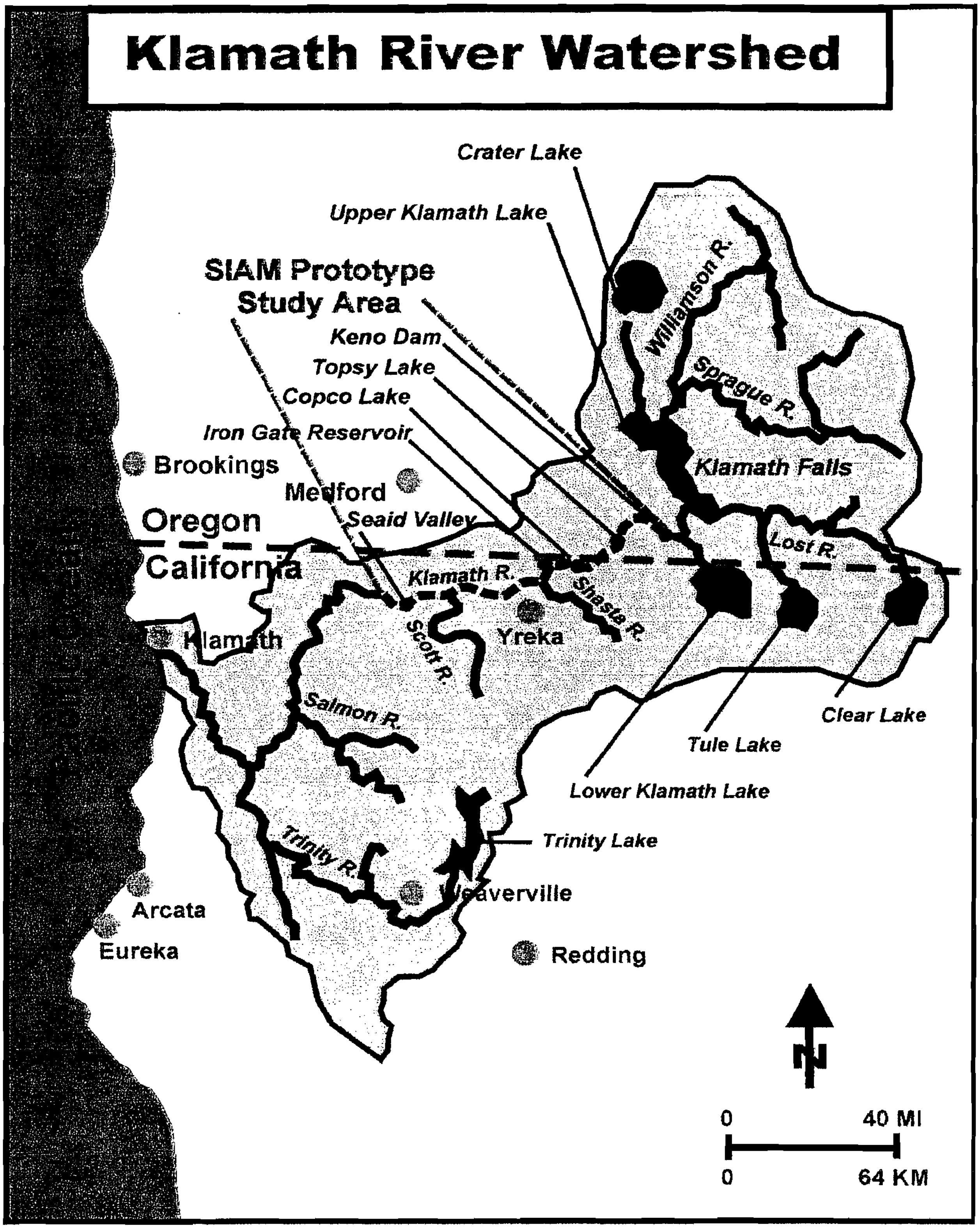

Figure 1.1 Klamath Basin Watershed and Study Area

Background

The overall objective for the Klamath River studies is to provide information for identification, development and selection of water management strategies. Competing needs for the available water resources in the Basin have become a driving force for initial efforts to develop some type of basin-wide approach to managing the Klamath Basin water supply. The USGS project represents an initial attempt to integrate physical, biological, and social factors for riverine ecosystems on a broad geographic scale, although the study reach represents only a portion of the entire Klamath River Basin.

The Klamath Basin has been artificially divided in three segments, the Upper (from Upper Klamath Lake downstream to Iron Gate Dam), Middle (Iron Gate Dam to Weitchpec) and Lower Basin (Weitchpec and the Trinity River tributary on down to the Klamath River mouth (Figure 1.1). The Upper Basin incorporates two states, Oregon and California, while the other two segments are contained within California. Each river segment may be managed/affected by different Federal, State, or private sector entities.

In the Upper Basin, listing of two species of endangered suckers has resulted in a biological opinion that specifies water surface elevations at specific time points in Upper Klamath Lake. Additionally, water rights adjudication for the Upper Basin in the state of Oregon is nearing completion. Four Federally recognized Indian Tribes in the Klamath Basin are currently quantifying Tribal water rights throughout the Basin as part of the adjudication process. In the Lower Basin, the Trinity River tributary will be re-operated to improve anadromous fish runs. Storage, diversion, hydropower, and in-stream needs for available water supply provide a near mandate for landscape scale resource management in the Klamath Basin.

USGS-BRD has been developing an integrated set of model components representing flow, water quality, habitat, sport fishing economic values, and fish production as a set of tools to aid managers in making resource allocation or operational decisions. The Systems Impact Assessment Model now has a beta test version and documentation available for download and use at :

http://www.mesc.nbs.gov/products/software/SIAM/siam.shtml

Although the need for managing natural resources at an ecosystem or landscape scale is widely recognized (Petak, 1980; Odum, 1983; Risser, 1985; Briassoulis, 1986; Caldwell, 1988; Edwards and Regier, 1990; Hansson and Angelstam, 1991; Slocombe, 1991), a well-defined process and methodology to achieve this goal is lacking (Slocombe, 1993). The need for ecosystem scale management arises because major river basins such as the Klamath River basin, are the focus for anthropogenic influences (Ambroggi, 1980) characterized by direct feedback from human action, and they exhibit a naturally evolving complex of energy flows (Pantulu, 1981). River basins are integrators of everything happening in their catchments and, along their longitudinal gradient from headwater to mouth, have been subjected to innumerable influences (Dovers and Day, 1988). River corridors generally support the greatest abundance and diversity of plants and animals, and are the focus of human habitation particularly in the arid West (National Research Council, 1992). The cumulative impacts of use for power, water supply, waste assimilation, irrigation diversion, industry, and mining along a river leads to conflicting needs for both water quantity and quality. This is particularly relevant in the Klamath Basin where endangered fish species needs in both the upper and lower basin share a limited water supply with well-documented water quality impairment that can adversely impact those species.

Ecosystem management emphasizes resource conditions and long-term resource sustainability. Managing ecosystems requires the maintenance of biological diversity and stresses ecological function and balance (Cortner and Moote, 1994). In this manner, objectives are related to sustaining resources for the future rather than obtaining maximum production of one resource or use, whether it is timber harvest, agriculture, municipal water supplies, rafting, hydropower or any of several others. Resource managers, whose decisions are based on maximum production or use, are struggling to make the transition to sustainable, multi-purpose management strategies to provide stewardship for the future. The public is also applying pressure on resource managers to maintain biodiversity, prevent habitat fragmentation, and be aware of and address cumulative impacts in management of resources (Kessler *et al.,* 1992). Scientists, public interest groups, resource users, and managers must work together in a collaborative decision making process (Ambroggi, 1980).

Land use has changed in the Klamath Basin, Oregon and California over the past 135 years. Mining and logging were the first two major land use changes that affected streams and rivers throughout the Basin (W.M. Keir Associates, 1991). Hydraulic mining caused serious disturbance in both channel and floodplain areas throughout the Lower Basin. The effects of timber harvest are well documented and erosion control is an important activity for natural resource management agencies. Pulp mills and effluent discharge from pulp processing, as well as storage of logs in holding areas, created their own set of water quality impacts. Irrigated agriculture and livestock grazing came a little later, but the major development of irrigation and hydropower in the Basin occurred over 50 years ago.

Land use conversion in a river basin can have significant impacts on both surface and groundwater quality (Charbonneau and Kondolf, 1993). Nonpoint source pollution, generated from multiple and diffuse origins over a large area, is the most difficult to isolate and control. Sedimentation and nutrient loading are most responsible for water quality degradation nationwide (USEPA, 1992). Suspended sediment directly affects water quality by increasing turbidity, damaging hydraulic structures and filling in reservoirs. Fine sediments indirectly affect water quality because adsorbed pollutants can be gradually released into overlying waters or instantaneously released when some physico-chemical event such as anaerobic conditions facilitates certain chemical reactions at the sediment-water interface (Wetzel, 1983).

Nutrients, i.e., phosphorus and nitrogen, may be derived from agricultural soils in adsorbed or soluble form (Charbonneau and Kondolf, 1993). Fine sediments have a higher per unit of mass capacity to adsorb nutrients and may have a greater proportion of organic material. Nutrients affect water quality because, when transported by sediment, they can cause nuisance algal growths, increase turbidity, and taste and odor problems. Chronic overgrazing is another contributor to soil erosion and sedimentation, with rangeland experiencing more erosion than pastureland (Myers, *et. al.*, 1985). Timber harvest can lead to increased erosion, generally from construction of access roads, but can also occur when steep slopes or naturally occurring erosive soils are exposed by logging operations.

Water quality is important because it is linked to the availability of water for various uses and its impact on public health (Maidment, 1992). Water provides the aquatic habitat of plants, microorganisms, insects, fish, birds, and mammals through a complex, dynamic set of interactions that include both quality and quantity. Increasing use of aquatic resources for municipal and industrial purposes, irrigation, hydropower, and others may change abiotic and biotic attributes of those resources. Those changes may in turn, adversely affect the organisms that live in or use aquatic habitats for all or part of their life-cycle requirements.

<u>Water Quality and Fish Relationships</u>

Water quality conditions may directly or indirectly affect various life stages of anadromous fish. Direct effects, such as point and nonpoint source effluents from sewage treatment facilities, industrial discharge outlets, irrigation return flows, sedimentation following timber harvest or other land disturbance, and mine tailing drainage may be important causal factors for impaired water quality conditions. Indirect effects, such as nutrient loading, cause changes in the physical environment that, in turn, can adversely affect salmonid life stages. The most obvious result is luxuriant growth of aquatic plants and algae in the river channel. The growth of aquatic plants and algae fosters sediment accumulation that decreases spawning and rearing habitat and may lead to decreased dissolved oxygen concentration and high pH values on a diel cycle. When these plants and algae die in the fall, dissolved oxygen can also decrease because of sediment and/or biological oxygen demand for the decomposition process. Another factor of concern when evaluating water quality conditions is that nearly all the Klamath Basin waters, except the Shasta River sub-basin, are weakly buffered (NBS, 1995). The buffering capacity of water determines the relative rate of chemical reactions in solution and refers to an ability to resist change in solute state. Therefore, photosynthetically induced changes in dissolved oxygen concentration and pH may be easily induced in weakly buffered systems. It is possible that many locations in the Klamath Basin, where aquatic plants and algae are abundant, may experience a wide range of dissolved oxygen concentrations and pH conditions that are lethal to eggs, larvae, and other life stages for aquatic organisms during the "growing" season (June through September).

Water quality must meet certain requirements for salmonid life cycle maintenance, particularly during the temporal periods when those fish occupy the riverine habitat throughout the Klamath River basin. Interactions between impaired water quality conditions and anadromous fish life stages are both acute and lethal, and subtle and chronic. For this report, USGS set acute water quality conditions as: temperature exceeding 22 °C and dissolved oxygen concentration falling below 5.5 mg//L (McCullough, 1999; NCRWQCB, 1994; USEPA, 1986). The chronic water quality conditions in this report were: temperature exceeding 16 °C and dissolved oxygen concentration falling below 7 mg/L (McCullough, 1999; NCRWQCB, 1994; USEPA, 1986).

Implications of impaired water quality for anadromous fisheries restoration efforts lie in identifying options available to improve water quality to meet the life stage needs of salmonids. Those options could include augmenting flow volume to dilute concentration, instituting significant land use changes to reduce nutrient loading and sedimentation, or restoring riparian habitat along river and stream corridors throughout the watershed. The important distinction in the Klamath Basin, is answering the question: are current water quality conditions impaired enough to adversely impact anadromous fish life cycle needs? If so, where within the study area does water quality impairment occur, when do adverse conditions occur, and how long do adverse conditions persist? In the instance of nutrient loading, is there a longitudinal gradient for loading from upstream to downstream that increases, stays the same, or decreases. Does nutrient loading have a temporal component relating to higher flow events or to in-reservoir processes? Finally, if the Klamath River is rich in nutrients, how does it compare to other rivers in geographic proximity to the study area?

METHODS

Water quality is regulated by the development of criteria and standards (Maidment, 1992). A criteria is that concentration, quality, or intensive measure, that if achieved or maintained, will allow a specific water use. Criteria do not have a regulatory role because they relate to the effects of pollution rather than the cause. A water quality standard is a legally enforceable ambient concentration, mass discharge or effluent limitation expressed as a definite rule, measure, or limit for a particular water quality parameter. Standards may be very different from criteria because some local quality conditions such as natural impairment, rather than anthropogenic impairment of water quality exists.

USEPA has published "Quality Criteria for Water 1986" which establishes criteria recommendations for many water quality parameters and pollutants. Each state also has water quality criteria and/or standards developed for waters within their domains (ODEQ, 1995; NCRWQCB, 1994). Table 2.1 summarizes the water quality constituents measured (continuous monitoring instrumentation) or analyzed for (nutrients) as part of the study in the Klamath Basin during 1996 -1998.

Table 2.1 - Typical range of and criteria for water quality constituents measured in the Klamath River study.

Constituent	Typical Range (Maidment, 1992)	Unit	Criteria Chronic Threshold	 Acute Threshold	Reference
Temperature	0-30	°C	>16	>22	McCullough, 1999; USEPA, 1986
Dissolved Oxygen	3-10	mg/L	< 7	<5.5	NCRWQCB, 1994; USEPA, 1986
Total Phosphorus	0.2-6	mg/L	0.1	none	Maidment, 1992
Ortho-phosphorus	0.1-0.5	mg/L	none	none	
Ammonia	0.1-0.5	mg/L	0.035[1]	0.184[1]	USEPA, 1986
Nitrate	0.1-3	mg/L	0.5-3	>3	Maidment, 1992
Total Kjeldahl Nitrogen	0.1-9	mg/L	none	none	
Total Nitrogen	0.1-10	mg/L	none	none	

[1] at pH 8 and 15°C for 4 days (chronic), 4 hours (acute)

McCullough, 1999 is an extensive review of temperature effects on salmonids. Thermal stress criteria were somewhat arbitrarily chosen from ranges listed in these references for various species of salmonids. The criteria listed are relevant to salmonid health, whenever possible, rather than human health.

Water quality includes physicochemical parameters, as well as substances and organisms that may be dissolved (solutes) or suspended (particulates) in the water at a given location, or spatial/temporal point. The growth and respiration cycles of aquatic plants affect dissolved oxygen concentration, primarily during that same summer season. These naturally occurring events interact synergistically and can have much greater impact than either temperature or dissolved oxygen concentration alone. Flow volume is also an integral part of the overall water quality in surface waters. Often low flow conditions may cause an increase in absolute concentrations of many water quality parameters, while high flows may generally result in lower concentrations or a dilution of solutes. Increasing flow volume to dilute concentration is a standard treatment for impaired water quality conditions. Flow volume is also a part of calculations for loading and assimilative capacity estimates in surface waters.

Continuous Monitoring Instrumentation

Water temperature and dissolved oxygen concentration were measured using continuous monitoring instruments that measured these parameters hourly and stored readings in internal memory. In 1996 and 1997, Instrumentation was deployed at 4 locations within the study area, Keno, OR, the Klamath River below J.C.Boyle Powerplant, the Klamath River near the Oregon/California State line, and below Iron Gate Dam, CA (Fig. 1.1). In 1998, the J.C. Boyle monitoring site was discontinued and the most downstream location at Seiad Valley, CA was utilized. Site identifications were Keno, Powerplant, Stateline, Iron Gate and Seiad, respectively.

Two instruments were used at each site in alternation. An instrument would be deployed for 1-2 weeks, depending on water temperature, and then replaced by the alternate instrument for an equivalent period. Each instrument was calibrated according to manufacturer's guidelines prior to deployment and post-calibrated following removal from the site.

Data stored in the internal memory of each instrument was downloaded to a personal computer in ASCII format. ASCII files containing 1-2 weeks of temperature and DO measurements for a site were imported to spreadsheet software such as Lotus 123 or Excel. Daily average values were calculated and, along with daily maximum and minimum values, were used for graphical and statistical analyses.

The continuous monitoring record of DO was affected by a phenomenon called "aging sensors". The instrumentation used during the study was provided by the Bureau of Reclamation's Klamath Area Office in Klamath Falls, OR, or by the Denver Office. Many of the instruments were of about the same vintage and had been used in other studies and locations for several years. DO sensors have a performance life and we failed to realize that they were reaching the end of that period. Since each instrument calibrated and post-calibrated, the problem with inaccurate DO values was not discovered until the end of 1997. A sample of a DO record showing a discontinuity in the record that is coincident with instrument exchange illustrates the problem (Fig. 2.1). In August, 1998, instruments were exchanged on 8/5, 8/13, 8/21, and 8/27/98. At the exchange boundaries on 8/5, 8/21, and 8/27, a marked discontinuity in the record is apparent. In most cases, the DO record was much higher or much lower than the previous recording period record. All DO sensors were been replaced, but failure rate for the newly installed sensors was initially >50%. Confidence in the DO record is considerably less than in the temperature record. Temperature values have a confidence interval of $\pm$ 0.1 degrees C. DO values have a confidence interval of $\pm$ 0.5 mg/L.

The instrumentation software calculates percent saturation of DO at temperature and barometric pressure. Using the measured water temperature and elevation of the site above sea level, the DO record for each site was adjusted. DO values less than 75% saturation were adjusted upward and values exceeding 105% were adjusted downward. Some subjectivity was used to screen the data and determine which and how much of the record was adjusted. For example, at 4 p.m. in mid-summer, there were many instances of DO values exceeding 105% saturation. These values were not adjusted, particularly when a regular daily pattern was discerned in preceding or following days. At the Keno site, the instrumentation site was in a deep-water pool just downstream from a highway bridge. Because this site did not have turbulent flow conditions, DO values of much less than 75% saturation were not adjusted, particularly if preceding or following weeks exhibited similar daily patterns and DO value ranges.

Water Quality Sampling

Water quality sampling was performed using USEPA, 1983 protocols for collection and preservation. During 1996 and 1997, samples were collected at the following Klamath River locations; Keno, J.C. Boyle Dam, Klamath Canyon, J.C. Boyle Powerplant, and Iron Gate Dam (Fig. 1.1). In 1998, the samples were collected at Keno, Iron Gate Dam, the Shasta River, the Scott River, and Seiad (Fig. 1.1). Samples were collected as grabs from turbulent flowing areas adjacent to the stream bank using a polypropylene bucket that had been rinsed with distilled water followed by a rinse with sample water. A 500 mL sample was preserved with 2 mL of 20% H_2SO_4. A 100 mL sample was filtered through a 0.45 micron cellulose-acetate syringe filter. Both samples were immediately iced and shipped to the laboratory on ice by overnight express to comply with USEPA, 1983 protocols for holding times prior to nutrient analysis.

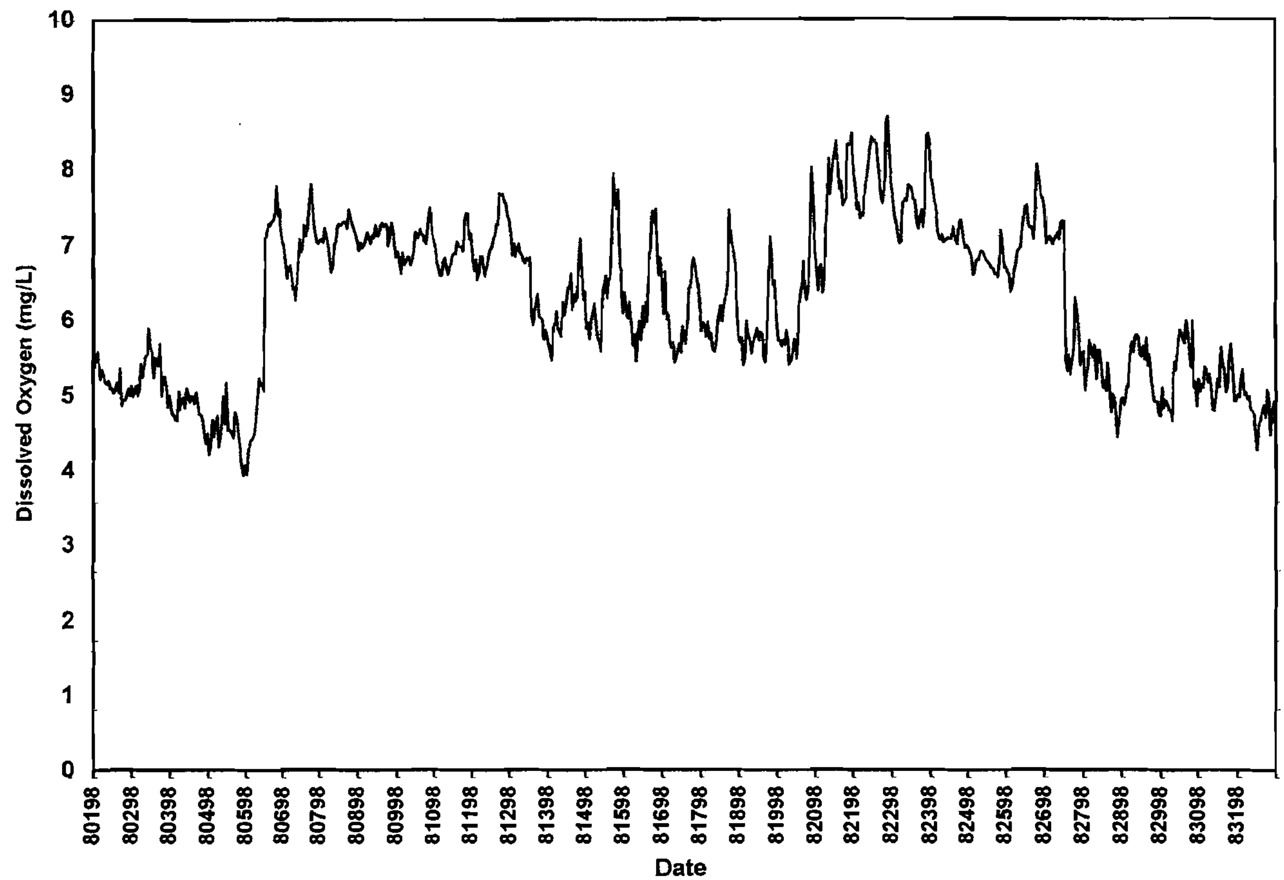

Figure 2.1 Example of discontinuity in dissolved oxygen record for August, 1998 at Iron Gate Dam, California illustrating the aging sensor phenomenon.

Nitrogen and phosphorus nutrient samples were processed by Reclamation's Pacific Northwest Region Laboratory in Boise, ID according to procedures outlined in their "Quality Assurance Plan - Soil and Water Quality Laboratory," July, 1987. Analytical procedures generally follow APHA Standard Methods, 1998 for the following parameters: total phosphorus, ortho-phosphorus, ammonia, nitrite plus nitrate, and total Kjeldahl nitrogen.

Approximately 20% of samples were field duplicates submitted with routine samples. At least twice each year, samples were submitted with known concentrations of total phosphorus and nitrate. Results from field duplicates indicate that laboratory analysis accuracy was within a range of ± 2-4.7% and precision ranged from 77-101% during the study period.

Loading Estimates

Total phosphorus and nitrogen loading estimates were calculated according to Chapra, 1997. Total nitrogen was not analyzed directly and was estimated by summing total Kjeldahl nitrogen, nitrite, and nitrate concentrations. Inorganic nitrogen was estimated by summing ammonia, nitrite, and nitrate concentrations. Organic nitrogen was estimated by subtracting ammonia from total Kjeldahl nitrogen concentration.

Loading was calculated in kg/day using the following convention:

Load = concentration * discharge*2.446848

where concentration is mg/L of constituent and discharge is in cubic feet per second, and (28.32 L/ft^3)(86,400 seconds/day)(1 kg/1,000,000 mg) yields an aggregated conversion factor of 2.446848.

Loading was estimated for each water quality sampling collection date. Annual loading estimates were calculated by summing the individual loading rate estimates at each site, and multiplying the average by 365 to estimate a total annual load. To compare results from this study to other rivers located in geographical proximity, reporting units for each study were converted to the same annual load in kg/yr as calculated for this study.

Statistical Analysis

Box plots to determine normality of data distributions were generated using SAS version 6.3 statistical software (SAS Institute, 1997). Because data were non-normally distributed, non-parametric analyses were used, i.e. Spearman correlations and Wilcoxon Rank Sign tests. Arithmetic daily averages of temperature and DO were calculated in spreadsheets using internal functions. Simple linear correlation was used for air temperature to water temperature comparisons in a spreadsheet using data analysis tools available in the software.

RESULTS AND DISCUSSION

Because continuous monitoring instrumentation was limited to a few sample sites, results and discussion of temperature and dissolved oxygen concentration will focus on Keno, Oregon, Iron Gate Dam and Seiad Valley, California (Fig. 1.1). In general, comparisons of nutrient concentrations and loading conditions will include Keno, Oregon; the Klamath River below J.C. Boyle Powerplant; and Iron Gate Dam, and Seiad Valley, California.

Temperature

Water temperatures recorded at Keno are displayed in Figure 3.1. In each of these figures the acute and chronic thresholds for salmonid health are displayed as colored bands across the graph at 22 °C and 16 °C, respectively. Gaps in these colored bands indicate missing data resulting from instrument failure. The period of record for each year was approximately April through November. Instrumentation is removed during the winter to prevent damage or loss during high winter and early spring flows. Average, minimum and maximum daily temperatures have been plotted to show the diel range for temperature. At Keno, in 1996 and 1997, water temperature generally exceeded the chronic threshold from May through September. In 1998, the chronic threshold is exceeded from June through September. The acute threshold was generally exceeded in July and August. Although visual comparison of data is hampered a few sections of missing data, it is apparent that the average, minimum, and maximum daily temperatures can exceed the acute threshold temperature criterion in mid-summer for periods of up to 7 weeks (Figure 3.1).

Figure 3.2 displays the water temperature records for the Klamath River below Iron Gate Dam. The absolute magnitude for temperature is about 2 °C less during the warm summer months at Iron Gate Dam than at the Keno site. Iron Gate Dam is a re-regulation reservoir that impounds peaking hydropower discharge from Copco-1 powerplant just upstream. Discharge from Iron Gate Dam is a sustained flow release that follows minimum discharge requirements from a FERC (Federal Regulatory Energy Commission) permit. Keno Reservoir is also a re-regulation reservoir, but rather than regulating releases, water surface elevation in Keno is held at full or near-full pool in the summer months to allow for efficient agricultural diversions (provides head to irrigation ditches and siphons). At Keno, water simply spills from the surface, while at Iron Gate Dam, water is discharged through hydropower turbines. The turbine intake is located at an average depth of about 11 feet below the water surface of the reservoir. The difference in discharge depth between the two reservoirs probably explains a large part of the difference in temperature.

Temperature below Iron Gate Dam also exceeded chronic and acute thresholds during the study period (Fig. 3.2). The chronic temperature threshold was exceeded from

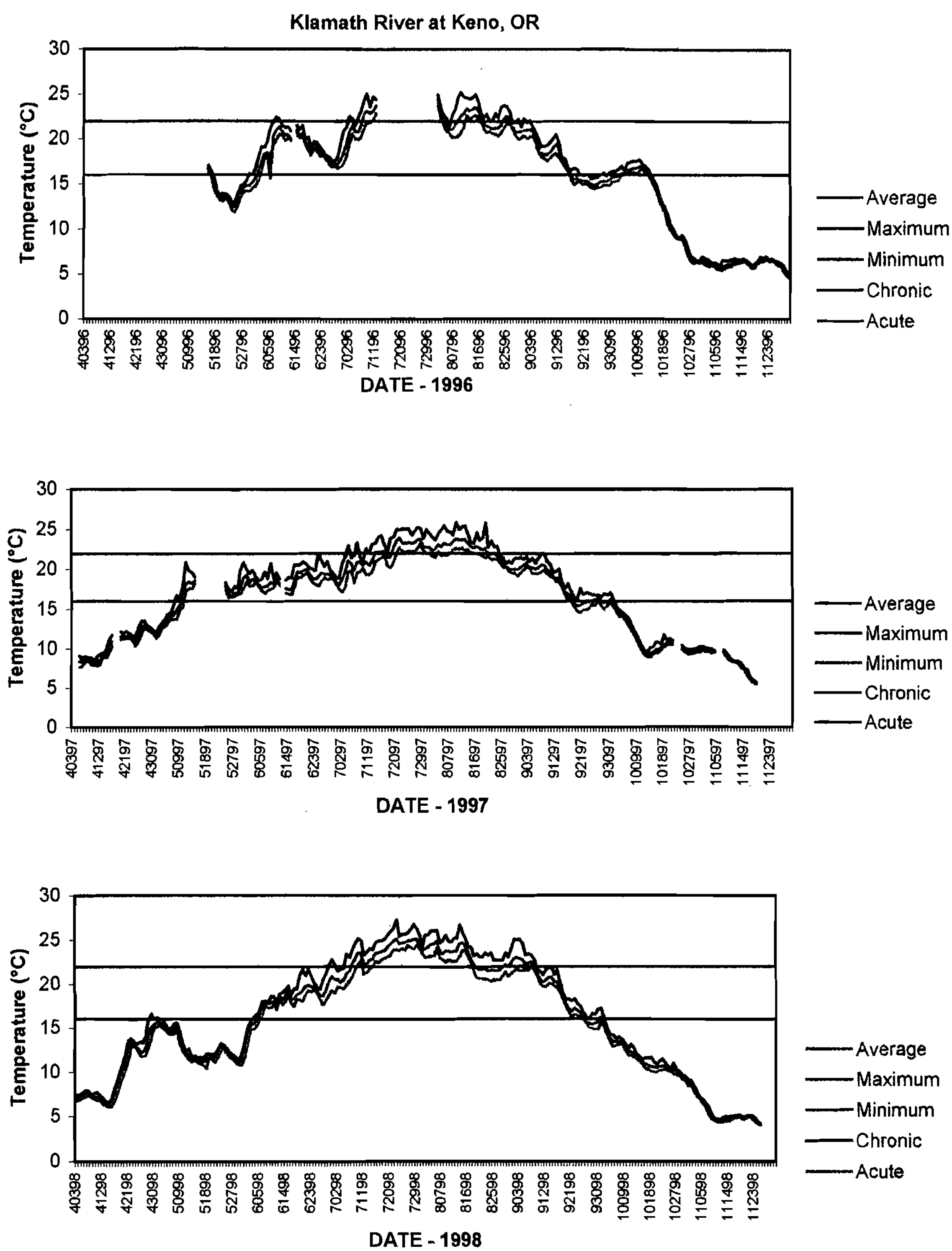

Figure 3.1 Water temperature records for Keno, Oregon from 1996 through 1998.

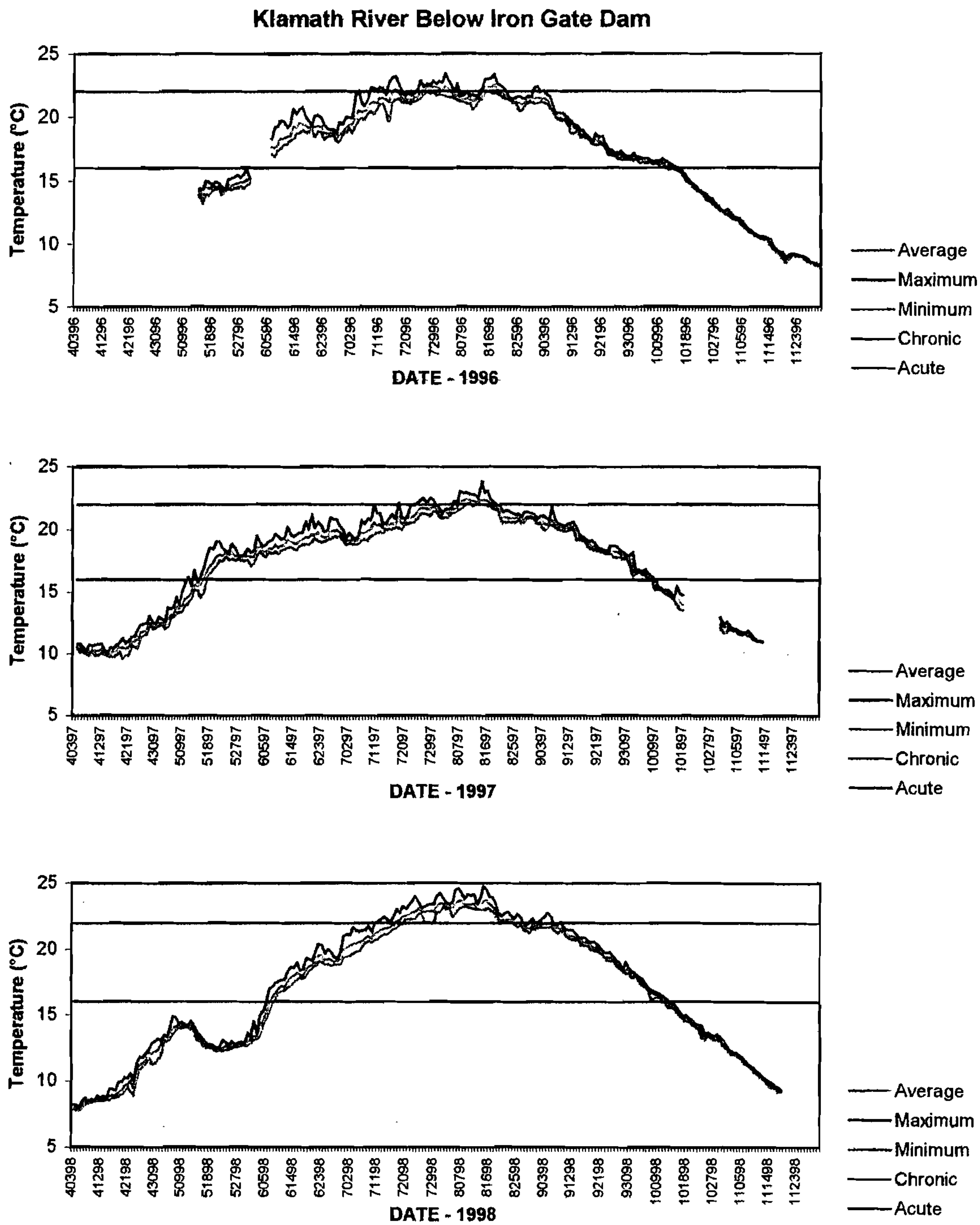

Figure 3.2 Water temperature records for Iron Gate Dam, California from 1996 through 1998.

May/June through September of each year, but the acute temperature threshold was exceeded for a much shorter time each year than at the Keno site. During the study period, elevated temperature persisted for periods ranging from 1- 4 weeks (Figure 3.2).

Meteorological conditions recorded at Montague, California airport indicate that the average summer air temperature in 1997 was about 1.2 °C cooler than in 1996 and about 0.3 °C warmer in 1998 compared to 1996. Air temperature and water temperature are closely correlated in the Klamath River study reach. At Keno, the air to water temperature correlation coefficient r = 0.89 in 1996 and r = 0.90 in 1997 and 1998. For the Iron Gate location, r = 0.85 in 1996, r = 0.81 in 1997, and r = 0.88 in 1998. It is interesting to note that meteorological conditions at the Klamath Falls airport, which is geographically closest to Keno do not show the same trend as the Montague airport between 1996 and 1997. The difference in average summer air temperature between 1996 and 1997 is just 0.3 °C, however in 1998 the summer air temperature was 0.8 °C warmer compared to 1996. The elevation change between Keno and Iron Gate Dam is also significant. Keno elevation is 3437' while Iron Gate dam elevation is 2162'. The difference in elevation and an intervening mountain range (the Siskiyou), create differences in climate between the two sites.

The temperature record during 1998 at Seiad, CA is displayed in Figure 3.3. The temperature range is somewhat higher than at Iron Gate Dam because this location is approximately 60 miles downstream and shows both greater diel variability as well as a more irregular daily pattern. Water temperature at this location is more directly related to meteorological conditions since it is not buffered by a reservoir such as Iron Gate Dam. The chronic temperature threshold at this location is exceeded beginning in June and ending in October (Fig. 3.3). The acute temperature threshold is exceeded beginning in July and continues through August (Fig. 3.3). The temperature record at Seiad in 1998 confirms that warm water conditions are prevalent throughout the Klamath River study area in the summer months.

Fishery biologists often use a calculated value called a "degree day" in determining egg incubation periods and growth rates for fish. A degree day is a 24 hour period when the temperature exceeds some value of interest. In the Klamath River, degree days are used as an estimate of stressful conditions for fish with the criteria being the chronic and acute temperature thresholds (16 °C and 22 °C, respectively). Since temperature was measured at hourly intervals, an actual duration or number of hours at or above these temperature criteria were summed from the continuous monitoring record. Table 3.1 presents the actual duration and calculated degree days above chronic and acute temperature thresholds at monitoring locations in the Klamath River study area.

Summing the number of hourly measurements when temperature exceeded the chronic or acute thresholds gives some indication of the length of time fish might have had to endure unfavorable meso-habitat conditions. Values for 1996 at the Keno site actually

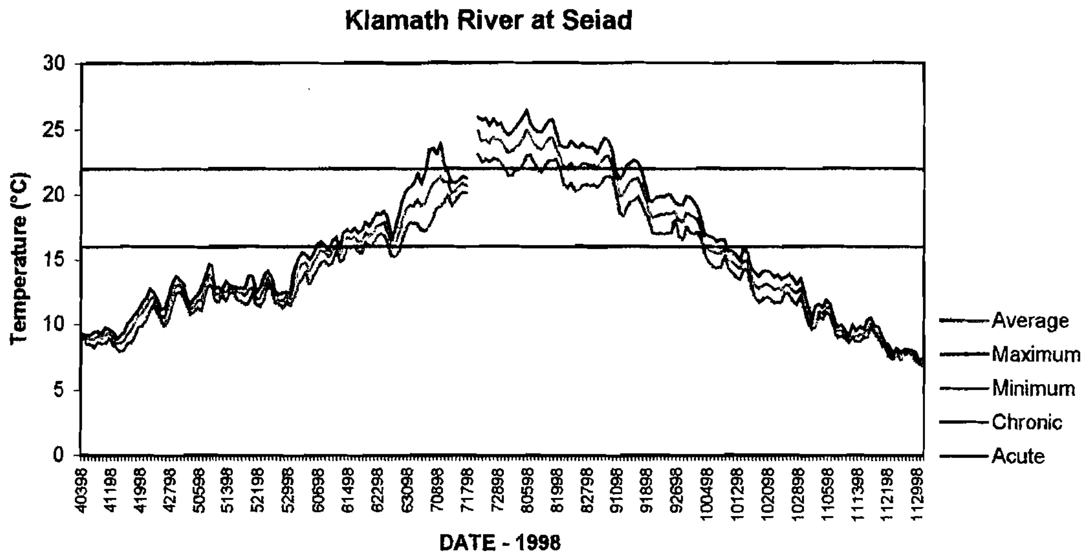

Figure 3.3 Water temperature record for Seiad Valley, California during 1998.

represent low estimates because 2 weeks of data in the warmest summer period (7/12-31/96) are missing. However, it can be seen from Table 3.1 that fish might experience extended periods of time when temperatures are unfavorable for growth. Two main points are illustrated in Table 3.1. First, elevated temperatures occur throughout the Klamath River study area. Second, acute temperature criteria are exceeded for periods of up to 6 weeks in some locations. Stress also makes fish more susceptible to disease and parasites. In 1997, a fish kill in the Klamath River was observed in August that probably resulted from bacterial infection (Williamson and Foote, 1998). Elevated water temperature and low dissolved oxygen concentrations preceding and during the fish kill were identified as stressors that reduced resistance to the bacteria.

Table 3.1.- Duration of and degree days for temperature exceeding chronic and acute thresholds in the Klamath River from 1996 – 1998.

	1996		1997		1998	
Location	Chronic[1]	Acute[2]	Chronic	Acute	Chronic	Acute
Duration						
Keno	95	19	124	34	115	52
Powerplant	64	9	70	10	-	-
Stateline	97	6	95	3	84	13
Iron Gate	127	15	144	10	128	41
Shasta	-	-	-	-	107	47
Scott	-	-	-	-	82	14
Seiad	-	-	-	-	94	32
Degree Days						
Keno	390	19	535	38	617	89
Powerplant	163	0	128	15	-	-
Stateline	306	0.3	256	0	315	4
Iron Gate	500	4	541	3	596	39
Shasta	-	-	-	-	610	87
Scott	-	-	-	-	273	0
Seiad	-	-	-	-	437	51

[1]Chronic threshold - >16°C
[2]Acute threshold - >22°C

A comparison of values for duration in Table 3.1 indicates that there may be substantial variation between years at the same location, presumably because meteorological and flow conditions vary from year to year. However, the period-of-record also varies from year to year and is another potential factor in inter-annual variation. Comparing the longitudinal trends from Keno to Seiad is possible only in 1998. The Scott River seems to be cooler than the mainstem Klamath River, therefore the duration of temperatures above 16 °C (chronic) is much less than either upstream at Iron Gate Dam or downstream at Seiad Valley. The Scott River could represent a significant cooling influence if flow volume were a greater percentage of total flow, however, the flow volume in the Scott River is less than 10% of the Klamath River mainstem flow volume in the summer. Because Iron Gate Dam is the terminus for anadromous fish spawning migration in the Klamath River, improving the temperature regime, if possible, is a management goal for fisheries restoration.

The estimates of degree day are provided as an additional indication of thermal stress for salmonids. The number of degree days can exceed the number of days in a calendar year and/or the period-of-record. Continuous monitoring instrumentation records for 1996 – 1998 were generally less than 210 days per year. There can be several degree days in one 24 hour period. For example, exceeding a thermal threshold, i.e., 16 °C, results in 3.5 degree days if the measured temperature was 19.5 °C.

Temperature can affect anadromous fish such as Chinook salmon during two periods of the year. In the spring (May-June), the out-migrating YOY (young of year) fish need to exit the Klamath River corridor to the ocean before the temperature exceeds 13 °C for optimal growth to occur (McCullough, 1999; USEPA, 1986). From the temperature record in Fig. 3.2, below Iron Gate Dam the temperature exceeds 13 °C for almost all of that spring period. YOY fish counted at a screw-trap site in the Klamath near Weitchpec, which is just above the confluence of the Trinity River, often die as soon as they are handled (T. Shaw, pers. comm.). The temperatures are very warm and any additional stress such as being handled to remove them from the screw trap holding cages, results in mortality for most of the fish. As a general practice, once water temperature exceeds 15 °C, screw trap operation is discontinued.

There are also two species of anadromous fish that over-summer in the Klamath River, steelhead and coho. Both species are currently listed as endangered species in this drainage. Very low incidence of both fish species have been observed in spawning, thermal refugia, and population sampling over the past 10 years (CDFG, 1997). For both species the maximum temperature at which growth can occur is about 23 °C (McCullough, 1999; USEPA, 1986). Temperature in the Klamath River generally exceeds this value for at least a month or more at the height of summer. Fish can move into the mouths of tributaries and other areas where temperatures may be cooler than in the mainstem Klamath River. However, the useable habitat area in these areas is not large (Belchik, 1997) and may constitute a limit on carrying capacity for over-summering salmonids in the Klamath.

Dissolved Oxygen

DO (Dissolved oxygen concentration) and temperature have an inversely proportional relationship. In the summer months when temperature is greatest, DO is less soluble in water and therefore, even at 100% saturation is less than periods when temperature is lower. The solubility of DO is also affected by altitude/barometric pressure. Higher elevation locations in the study area have slightly lower DO than those at lower elevations. For Keno and Iron Gate Dam, that difference is about 0.4 - 0.5 mg/L at any temperature and 100% saturation (Hydrolab Corp., 1989). This means that Keno DO is always lower than Iron Gate Dam DO values simply because they are at different elevations. The Keno location where the continuous monitoring instrumentation was deployed is also in a slack water site out of the main flow channel. Because turbulent mixing did not occur, this site was more subject to lacustrine processes governing DO. The Klamath River reservoirs are dominated by a blue-green alga, *Aphanizomenon flos-aquae*, during the summer months. This algae forms a surface scum that has the appearance of grass clippings on the water. DO exhibits wide diel variability in waters influenced by algal growth and respiration. During the day, photosynthesis releases oxygen as a by product and in the afternoon of any given sunny day, the DO may rise above 100% saturation values for several hours. At night, the algae respire and deplete oxygen from the water and DO values may be very low just before sunrise for a few hours. The Keno DO record displays some of that diel variability.

As previously discussed, the DO record for all locations has been adjusted during the study period due to the 'aging sensor phenomenon". However, there is still sufficient reliable data remaining to discern some trends (Fig 3.4). As with temperature, two criteria are displayed on the figure as colored bands representing the California State standard for DO (NCRWQCB, 1994) and a general standard for salmonid health (NCRWQCB, 1994; USEPA, 1986) of 7 mg/L and 5.5 mg/L, respectively. In this case, thresholds are exceeded when dissolved oxygen concentration is below the criterion rather than above as in the temperature figures. During the study period at Keno, DO generally is below the chronic threshold beginning in late June and below the acute threshold for most of the summer. However, the diel variation in DO can clearly be seen in the 1997 and 1998 records (Fig. 3.4) when maximum DO and minimum DO on a given day may range from 2-3 mg/L to 10-11 mg/L. Missing data in 1997 obscures this phenomenon, but it is still present. A fish kill in Keno Reservoir in 1998 resulted when daily average temperature exceeded 25 °C and DO was below 3 mg/L for about 10 days (L. Dugan, pers. comm.). It is unlikely that salmonids could survive at this location even if they were able to pass the downstream dams by fish ladders or other mechanisms.

At Iron Gate Dam, DO is generally better than at Keno (Fig. 3.5). Again, DO is always higher at Iron Gate Dam simply as a function of lower elevation. However the chronic threshold (California Standard) during the study period is exceeded beginning in June and the acute threshold (general standard) is usually exceeded in September. The fall

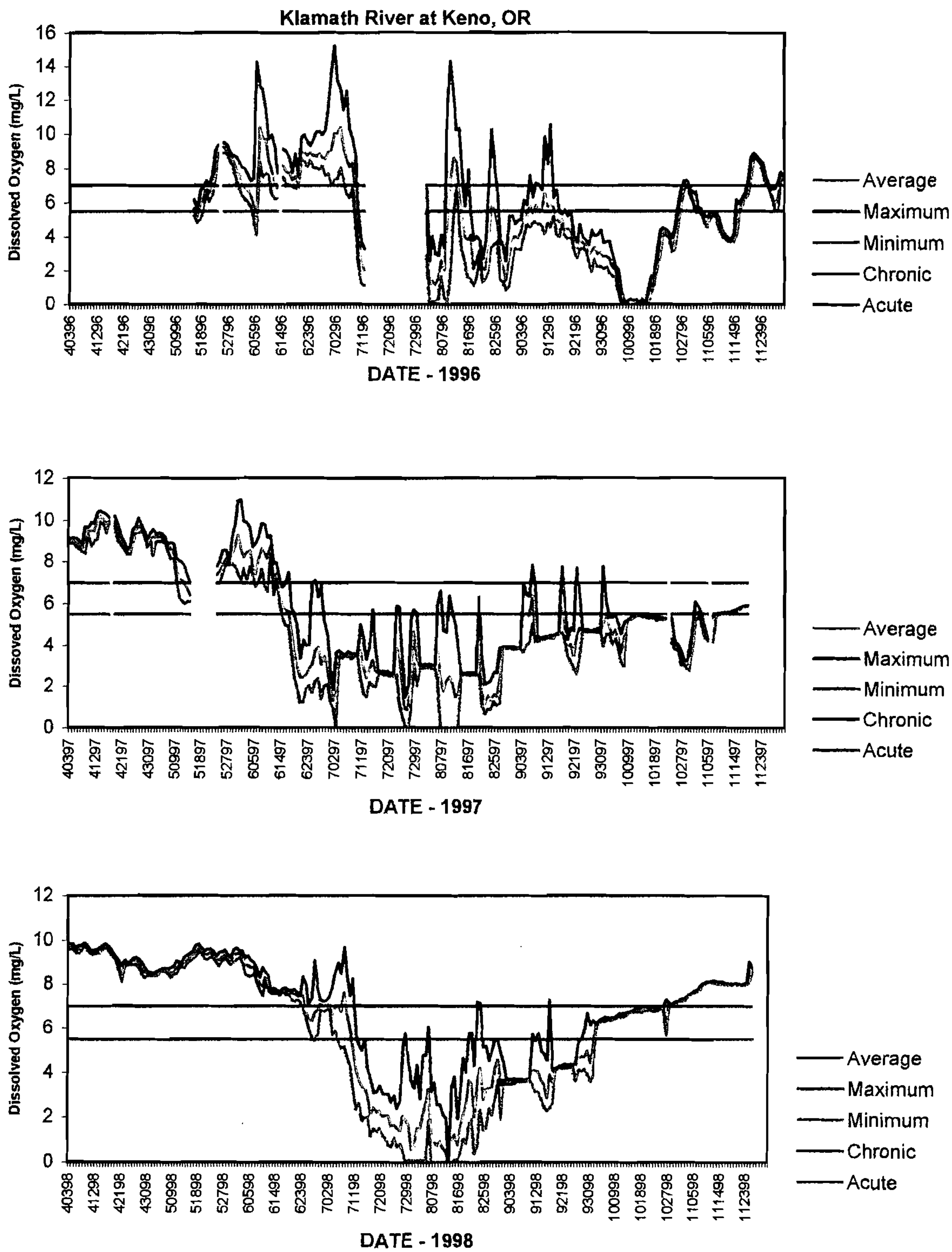

Figure 3.4 Dissolved Oxygen record for Keno, OR, from 1996 through 1998.

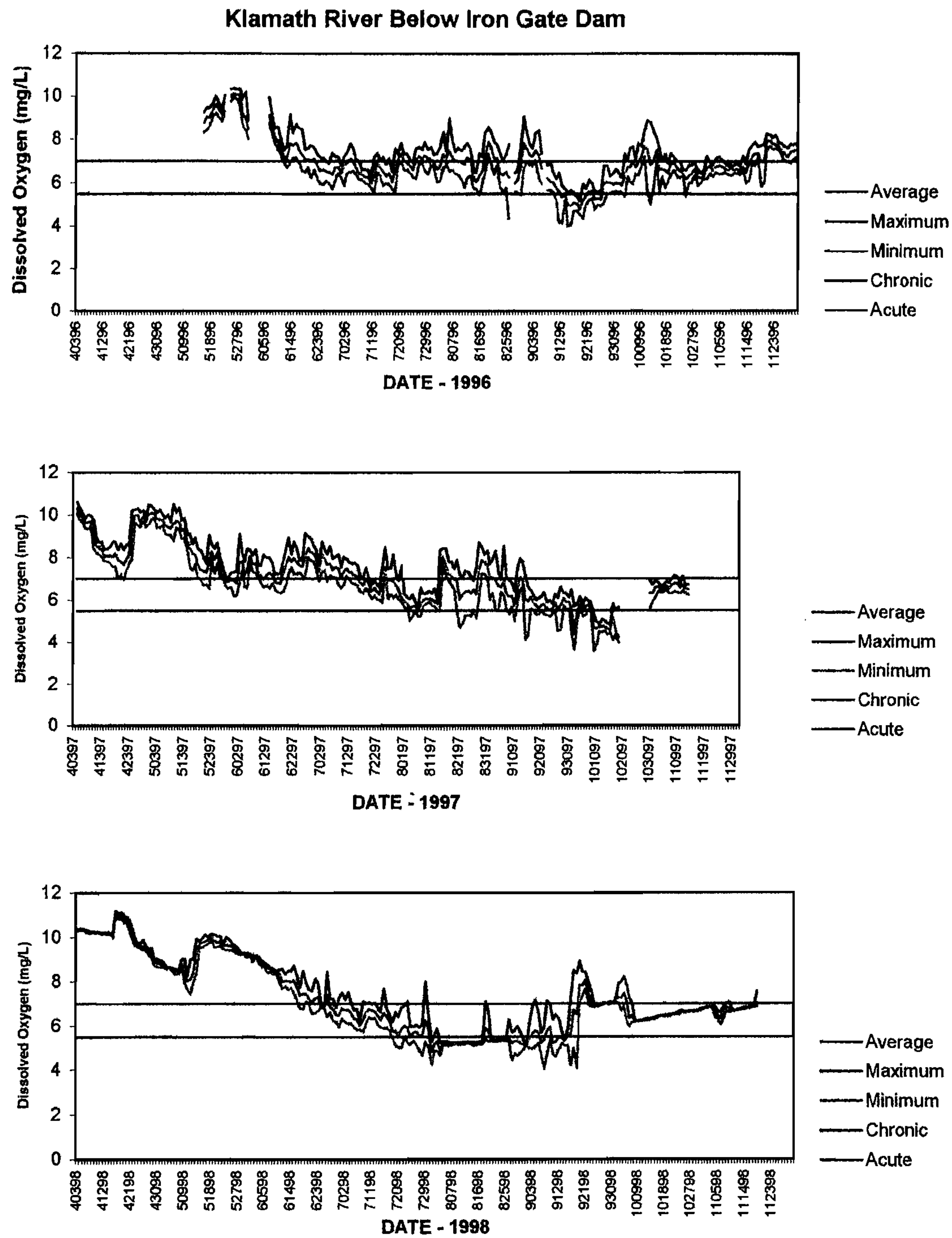

Figure 3.5 Dissolved Oxygen record at Iron Gate Dam, CA, from 1996 through 1998.

period is one that is important for spawning runs of fall chinook salmon. Although the spawning run is terminated at Iron Gate Dam, salmon arrive at the Dam at just about this time each year. They utilize what habitat is available for spawning near the dam and some are removed and both eggs and milt stripped to use at the fish hatchery near Iron Gate Dam. The combination of high temperature and low DO can adversely impact the number of viable eggs and sperm. The optimum incubation temperature for salmonids is 10 °C and the maximum incubation temperature is 13 °C (USEPA, 1986). Above this temperature, fertilized eggs are not viable. For the embryo and larval states of salmonids, DO values of 7-9 mg/L may still result in severe to moderate impairment (USEPA, 1986). Any DO values below 6 mg/L may result in acute mortality. From the DO record at Iron Gate Dam both temperature and DO are unfavorable for viable fertilized salmonid eggs. It would seem likely that many of the early spawners at Iron Gate Dam do not contribute to the gene pool as their fertilized eggs will not develop.

Table 3.2.- Duration of and DO days for dissolved oxygen concentrations below chronic and acute thresholds in the Klamath River from 1996 – 1998.

	1996		1997		1998	
Location	Chronic[1]	Acute[2]	Chronic	Acute	Chronic	Acute
Duration						
Keno	119	89	147	135	119	83
Powerplant	27	<1	22	<1	-	-
Stateline	32	2	30	2	40	5
Iron Gate	108	12	98	18	133	42
Shasta	-	-	-	-	70	4
Scott	-	-	-	-	41	<1
Seiad	-	-	-	-	36	<1
DO Days						
Keno	369	206	274	162	355	216
Powerplant	8	0	13	0	-	-
Stateline	12	0	13	4	23	0
Iron Gate	71	0	94	4	124	9
Shasta	-	-	-	-	38	0
Scott	-	-	-	-	6	0
Seiad	-	-	-	-	15	0

[1]Chronic threshold -<7 mg/L
[2]Acute threshold -<5.5 mg/L

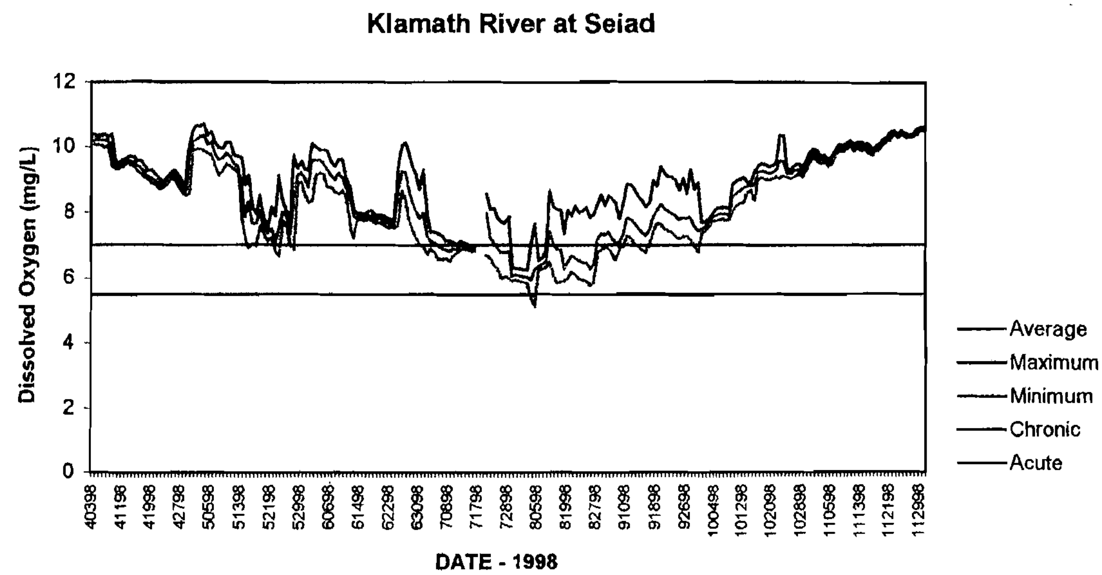

Figure 3.6 Dissolved Oxygen record at Seiad Valley, California during 1998.

The DO record from 1998 at the Seiad location is displayed in Figure 3.6. In general, the chronic DO criteria was exceeded during July and August at this monitoring location. The acute DO criteria was not exceeded on a daily average basis, although minimum DO values occasionally were below 5.5 mg/L at this location in 1998. Again, the DO record at Seiad confirms that sub-optimal DO conditions are pervasive in the Klamath River study area during the summer months. The effect on chinook salmon is negligible since they are not present in the system in the summer, but resident fish or those who spend 1-2 summers in the system may be adversely impacted by sub-optimal DO conditions.

As with temperature, the actual duration of time and a DO day index, similarly calculated for degree days, is summarized in Table 3.2. A DO day is defined as 1 mg/L DO below a threshold value. These values are based on the available data in each year and at Keno there was a large block of missing data in 1996. However, it is still apparent that DO conditions are extremely unfavorable for salmonids at Keno for extended periods of time in summer. DO records at Iron Gate Dam also indicate up to 2 weeks in late summer when the acute threshold for DO is exceeded. This period coincides with the early part of the fall chinook salmon run and may be a factor in limiting fish production.

Continuous monitoring instrumentation further downstream and in the tributaries to the Klamath River were utilized in 1998. It seems that acute DO duration and DO days are nearly absent or much reduced however, at the chronic threshold for DO is exceeded for up to two weeks, even at the most downstream study sites. Other factors are also involved such as limited spawning habitat, but the management implication for fish restoration is to improve temperature and DO to benefit the early spawning fish eggs and larvae by increasing viability.

Phosphorus and Nitrogen Nutrients

Why are both nutrient concentrations and loading a consideration in anadromous fish restoration in the Klamath River? Nutrients, particularly phosphorus, stimulate plant growth (Maidment, 1992). Land use practices in the Klamath River watershed include timber harvest, agriculture and cattle grazing. These land uses tend to increase nutrients in receiving waters (National Research Council, 1992). Although plant production is desirable for fish, too much production leads to warmer temperatures and lower DO, which adversely affect growth and reproduction of fish. The Klamath River is naturally enriched because the upper watershed drains volcanic and peat soils that are relatively high in phosphorus (USGS, 1999). In many lakes and reservoirs, phosphorus is the limiting nutrient for plant growth (Wetzel, 1983). In the Klamath River reservoirs, nitrogen tends to be the limiting nutrient, particularly in the summer months (Campbell, *et al.*, 1992).

With an abundance of nutrients in the water, aquatic plants thrive in the Klamath River and the mainstem reservoirs. When aquatic plants photosynthesize during daylight hours, free oxygen is produced as by-product. Dissolved oxygen concentration increases, sometimes reaching super-saturation and little bubbles of O_2 can be seen on underwater leaf surfaces or even bubbling from the water surface in slack waters. During the night, plants respire and consume dissolved oxygen from the water. Just before sunrise, dissolved oxygen concentrations can be considerably reduced. This diel variation in dissolved oxygen concentration can limit use of lower velocity water at stream margins that would otherwise be energetically favorable for larval and juvenile fish use. Although aquatic plants can also provide cover to escape from predation, larval and juvenile fish cannot utilize that cover continuously. When they move to a location with better water quality, they might have to expend more energy actively swimming against a stronger current or spend less time feeding and more time swimming. All of these factors can adversely affect growth rates of fish as well survival. Excess nitrogen in the forms of ammonia and nitrite can also reduce dissolved oxygen concentrations through nitrification, the oxidation of these constituents to nitrate (Maidment, 1992).

The amount of nutrients in the Klamath River is indirectly important to fish health. There are two main techniques for assessing nutrient conditions; concentration and loading. The concentration of nutrients tends to be more critical in non-flowing waters such as ground waters, ponds, lakes or reservoirs. In flowing waters, nutrient loading as a function of discharge, may be more relevant.

Nutrient Concentrations

Table 3.3 presents results of nutrient analysis for samples collected in the Klamath River study area from 1996 through 1998. As a space saving measure, the various nutrient constituents are abbreviated as follows: Total P = Total Phosphorus; Ortho-P = Ortho-phosphorus; TKN = Total Kjeldahl Nitrogen; Total N = Total Nitrogen; and TON = Total Organic Nitrogen. The summary values in Table 3.3 indicate that mean total phosphorus concentration increased slightly in the mainstem Klamath River reservoirs, although the median values were identical. Both mean and median Total P concentration then decreased longitudinally downstream between Iron Gate and Seiad. This phenomenon is represented in Figure 3.7, a simple box plot of Total P concentrations during the study period for all Klamath River sampling locations from up- to downstream. At locations below the mainstem Klamath Reservoirs (Keno, J.C. Boyle Powerplant, and Iron Gate) Total P concentrations are very similar, although there is more scatter in the values for Keno. The sharp decrease in Total P concentration in the river reach between Iron Gate and Seiad is very obvious in the box plot (Fig. 3.7). Mean and median ortho-P concentration seemed to increase more markedly through the reservoir segment from Keno downstream to Iron Gate, and decrease between Iron Gate and Seiad in the mainstem Klamath River (Table 3.3, Figure 3.8). Mean ammonia

Table 3.3. – Phosphorus and Nitrogen nutrient concentration (mg/L) summary for the Klamath River study area from 1996 -1998.

Station	Variable	N	Median	Mean	Std Dev	Minimum	Maximum
Keno	TOTALP	26	0.160	0.170	0.061	0.086	0.313
1996-98	ORTHOP	26	0.076	0.095	0.053	0.031	0.243
	AMMONIA	26	0.280	0.393	0.341	0.030	1.150
	NITRATE	26	0.105	0.140	0.101	0.030	0.420
	TKN	26	1.410	1.471	0.535	0.630	2.580
	TN	26	1.230	1.610	0.549	0.780	2.670
	TON	26	1.080	1.077	0.271	0.580	1.595
JC Boyle	TOTALP	17	0.170	0.186	0.070	0.101	0.336
1996-97	ORTHOP	17	0.117	0.127	0.057	0.053	0.239
	AMMONIA	17	0.160	0.187	0.131	0.040	0.505
	NITRATE	17	0.550	0.537	0.348	0.100	1.200
	TKN	17	1.140	1.118	0.263	0.745	1.505
	TN	17	1.480	1.655	0.582	0.950	2.625
	TON	17	1.000	0.932	0.183	0.680	1.260
Canyon	TOTALP	17	0.910	0.095	0.016	0.068	0.127
1996-97	ORTHOP	17	0.072	0.073	0.014	0.049	0.102
	AMMONIA	17	0.005	0.009	0.009	0.005	0.040
	NITRATE	17	0.260	0.260	0.099	0.090	0.430
	TKN	17	0.220	0.244	0.109	0.160	0.595
	TN	17	0.515	0.504	0.124	0.300	0.755
	TON	17	0.215	0.236	0.103	0.155	0.575
Powerplant	TOTALP	17	0.161	0.167	0.068	0.092	0.317
1996-97	ORTHOP	17	0.113	0.114	0.056	0.044	0.228
	AMMONIA	17	0.160	0.151	0.127	0.005	0.410
	NITRATE	17	0.390	0.466	0.335	0.018	1.210
	TKN	17	0.990	0.884	0.444	0.075	1.420
	TN	17	1.190	1.350	0.733	0.093	2.630
	TON	17	0.890	0.733	0.362	0.025	1.260
Iron Gate	TOTALP	23	0.160	0.194	0.104	0.025	0.440
1996-98	ORTHOP	23	0.120	0.134	0.074	0.017	0.295
	AMMONIA	19	0.070	0.087	0.040	0.030	0.165
	NITRATE	23	0.170	0.243	0.173	0.040	0.530
	TKN	23	0.680	0.732	0.238	0.500	1.660
	TN	23	0.890	0.975	0.333	0.600	2.180
	TON	19	0.590	0.658	0.254	0.390	1.540
Shasta	TOTALP	9	0.181	0.175	0.048	0.120	0.257
1998	ORTHOP	9	0.165	0.140	0.058	0.043	0.224
	AMMONIA	9	0.020	0.016	0.006	0.005	0.025
	NITRATE	9	0.020	0.049	0.059	0.005	0.180
	TKN	9	0.420	0.411	0.109	0.240	0.590
	TN	9	0.420	0.449	0.114	0.259	0.680
	TON	9	0.400	0.395	0.103	0.235	0.565

Table 3.3. (Continued)– Phosphorus and Nitrogen Nutrient Concentration (mg/L) Summary for the Klamath River Study Area from 1996 -1998.

Station	Variable	N	Median	Mean	Std Dev	Minimum	Maximum
Scott	TOTALP	9	0.031	0.029	0.014	0.011	0.048
1998	ORTHOP	9	0.008	0.009	0.003	0.005	0.014
	AMMONIA	9	0.010	0.010	0.003	0.005	0.015
	NITRATE	9	0.305	0.264	0.132	0.070	0.440
	TKN	9	0.130	0.128	0.024	0.090	0.157
	TN	9	0.420	0.392	0.126	0.205	0.575
	TON	9	0.120	0.118	0.022	0.080	0.147
Seiad	TOTALP	9	0.103	0.109	0.037	0.070	0.180
1998	ORTHOP	9	0.062	0.074	0.042	0.033	0.143
	AMMONIA	9	0.020	0.016	0.005	0.010	0.025
	NITRATE	9	0.140	0.179	0.146	0.013	0.440
	TKN	9	0.380	0.377	0.121	0.170	0.565
	TN	9	0.400	0.548	0.231	0.205	0.845
	TON	9	0.360	0.361	0.119	0.155	0.545

concentrations showed a strong tendency to decrease longitudinally from Keno downstream to Seiad (Table 3.3, Figure 3.9). Mean nitrate concentrations tended to increase from up- to downstream between Keno and Iron Gate. Although mean nitrate concentration was slightly less at Seiad than at Iron Gate, it was still greater than the mean nitrate concentration at Keno (Table 3.3, Figure 3.10). Mean total Kjeldahl N and total organic N concentrations shared a tendency to decrease in the downstream direction from Keno to Seiad (Table 3.3, Figures 3.11 and 3.12, respectively). Figure 3.13 is a simple box plot of Total N concentrations at all the sampling locations in the Klamath study area from up- to downstream. In contrast to Total P, Total N concentrations generally decline longitudinally from up- to downstream in the Klamath River study area.

There is a sequence of changes in the form of nitrogen that occur as it is oxidized (Maidment, 1992). Total organic nitrogen and ammonia are converted to nitrate usually in an upstream to downstream direction beginning where point or nonpoint sources of these constituents enter a stream. Nitrate then decreases longitudinally as plant uptake begins.

In the absence of sewage wastewater, ammonia concentration in streams ranges from 0.5 - 3.0 mg/L, however, concentrations in excess of 0.5 mg/L can cause significant toxicity to fish and other aquatic organisms (Maidment, 1992). Ammonia concentration exceeded 0.5 mg/L on 54% of sample dates at the Keno site and the mean value for this location was substantially greater than at the other Klamath River sampling locations (Figure 3.9).

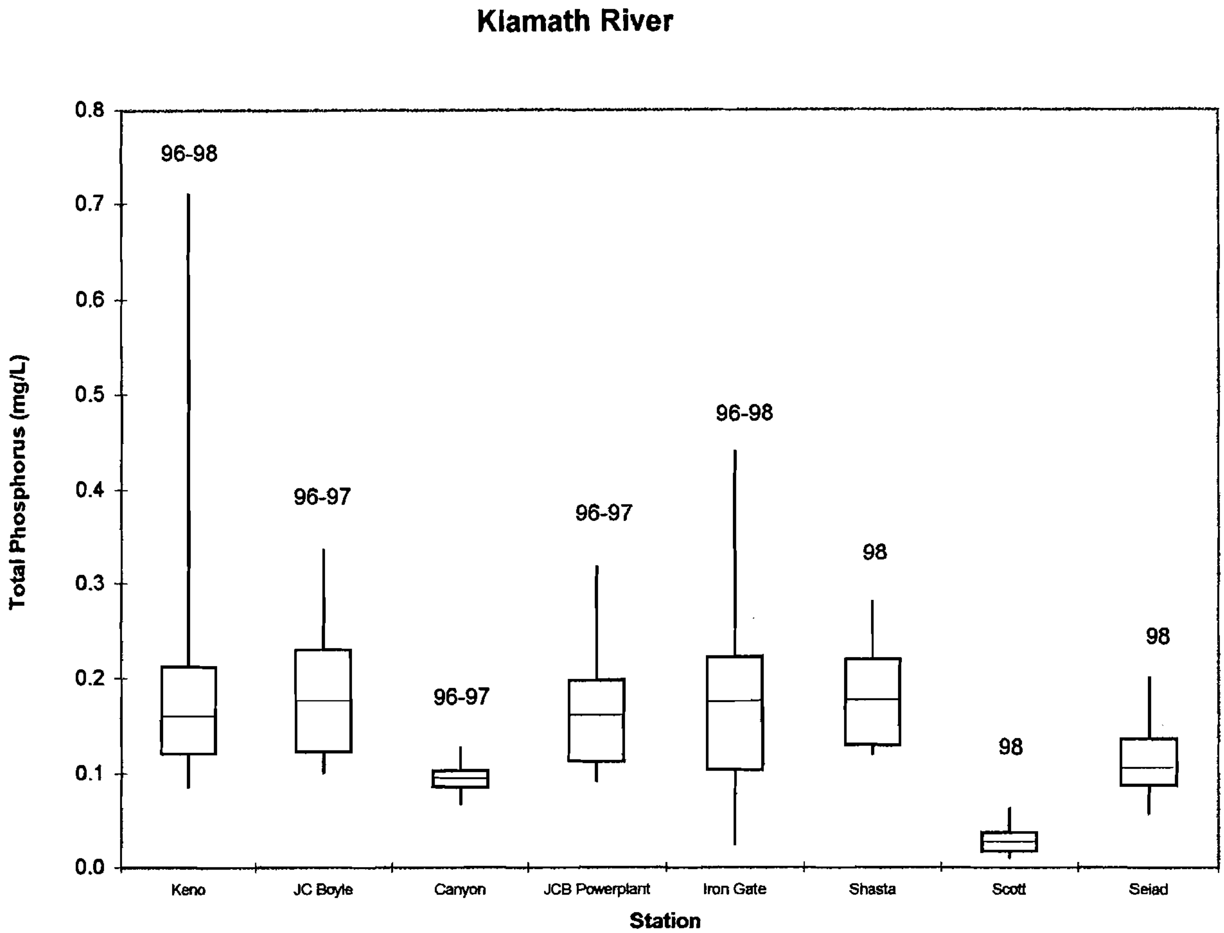

Figure 3.7 Simple box plot of total phosphorus concentration in the Klamath River at eight locations for the study period 1996-1998.

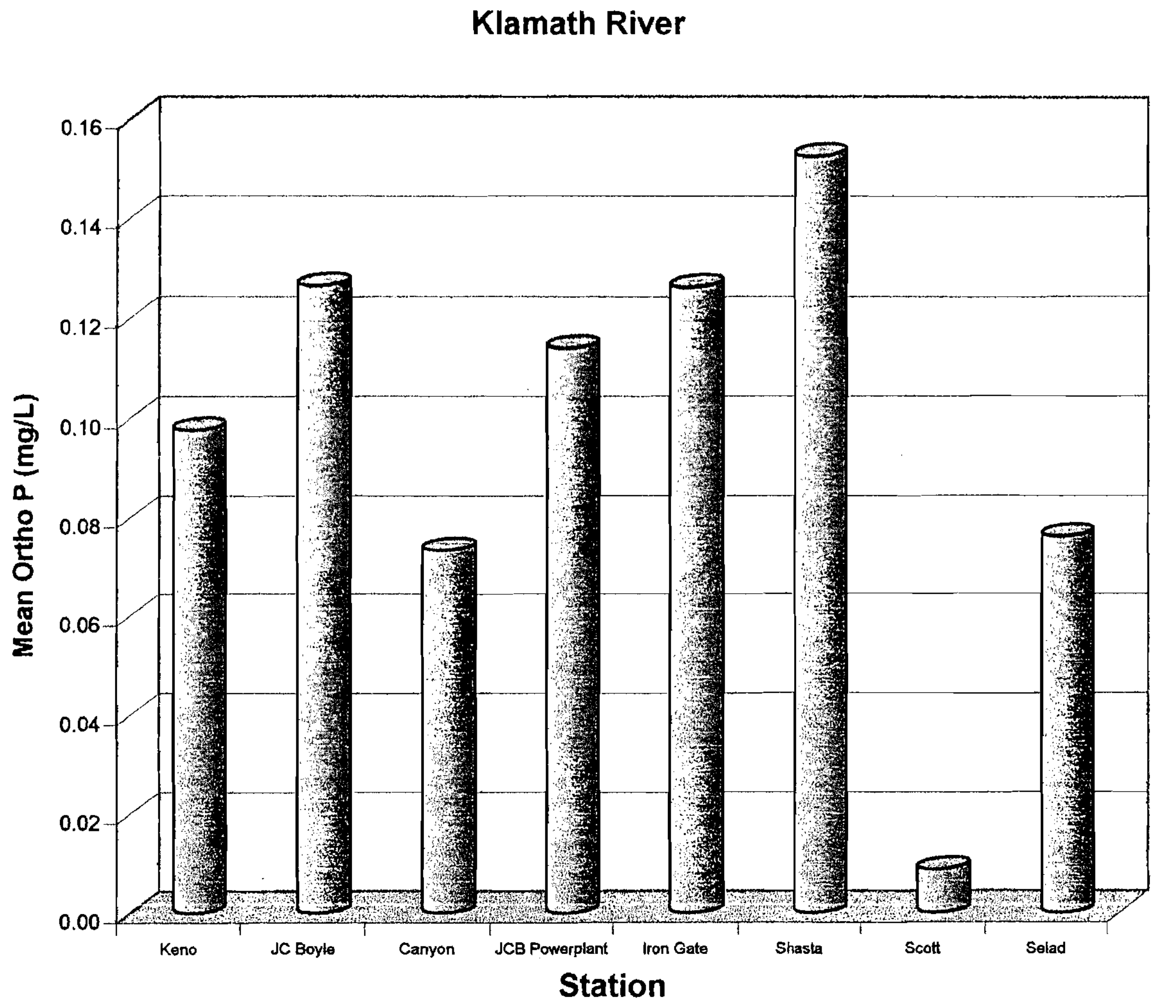

Figure 3.8 Mean ortho phosphorus concentration at eight locations in the Klamath River for the study period 1996-1998.

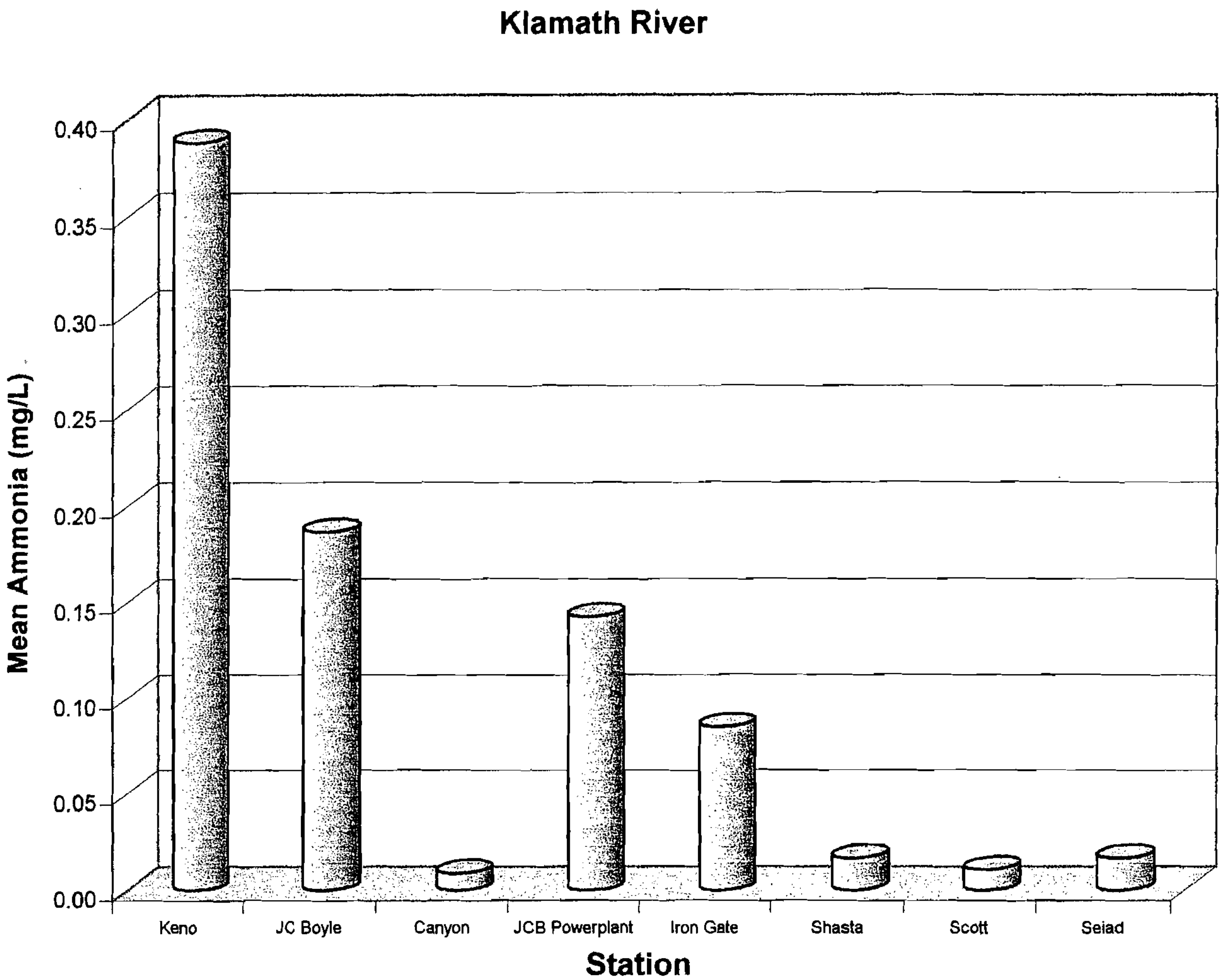

Figure 3.9 Mean ammonia concentration at eight locations in the Klamath River for the study period 1996-1998.

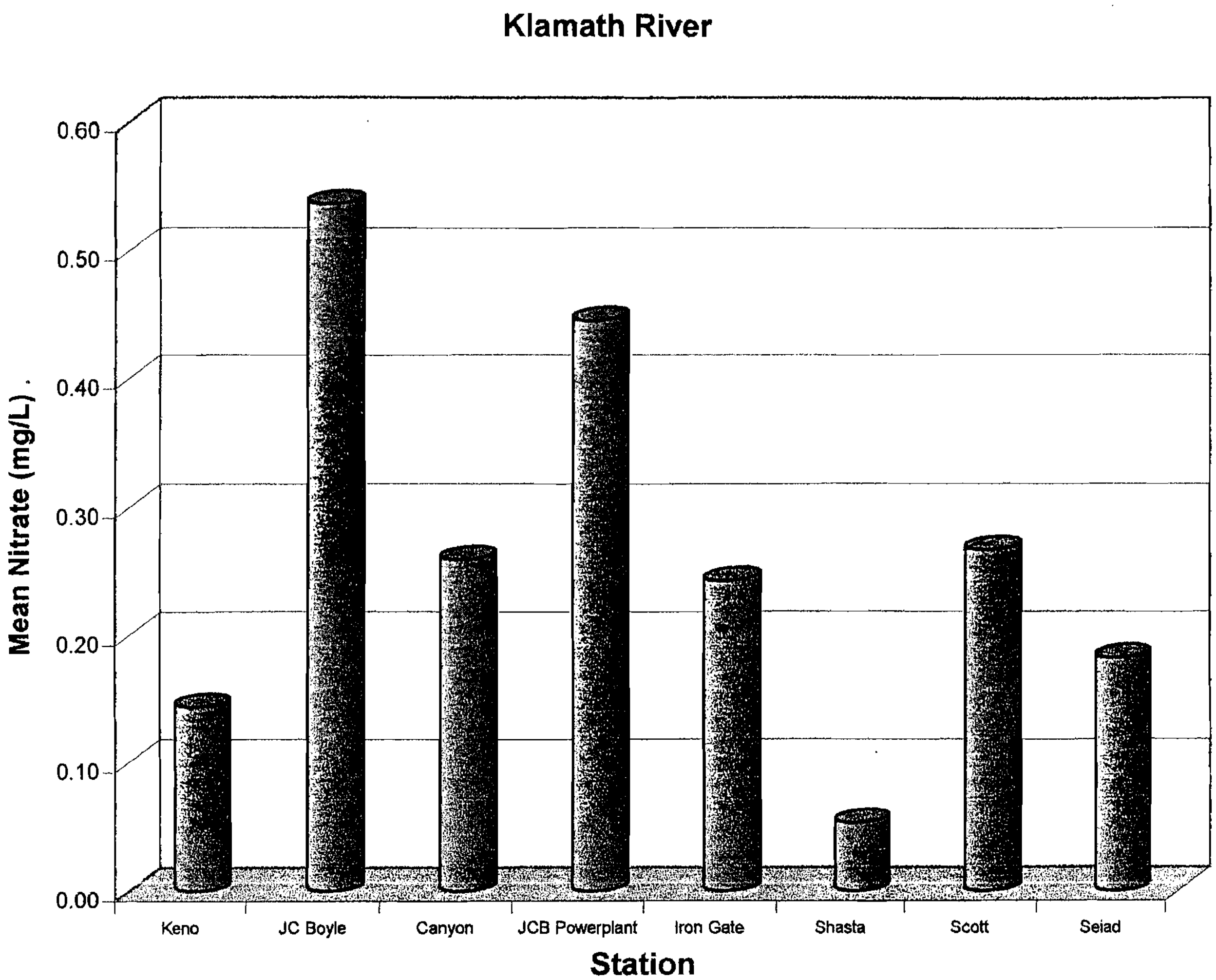

Figure 3.10 Mean nitrate concentration at eight locations in the Klamath River for the study period 1996-1998.

TON (Total organic nitrogen), as with ammonia, decreases from upstream to downstream in the Klamath study area (Figure 3.12). Combined sewer outflows typically contain 1-2 mg/L TON, while most streams are in the range of 0.2 - 0.8 mg/L (Maidment, 1992). At Keno, both the average and median were in the range for combined sewer outflows (Table 3.3). TON concentration exceeded 1.0 mg/L for 77% of sample dates at the Keno location.

Nitrate concentration in streams in the absence of sewage wastewater usually ranges from 0.1-0.5 mg/L (Maidment, 1992). Values in excess of 0.5 mg/L may indicate the presence of agricultural return flows containing fertilizers or animal waste deposition in the watershed. Organic wastes are oxidized to nitrate in the soil. Since nitrate is nearly always found in dissolved form, it is then easily carried to streams with runoff. Nitrate concentration at J.C. Boyle Powerplant exceeded 0.5 mg/L on 53% of sampling dates (Figure 3.10). Both the median and mean nitrate concentration exceed 0.5 mg/L, indicating possible point or nonpoint source pollution in the watershed (Table 3.3).

Figure 3.14 displays ammonia and nitrate concentrations at 3 locations in the Klamath River study area. Ammonia concentration at the Keno site was significantly greater than at Iron Gate ($p = 0.002$) or Seiad ($p = <0.001$) while nitrate concentration at Iron Gate was significantly greater than at Keno ($p= 0.030$). There may be unknown point or nonpoint sources of nitrate from sewage effluent, agricultural runoff, or animal wastes that enter the Klamath River between Keno and J.C. Boyle Powerplant, or reservoir cycling processes that were unquantified in this study. The nitrification process may be apparent in this shift from ammonia to nitrate trends seen between the upstream (Keno) and downstream (Iron Gate and Seiad) locations, although it is equally likely that other process are involved.

Most of the known agricultural return flows enter the Klamath River above Keno, Oregon. The longitudinal trend in both ammonia and TON seem to reflect the effect of agriculture on water quality in the Klamath River. The shift in nutrient speciation from ammonia and TON to nitrate is typical of nitrification occurring below point sources of nitrogen described by Maidment [1992]. Further support for the trend in nutrient speciation was found in correlations among total nitrogen, ammonia, and nitrate concentrations. At the Keno location, total nitrogen was strongly correlated with ammonia ($r=0.93$) during 1996-98. At Iron Gate, total nitrogen was more strongly correlated with nitrate ($r=0.73$) than with ammonia ($r=0.39$) during the study period.

Total and ortho-P concentrations for 3 sampling locations in the Klamath River study area are displayed in Figure 3.15. Ortho-phosphorus concentration can tend to remain constant over long reaches of rivers, unless photosynthesis is occurring or until point or nonpoint loading enters the stream (Maidment, 1992). In the Klamath River study, ortho-P remained relatively constant from Keno to Seiad, as the two sites were not

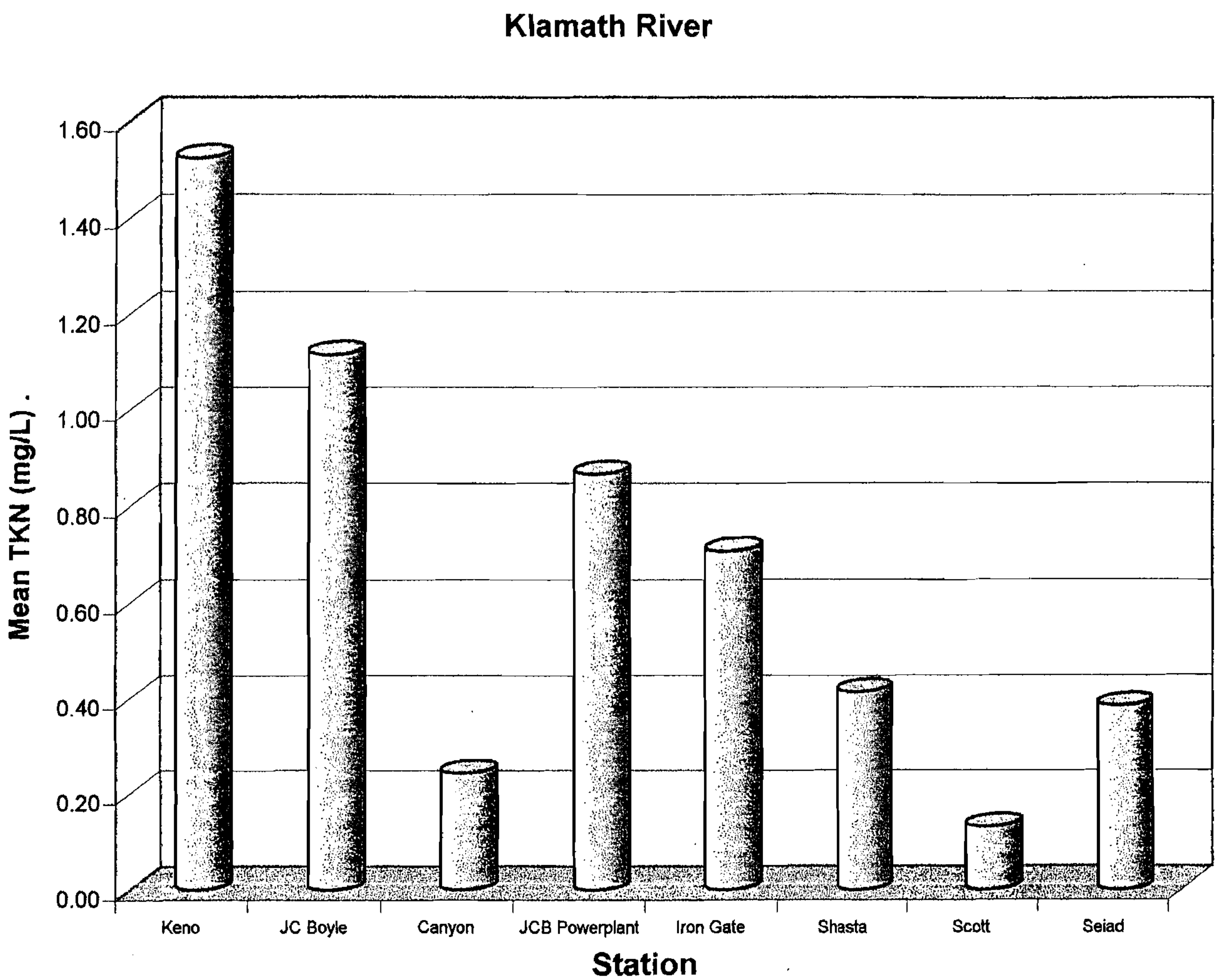

Figure 3.11 Mean total Kjeldahl nitrogen concentration at eight locations in the Klamath River for the study period 1996-1998.

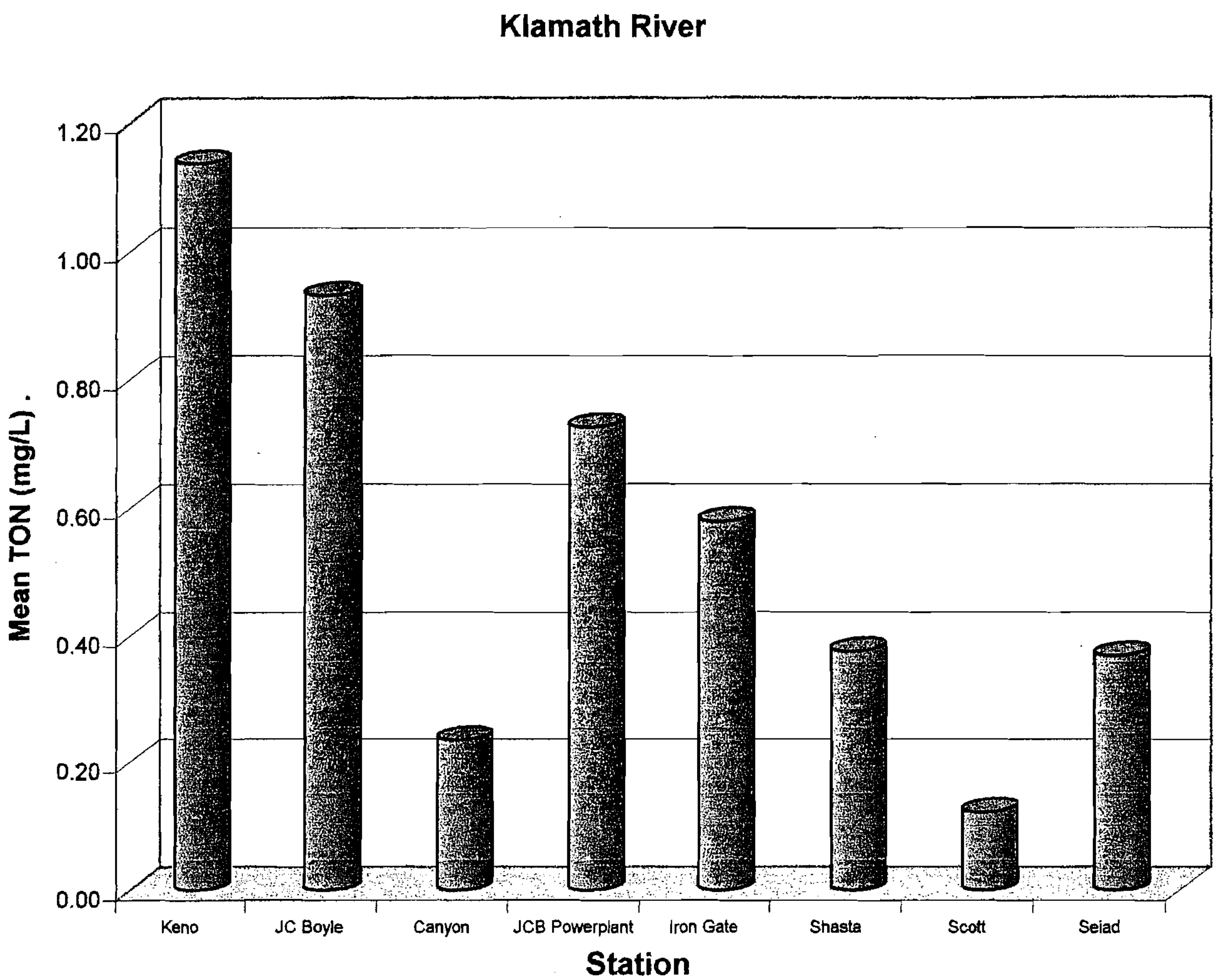

Figure 3.12 Mean total organic nitrogen concentration at eight locations in the Klamath River for the study period 1996-1998.

Klamath River

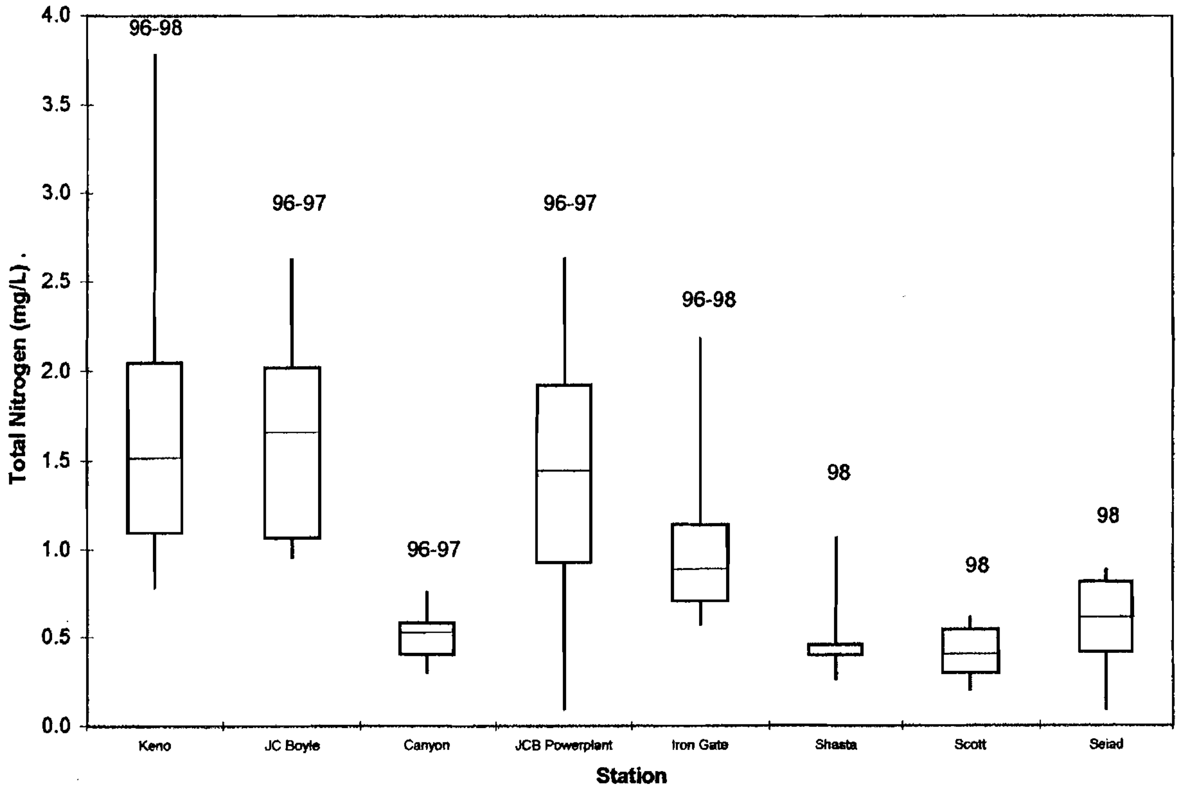

Figure 3.13 Simple box plot of total nitrogen concentration at eight locations in the Klamath River for the study period 1996-1998.

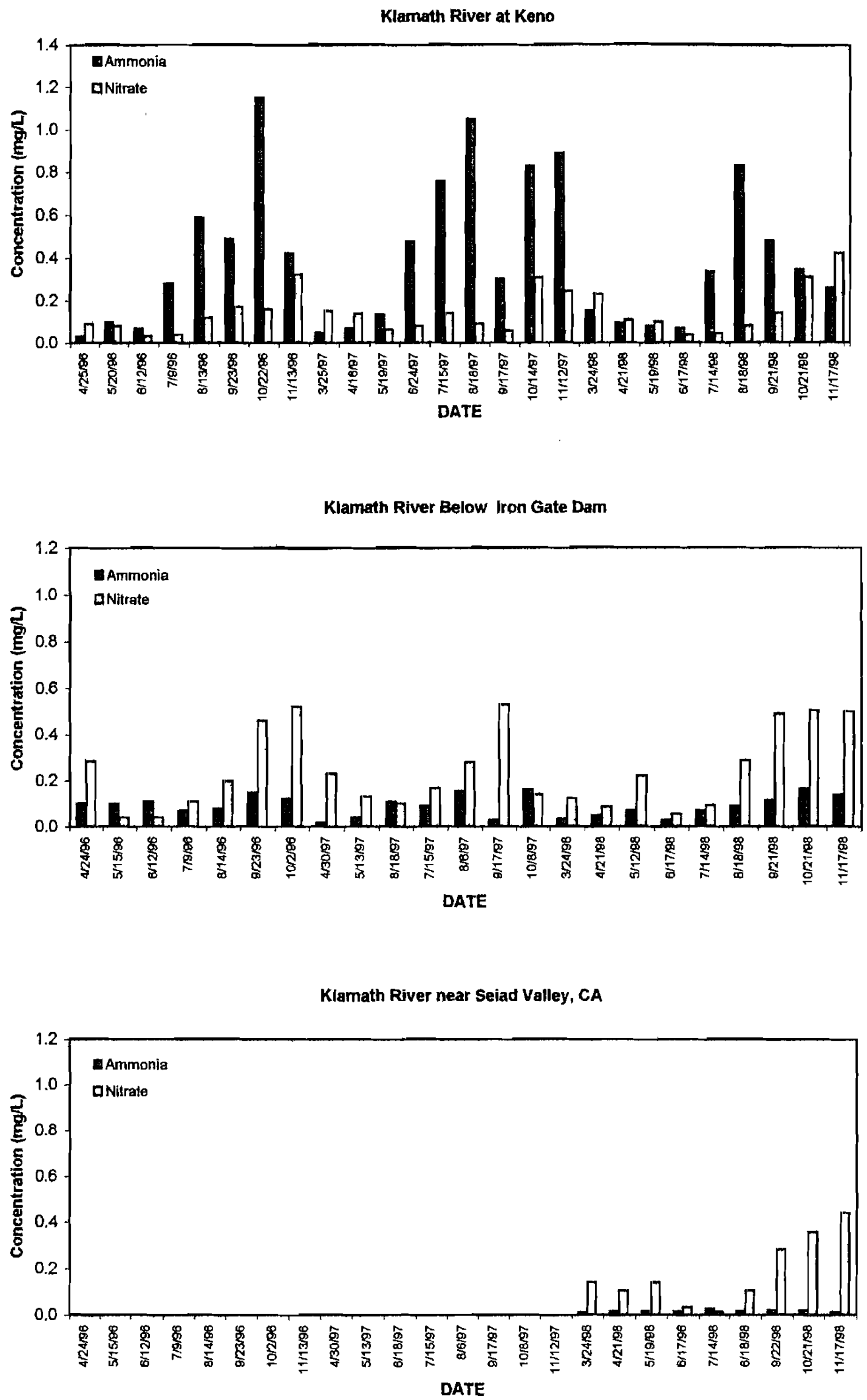

Figure 3.14 Ammonia and nitrate concentrations at 3 locations in the Klamath River for the study period 1996-1998.

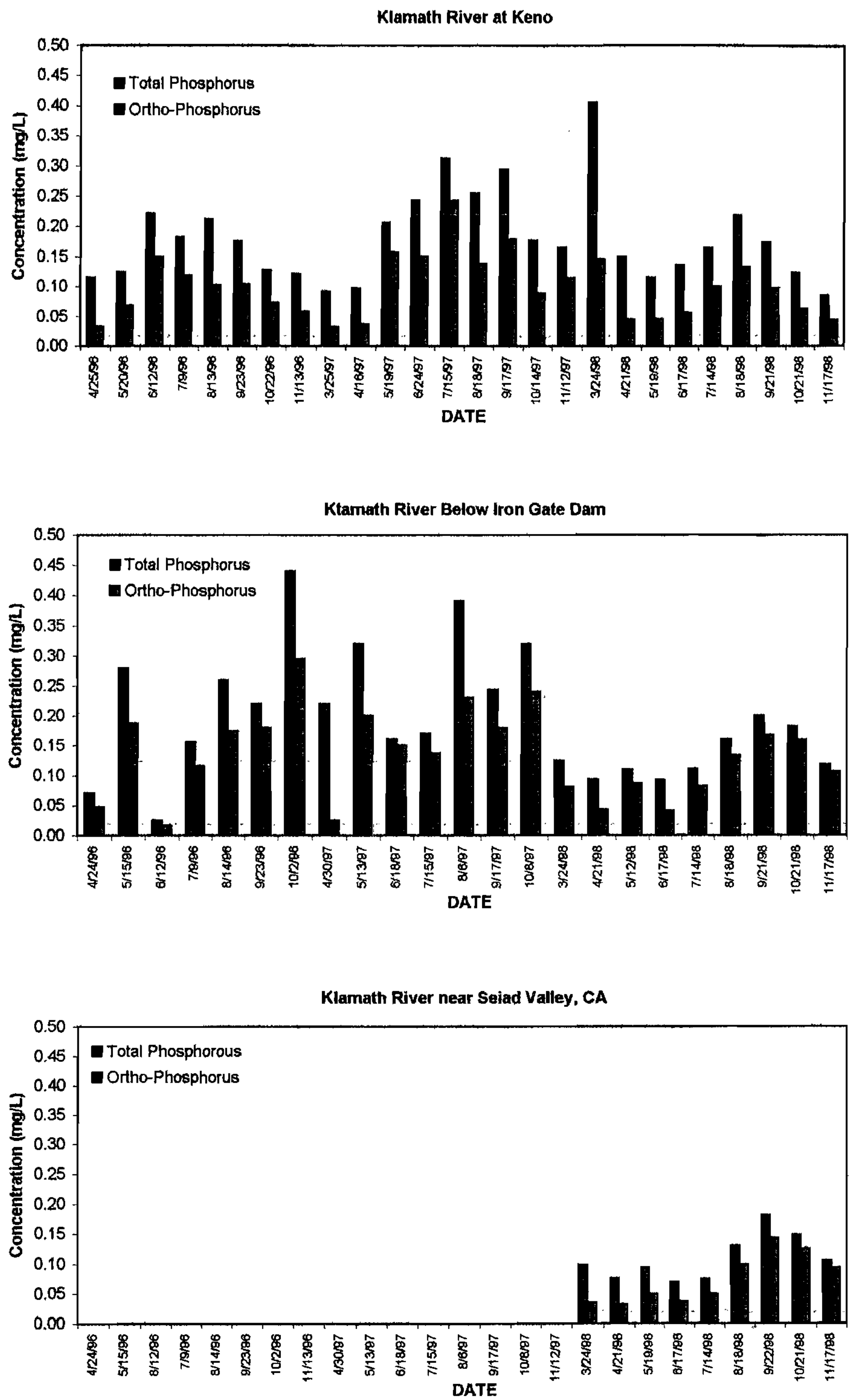

Figure 3.15 Total and ortho phosphorus concentrations at 3 locations in the Klamath River for the study period 1996-1998.

significantly different from one another (p=0.27). However, there was a significant difference between Total P concentrations from up to downstream. Keno Total P was significantly greater than at Seiad (p=0.007), however, Iron Gate Total P was not significantly different from Keno (p=0.60).

In many streams, there is a negative relationship between discharge and concentration, i.e., as discharge decreases, concentration of nutrient constituents increases. Generally, at Keno, nutrient concentrations and discharge (Q) followed this typical pattern and were negatively correlated, although the correlation was relatively weak. The strongest correlation between discharge and nutrient concentration at the Keno location was r = -0.59 for Total N and Q. This same typical pattern of correlation was also true at the Iron Gate and Seiad Valley locations, but the correlations were very weak at Iron Gate, the strongest being r = -0.45 between Ortho P and Q. In contrast, at the Seiad Valley location, the correlations were much stronger for all nutrient constituents except nitrate (r = -0.28), ranging from r = -0.50 for Total P to r = -0.66 for Ortho P, with values for other nitrogen constituents ranging from r = -0.56 to r = -0.60.

Some seasonality is usually apparent in determining water quality trends. It is often apparent that spring runoff with it's concomitant increase in flow influences water borne constituents. Seasonal trends in nutrient concentration were examined using Spearman correlations. The data were aggregated into 3 seasons; spring (March, April, May), summer (June, July, August), and fall (September, October, November). The "n" for each season was <10 in all cases, therefore the power of even the non-parametric procedures is weakened. During spring and fall at the Keno location, nutrient concentrations are not significantly correlated with discharge while in the summer a fairly strong, negative correlation was found. The highest correlation at Keno during the summer was r = -0.72 between Nitrate and Q. Because the Keno location is in close proximity to the intensively farmed areas at the upper boundary of the USGS study area, the lack of correlation between nutrients and discharge in spring and fall may be related to seasonal farming practices. Farmland tends have crops in the summer and be fallow or bare in early spring and late fall. The lack of correlation may also be related to the scatter in the data for the various seasons, with both high and low values for nutrient concentration in the data set resulting in little positive or negative correlation. However nutrient concentrations and discharge display a consistent, negative correlation that ranges from r = -0.67(Nitrate, summer) to r = -0.75 (TKN, spring) at the Iron Gate location.

<u>Nutrient Loading</u>

When reservoirs are in series, typically nutrient loading tends to decrease longitudinally because Total P is often bound to sediment particles. Impoundments allow sediment particles to settle, thus "trapping" sediment and allowing the reservoir to act as a nutrient sink, at least seasonally. However, sedimentation is not the only physical process that can reduce or increase phosphorus concentrations in reservoirs.

Reservoirs also stratify in summer. One of the basic properties of water is the density/temperature relationship. Water is densest at 4 °C and less dense both above and below that temperature. In the summer, reservoirs are compartmentalized into a freely mixing layer or epilimnion and a cooler layer below that called the hypolimnion. Because the two compartments or layers don't intermix to a significant degree, the hypolimnion becomes oxygen depleted (Wetzel, 1983). The reduction portion of chemical equilibrium reactions is favored during anoxic conditions. Phosphorus tends bind with iron compounds and when reduced, P is released from the complex. P then accumulates in the hypolimnion and fall turnover allows both "compartments" of a lake or reservoir to mix freely and P concentrations may increase.

Figure 3.16 displays total phosphorus loading at 3 locations within the study area. Note that data for the downstream boundary of the study area at Seiad was collected in 1998 only. The overall trend for Total P loading increases in the downstream direction. Thee also seems to be a seasonal effect with peaks occurring in both spring and fall in the downstream portions of the Klamath River study area below Iron Gate Dam and at Seiad. In the spring, Total P concentrations may be greater simply because there is a larger volume of water with spring run-off or more sediment entrained in flows entering the reservoir. The fall peak may be associated with turnover in the reservoirs above the sampling locations. It also seems apparent that total P loading tends to increase from upstream to downstream. Because loading includes flow volume, it is possible that an increase in flow from upstream to downstream is solely responsible for the increasing trend in Total P loading from upstream to downstream displayed in Fig. 3.16. However, the average difference in annual flow for 1996-98 between Keno and Iron Gate Dam is about 22% and the average difference in annual total P loading is about 60%. Total P loading below Iron Gate Dam is 1.5 times the Total P loading at Keno, while flow increases by 1/5 (Table 3.4). This is further evidence that point or non-point sources of phosphorus may be present in the watershed between the Keno and Iron Gate Dam locations or that unquantified in-reservoir processes are also affecting nutrient loading in the system.

The null hypothesis being tested in the Klamath River study is that there is no difference between upstream and downstream nutrient loading values. The alternative hypothesis is that nutrient loading either increases or decreases from upstream to downstream in the study area. To test the null hypothesis, a Wilcoxon rank sum test was performed on Total P loading data for Keno, Iron Gate and Seiad Klamath River locations. The non-parametric test was used because the data were non-normally distributed. The probability of the null hypothesis being accepted was $p = .005$ when Total P loading values at Keno are compared to those at Iron Gate, therefore at the alpha 0.5 level, the null hypothesis is rejected. The distribution of Total P loading values below Iron Gate Dam is shifted to the right (greater) than the Total P loading values at Keno. When Keno Total P values are compared to those at Seiad, the probability of accepting the null hypothesis is $p = .03$, therefore at the alpha 0.5 level, the null hypothesis is also rejected. The distribution of Total P values at Seiad, as at Iron Gate, is shifted to the right (greater) than the Total P loading values at Keno. The difference in Total P loading values from up to downstream is statistically significant and Total P generally increases in the downstream direction. Therefore, the reservoirs in series in the Klamath River study area are not sinks for phosphorus on an annual basis as might typically be expected. During the summer, when flows decrease and the reservoirs stratify, the reservoirs in series in the Klamath study area do appear to sequester Total P and act as a nutrient sink for phosphorus. The probability of accepting the null hypothesis is $p = .36$, therefore, the null hypothesis cannot be rejected and Total P loading values at Keno, Iron Gate and Seiad are not significantly different. It seems that during spring and fall the reservoirs act as sources of nutrient loading, possibly due to spring runoff and reservoir mixing in the fall and a sink for nutrients in summer when flows decrease and the reservoirs are thermally stratified.

Trends for Total N loading are similar to those for Total P (Fig. 3.17). There seem to be both spring and fall peaks in Total N loading from up to downstream in the Klamath study area. If the same null hypothesis testing is applied to Total N loading, the probability of accepting the null hypothesis is $p = 0.5$, the null hypothesis cannot be rejected and annual Total N loading values are not significantly different at Keno, Iron Gate and Seiad. There is a slight tendency for Total N loading to decrease in the downstream direction from Keno to Seiad (Table 3.4). The average annual Total N loading value for Keno is 1.86 kg/yr x 10^6, at Iron Gate average annual Total N is 1.7 kg/yr x 10^6, and at Seiad average Total N is 1.55 kg/yr x 10^6 . The reservoirs in series may act as a seasonal sink for Total N loading in the summer, however, this seems to be true only for the river reach between Keno and Iron Gate. The probability of accepting the null hypothesis is $p = .02$, the null hypothesis is rejected and the distribution of Total N loading is shifted to the left (increased) when Keno is compared to Iron Gate. Total N loading decreases significantly in the reservoirs between these two Klamath River locations during the summer.

The Klamath River is highly productive. Upper Klamath Lake is classified as hypereutrophic (USGS, 1998). N to P ratios were calculated for each season and compared using the ratio of 10 N: 1 P to determine nitrogen limitation (N/P ratio <10:1) or phosphorus limitation (N/P ratio >10:1) (Horne and Goldman, 1994).
Seasonal changes in N/P ratios are commonly seen when spring runoff or water column mixing events in reservoirs provide ample phosphorus for plant growth. P limitation changes to N limitation later in the summer and allows species of plants that can fix nitrogen from the atmosphere under usually warmer summertime conditions to be more competitive and dominate the algal assemblage. Since the reservoirs throughout the study area do exhibit blue-green algal dominance in summer, the change from P limitation to N limitation may be explained by the succession of algal communities within the reservoirs and immediately below the reservoirs in the mainstem Klamath River.

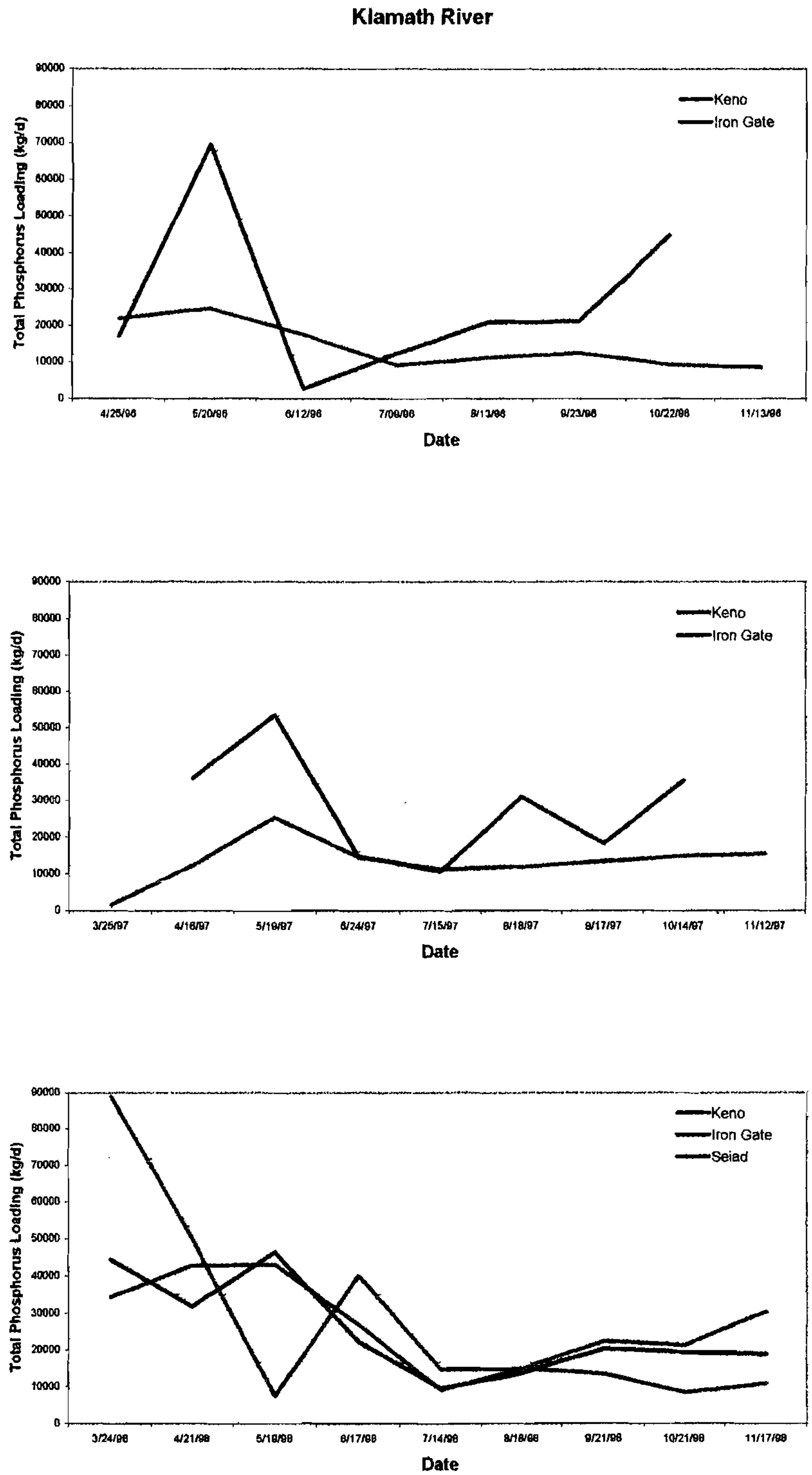

Figure 3.16 Total phosphorus loading estimates at 3 locations in the Klamath River for the study period 1996-1998.

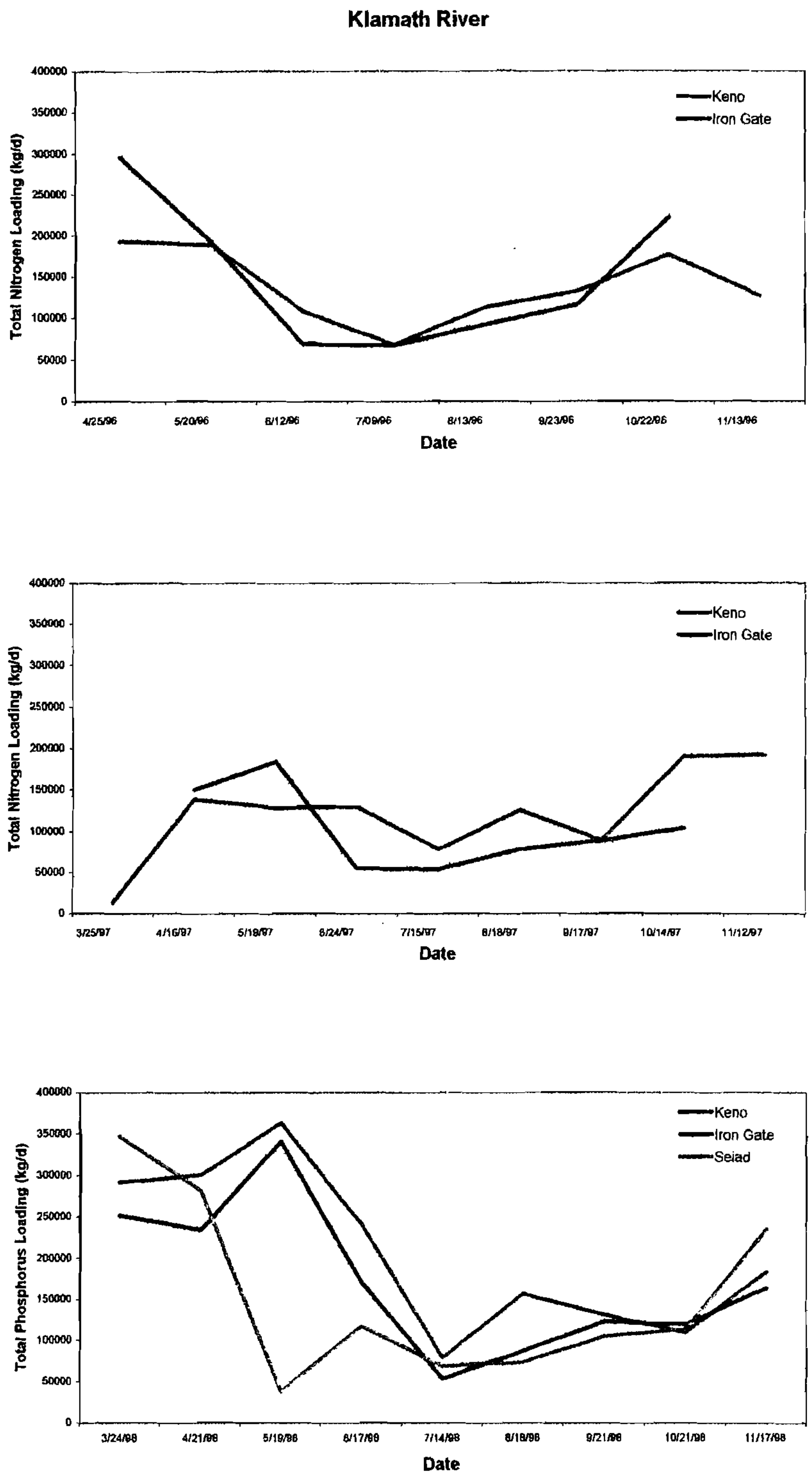

Figure 3.17 Total nitrogen loading estimates at 3 locations in the Klamath River for the study period 1996-1998.

Trends in N/P ratio are displayed in Figure 3.18. Some differences were noted both seasonally and spatially in the study area. For example, Keno was strongly P-limited in the fall and that trend was exhibited in all years of the study. Iron Gate was P-limited in the summer of 1996, but was not in any of the other two years of the study. In general, the Klamath River study area exhibited N-limitation. Because the Klamath River reservoirs are dominated by blue-green algal blooms in the late spring to early fall period, this result is not unexpected.

Table 3.4 compares the up-river site at Keno, OR and the down-river sites at Iron Gate Dam and Seiad, CA, to rivers in Oregon, Idaho, and Nevada to gain some idea of how the Klamath River compares to others in terms of both N and P loading. The three rivers that are most directly comparable in size to the Klamath River are the Truckee River, NV, the Long Tom River and South Yamhill River, OR. These rivers also have loading values based on "wet" hydrologic years, as is the case for the Klamath River during the study period. The annual Total P load for the Long Tom River, OR, and the Truckee River, NV. , in 1982, is very similar to the Klamath River loading values, but the mean annual discharge is substantially less. The South Yamhill River is most directly comparable to the Klamath River in terms of mean annual discharge, but P loading is only about 36% and N loading is approximately 44% of the 3-year average Iron Gate values.

The difficulty in doing direct comparisons of P- and N loading values from Table 3.4 led to performing a flow-normalized comparison. To normalize the flow, the discharge value for each river listed in Table 3.4 was divided by the mean of Iron Gate Dam discharge from 1996-98 and the loading values were divided by that ratio. The Keno site discharge and the Seiad site in 1998 were divided by the Iron Gate discharge for each year rather than by the average of the three years. The resulting loading comparison is displayed in Figures 3.19 and 3.20. As previously discussed, total P loading at Keno is still generally less than at Iron Gate Dam (Fig. 3.19). When flow is normalized, total N loading is much greater at Keno than at Iron Gate Dam (Fig. 3.20). When total P loading among rivers is compared, it becomes obvious that the Carson River, NV was also another phosphorus enriched river (Fig. 3.19). Comparing total N loading among rivers indicates that the Long Tom River, OR and the Truckee River, NV from 1973-87 are not as N depauperate as the Wood River, OR or lower portion of the Klamath River study area (Fig. 3.20).

Using the N/P ratio criterion (Horne and Goldman, 1994) where N/P <10 indicates nitrogen limitation and >10 indicates phosphorus limitation, the Truckee over a 15 year period (73-87), Long Tom, Snake and Wood Rivers were all phosphorus limited (Table 3.4, Fig 3.19). The Carson, South Yamhill, and the Klamath River at all 3 locations listed in Table 3.4 were all nitrogen limited (Fig. 3.20).

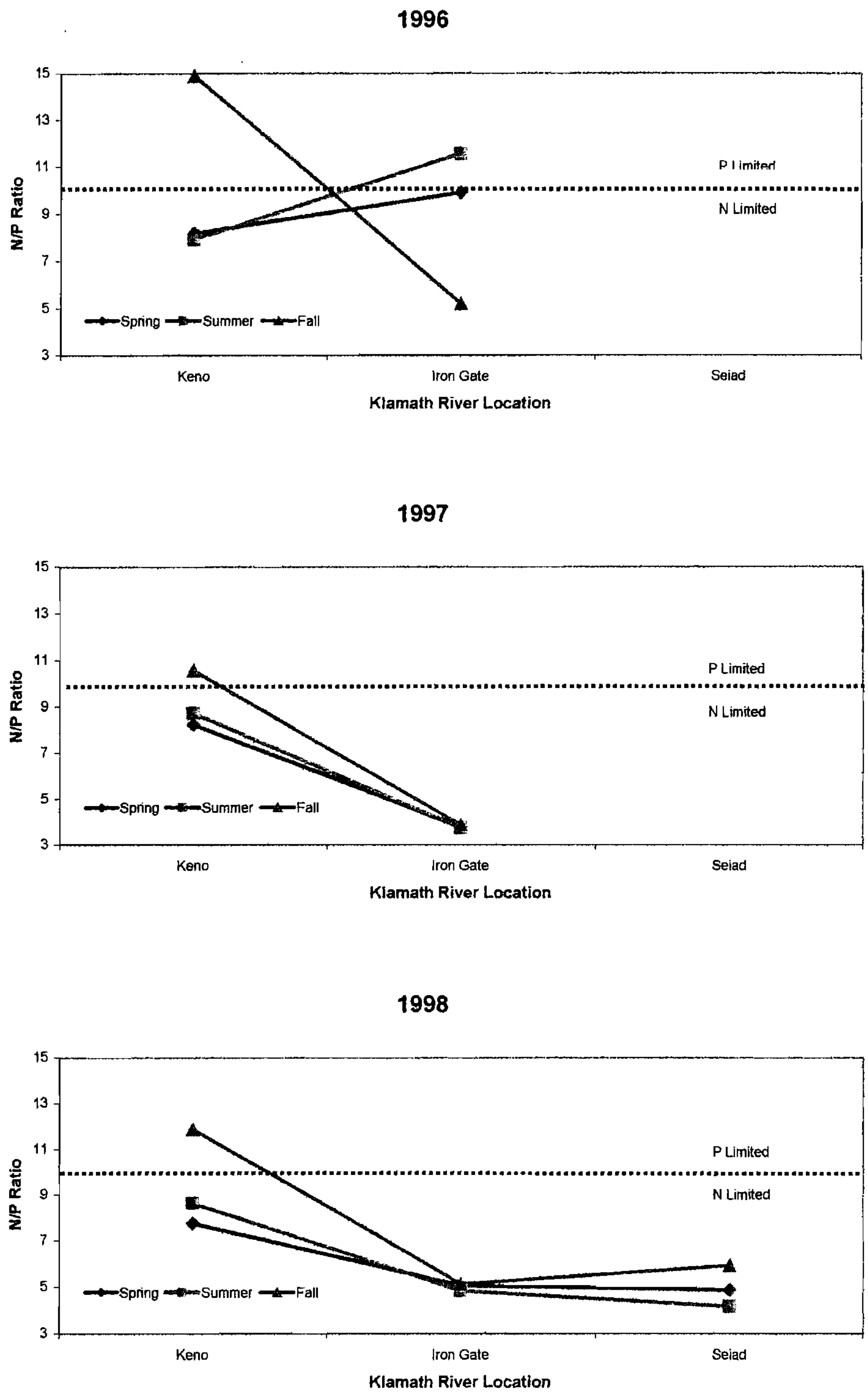

Figure 3.18 Nitrogen to phosphorus ratios at 3 locations in the Klamath River for the study period 1996-1998.

Table 3.4 - Nutrient loading comparison for the Klamath River study sites and selected rivers in geographical proximity.

Location	Year	Total P Load kg/y x10^5	Total N Load kg/y x10^6	Discharge cfs	Reference
Carson River, NV	1980	1.63	0.74	658	Garcia and Carman, 1985
Truckee River, NV	1973-87	0.96	1.04	735	Galat, 1990
	1982	2.97	1.57	1615	*ibid*
Long Tom River, OR	1982	2.36	2.54	1200	Bonn, *et. al.*, 1995
South Yamhill River, OR	1982	1.18	0.74	2348	*ibid*
Snake River, ID	1984	0.32	0.50	512	Clarke and Ott, 1996
Wood River, OR	1991	0.28	0.06	250	Campbell, *et. al.*, 1992
	1992	0.26	0.05	240	Campbell, *et. al.*, 1993
	1993	0.35	0.06	255	Campbell, unpub. data
Klamath River at Keno	1996	1.72	1.66	2110	
	1997	1.62	1.45	2028	
	1998	2.72	2.48	2432	
Klamath River at Iron Gate	1996	3.25	1.81	2824	
	1997	3.43	1.22	2738	
	1998	3.03	2.06	2907	
Klamath River at Seiad	1998	3.03	1.55	5692	

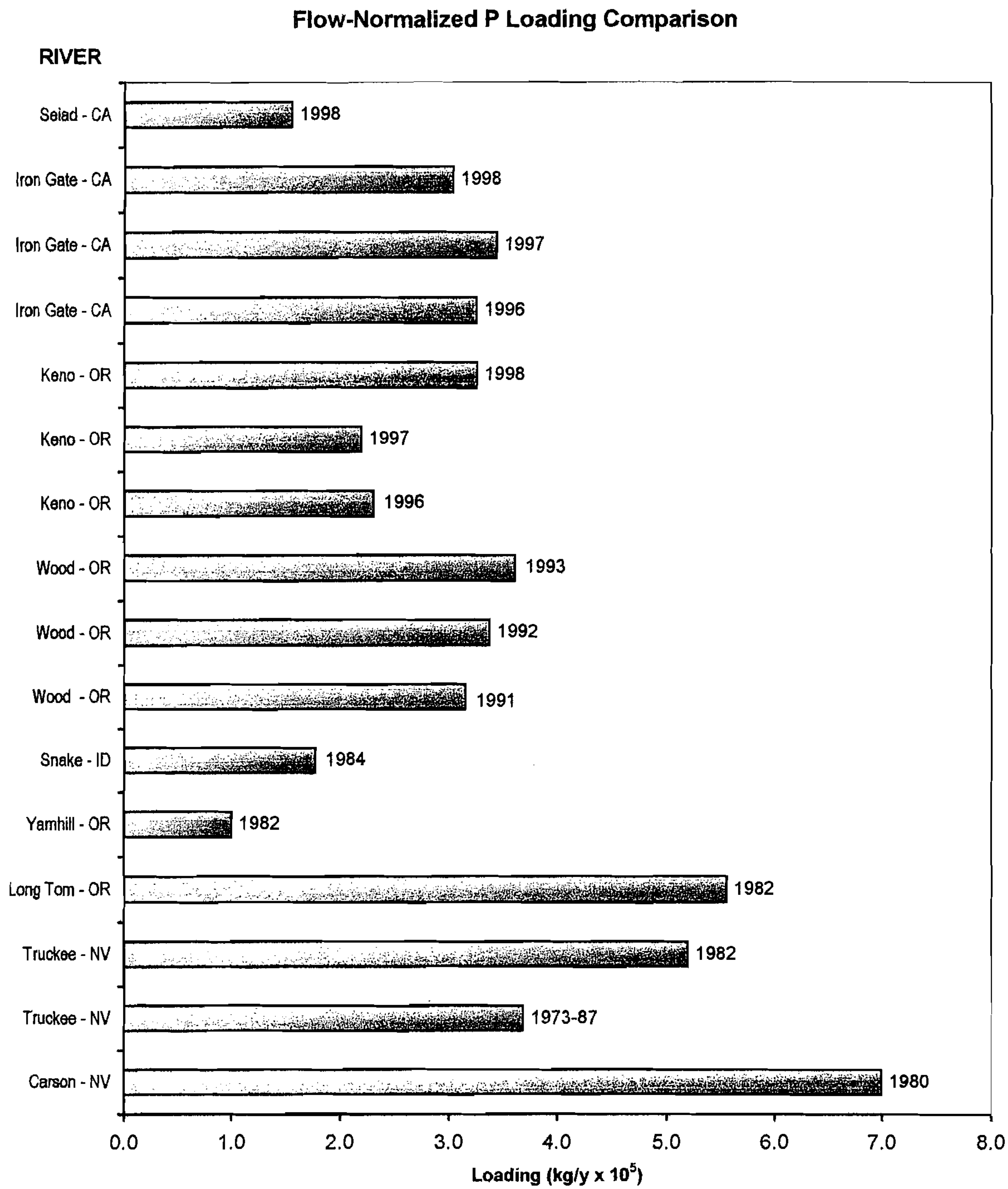

Figure 3.19 Phosphorus loading comparisons using flow normalized estimates for selected rivers in the north western United States.

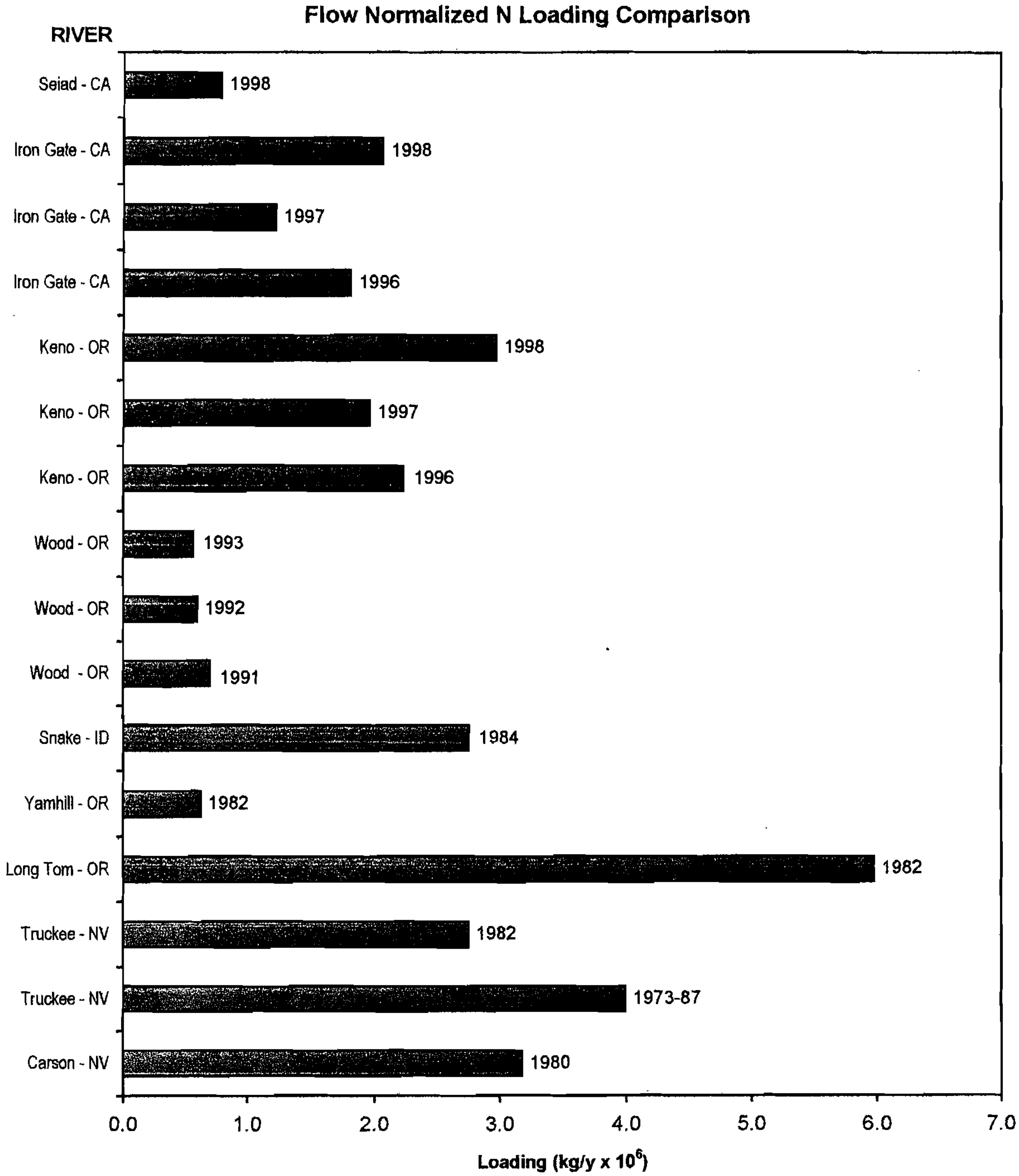

Figure 3.20 Nitrogen loading comparisons using flow normalized estimates for selected rivers in the north western United States.

CONCLUSIONS

Temperature

Water temperature conditions were unfavorable for the anadromous fish species of concern (chinook, coho and steelhead) during the summer months of the study period from 1996 through 1998. Chronic conditions (>16 °C) were exceeded from late May through the 3rd week in September of all years from 1996-98. The duration of chronic conditions ranged from 64 - 144 days, depending on Klamath River location and year. Conditions were a little cooler (1-2 °C) immediately below Iron Gate Dam, but other studies have confirmed that the cooling effect that may reduce temperature below chronic or acute thresholds does not persist downstream past the confluence of the Shasta River. Acute conditions (>22 °C) were exceeded for much shorter time periods than chronic temperature conditions. The duration of acute thermal conditions ranged from 3-52 days, again depending on the monitoring location and year. There were generally fewer days when acute temperature was exceeded below Iron Gate Dam in the mainstem Klamath River and other studies confirm that some cooling below the acute threshold does persist downstream to the lower boundary of the study area at Seiad Valley, CA.

Dissolved Oxygen

Dissolved oxygen concentrations were unfavorable for anadromous fish during summer months. Chronic conditions (<7 mg/L) were exceeded during the summer months through the reservoirs in series portion of the study area, particularly at Keno. Because the Keno monitoring location is in slack water, not within turbulent flow in the channel, DO was generally lower and there were wider diel differences in DO concentrations at this site. Acute conditions (<5.5 mg/L) were exceeded for in this same reservoir in series portion of the study area for varying lengths of time. The highest longest duration of acute DO conditions occurred at Keno and ranged from 83 - 135 days during the study period. Anadromous fish cannot pass Iron Gate Dam, therefore the relevant temperature and DO criteria are of concern for locations below this location. The values reported for the Keno site are relevant only because poor water quality conditions may persist further downstream and in some cases may even deteriorate further. In general, in the mainstem Klamath River below Iron Gate Dam, acute DO conditions do not occur except in slack water areas along the river margins or perhaps, in deep pools.

A management consideration in the Klamath is the potential for water quality to deteriorate as flow is increased through the system. Since no clean, cold water inflow of any appreciable size enters the Klamath River between Keno and Iron Gate Dam, increasing flow may actually cause further warming and DO impairment that would further adversely impact anadromous fish. For example, if temperature decreases by 1-2 °C between Keno and Iron Gate, will that same temperature decrease occur if flows are increased by 50% or more? If DO is generally 1-2 mg/L greater below Iron Gate

Dam, will that remain the case if flow is augmented? Characterization of water quality in the Klamath River will not answer these questions, but the modeling application being developed using the data collected during this study can do just that. The modeling application does not yield the duration of time for chronic or acute conditions because it generates daily average information. These two uses for a common data set are complimentary.

Nutrient Concentration

Total P concentration tended to remain constant through the reservoirs in series potion of the Klamath River study area and then decrease sharply in the mainstem below the reservoirs. Ortho P concentration actually increased through the reservoirs in series and then decreased below those reservoirs in the mainstem Klamath River. Ammonia, TKN, TN and TON concentrations exhibited a strong tendency to decrease in the downstream direction while nitrate concentration tended to increase from up- to downstream. Nitrification processes were apparent in a shift from ammonia and organic nitrogen species to nitrate downstream through the four reservoirs-in-series and the mainstem Klamath River downstream in the study area.

The trend in nutrient speciation was supported statistically by correlations among total nitrogen, ammonia and nitrate concentrations. At the Keno location total nitrogen was strongly correlated with ammonia, while at the Iron Gate location, total nitrogen was strongly correlated with nitrate. At the Keno location, ammonia exceeded 0.5 mg/L, a value that some researchers believe can cause significant toxicity to fish and other aquatic organisms on 54% of sample dates and total organic nitrogen was in the range of 1-2 mg/l which is characteristic of combined sewer outflows on 77% of sample dates. Nutrient concentrations were in general negatively correlated with discharge, but the correlation was much weaker in the downstream portion of the study are below the Klamath River reservoirs.

Nutrient Loading

There was a tendency toward spring and fall peaks in both phosphorus and nitrogen loading. The spring peak was apparently associated with higher flows during runoff. The fall peak may be associated with reservoir turnover that mixes hypolimnetic water enriched with phosphorus and/or nitrogen throughout the water column and increases concentrations for a period of time. There was a general increase in phosphorus loading longitudinally from the upstream location at Keno, OR as compared to the Klamath River below Iron Gate Dam. This increase in loading was not completely explained by increase in flow between the two sites and may indicate additional external loading sources entering between Keno and Iron Gate Dam or may be caused by internal nutrient cycling in the reservoirs. Because internal nutrient cycling in the reservoirs was not quantified, this phenomenon cannot be readily explained. However, the reservoirs-in-series do not seem to be functioning as a significant nutrient sink between the Keno, OR and Iron Gate Dam, CA locations in the Klamath River study area.

Nitrogen to phosphorus ratios indicate that although the study area was generally nitrogen limited, there seems to be a seasonal change from N limitation in spring and summer to P limitation in the fall at the Keno location. In comparing the Klamath River to other rivers in the northwestern U.S., the Carson and Truckee Rivers, NV, and the Long Tom River, OR also appear to be nutrient rich systems. The Truckee River, NV, Long Tom River, OR, Wood River, OR, and the Snake River, ID, appear to be P limited systems, while the Carson River, NV, South Yamhill River, OR, and the Klamath River appear to be N limited.

The management implications of this study indicate that improving the thermal regime or the DO concentration to benefit anadromous fish may be difficult. The reservoirs are shallow and have a relatively short detention time. The reservoir outlet is at or near the surface in the epilimnion where warming and algal growth are at maximum levels. Changing the reservoir outlet depth would be very expensive and may adversely impact water quality if hypolimnetic waters depauperate in DO, further nutrient enriched, or containing high concentrations of trace metals are discharged from low-level outlets.

Focusing management of the reservoirs and stream flow on certain limited time periods to benefit some species or life stages of anadromous fish may have some utility if performed consistently year after year. For example, if flows are increased in late May/early June of each year to foster rapid downstream movement of out-migrating salmonids, then thermal stress might be minimized enough to allow better survival rates. If cool water stores in Iron Gate Reservoir are depleted in late summer/early fall to improve the thermal regime in the Klamath River immediately below the Dam, perhaps some relief to over-summering species and life stages of salmonids could be provided. However, cool water stores in Iron Gate Dam currently provide water to the fish hatchery near Iron Gate operated by California Department of Fish and Game to mitigate loss of access to spawning habitat above the Dam. Some other mechanism for providing water of a suitable temperature to the hatchery would have to be developed and associated costs for installation, maintenance, and operation provided.

Decreases in nutrient loading may be possible through best management practices in the watershed to reduce sediment loading, re-establish riparian corridors along the river and tributaries, or change land use to reduce agriculture or pasturing in the Basin. These are probably worth implementing on a gradual or long-range basis to generally protect water resources in the Klamath Basin. However, the internal nutrient cycling component for plant growth in these reservoirs is unknown. There may already be enough nutrients stored in the sediment to continue algal growth for many years even if nutrient loading from the watershed is significantly decreased.

Anadromous fish stocks in the Klamath River may best be preserved by eliminating sport fishing in both the marine and fresh-water environments for an extended period, as well as implementing the various operational and watershed management strategies discussed above.

REFERENCES

Ambroggi, R.P. 1980. Water. Scientific American, Vol 243:91-104.

American Public Health Association. 1995. Standard Methods for the examination of water and wastewater. 19th Edition. Washington, DC.

Bartholow, J. 1998. SIAM - A System Impact Assessment Model for Riverine Ecosystems. Chronicle of Instream Flow Activities; USGS, Ft. Collins, CO. Vol 2(2) online at http://www.mesc.usgs.gov/rsm/ifim-chron/2-2Chronicle/siam.htm.

Belchik, M. 1996. Summer Locations and Salmonid Use of Cool Water Areas in the Klamath River - Iron Gate Dam to Seiad Creek, 1996. Prepared for the National Biological Service, Yurok Tribal Fisheries Program, Klamath, CA. 13 pp.

Bonn, B.A., S.R. Hinkle, D.A. Wentz, and M.A. Uhrich. 1995. Analysis of Nutrient and Ancillary Water-Quality Data for Surface and Ground Water of the Willamette Basin, Oregon, 1980-90. U.S. Geological Survey, Water Resources Investigations Report 95-4036. 88 pp.

Briassoulis, H. 1986. Integrated economic-environmental-policy modeling at the regional and multiregional level: Methodological characteristics and issues. Growth and Change. Vol. 17:22-34.

Caldwell, L.K. (ed.). 1988. *Perspectives on ecosystem management for the Great Lakes: A reader.* State University of New York Press, Albany. 365 pp.

California Department of Fish and Game. 1998. Klamath River Basin Fall Chinook Salmon Run-Size In-River Harvest and Spawner Escapement. California Department of Fish and Game\Region 1\Redding. December, 1998. 5 p.

Campbell, S. G., ed. 1993. Environmental Research in the Klamath Basin, Oregon. 1991 Annual Report. R-93-13. Bureau of Reclamation, Denver, CO. 214 pp.

Campbell, S. G., ed. 1993. Environmental Research in the Klamath Basin, Oregon. 1992 Annual Report. R-93-16. Bureau of Reclamation, Denver, CO. 341 pp.

Charbonneau, R., and G.M. Kondolf. 1993. Land Use Change in California, USA: Nonpoint Source Water Quality Impacts. Environmental Management. 17(4): 453-460.

Chapra, S.C. 1997. *Surface Water-Quality Modeling.* McGraw-Hill Companies, Inc. New York. 844 pp.

Clarke, G.M., and D.S. Ott. 1996. Springflow Effects on Chemical Loads in the Snake River, South-Central Idaho. *Water Resources Bulletin*. Vol. 32, No. 3. Pp. 553-563.

Cortner, H.J., and M.A. Moote. 1994. Trends and Issues in Land and Water Resources Management: Setting the Agenda for Change. Environmental Management. Vol. 18(2):167-173.

Dovers, S.R. and D.G. Day. 1988. Australian rivers and statute law. Environmental Planning and Law Journal, Vol. 5:90-108.

Edwards, C.J., and H.A. Regier (eds.). 1990. An ecosystem approach to the integrity of the Great Lakes in turbulent times. Great Lakes Fishery Commission Special Publication 90-4, Ann Arbor, Michigan. 299 pp.

Galat, D.L. 1990. Seasonal and Long-Term Trends in Truckee River Nutrient Concentrations and Loadings to Pyramid Lake, Nevada: A Terminal Saline Lake. *Water Resources*. Vol. 24, No. 8. Pp. 1031-1040.

Garcia, K.T., and R. L Carman. 1986. Water-Quality Characteristics and Nutrient and Suspended-Sediment Loads, Carson River and Truckee Canal, Western Nevada, Water Year 1980. U.S. Geological Survey. Water Resources Investigations Report 85-4147. 115 pp.

Hansson, L., and P. Angelstam. 1991. Landscape ecology as a theoretical basis for nature conservation. Landscape Ecology. Vol. 5(4):191-201.

Horne, A.J., and C.R. Goldman. 1994. *Limnology*, 2nd Edition. McGraw-Hill, Inc., New York. 576 pp.

Hydrolab, Corporation. 1984. Hydrolab Surveyor II Operating and Performance Manual. Hydrolab, Corp., Austin, TX. 100 pp.

Kessler, W.B., H. Salwasser, C.W. Cartwright, Jr., and J.A. Caplan. 1992. New perspectives for sustainable natural resources management. Ecological Applications, Vol. 2(3):29-31.

McCullough, D.A. 1999. A Review and Synthesis of Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon. USEPA, Region 10, Seattle, WA. EPA-910-R-99-10. 279 pp.

Maidment, D.R., ed. 1992. Handbook of Hydrology. McGraw-Hill, Inc., New York, NY.

Myers, C.F., J. Meek, S. Tuller, and A. Weinberg. 1985. Nonpoint sources of water pollution. Journal of Soil and Water Conservation. 40(1): 14-18.

National Biological Service. 1995. Compilation of Phase I Reports for the Klamath River Basin. Prepared for the Klamath River Basin Fisheries Task Force Technical Work Group. 330 pp.

National Research Council. 1992. Restoration of Aquatic Ecosystems. National Academy Press, Washington, D.C., 552 pp.

North Coast Regional Water Quality Control Board. 1994. Water Quality Control Plan for the North Coast Region. Santa Rosa, CA.

Odum, H.T. 1983. Systems ecology: An introduction. John Wiley, New York.

Oregon Department of Environmental Quality. 1995. 1992-1994 Water Quality Standards Review. Standards and Assessment Section, 811 6th Av., Portland, OR. June, 1995.

Pantulu, V.R. 1981. Role of environmental factors in internationally shared water resources. United Nations Inter-regional meeting of International River Organization, Dakar, Senegal, January 20-29, 1981.

Petak, W.J. 1980. Environmental planning and management: the need for an integrative perspective. Environmental Management. Vol. 4(4):287-296.

Risser, P.G. 1985. Toward a holistic management perspective. Bioscience. Vol. 35(7):414-418.

SAS Institute, Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute, Inc., Cary, NC. 1028 pp.

Slocombe, D.S. 1991. An annotated, multidisciplinary bibliography of ecosystem approaches. Cold Regions Research Centre, Wilfrid Laurier University & Commission on Environmental Strategy and Planning, IUCN, Sacramento, California. 58 pp.

Slocombe, D.S. 1993. Environmental Planning, Ecosystem Science, and Ecosystem Approaches for Integrating Environment and Development. Environmental Management. Vol. 17(3):289-303.

U.S. Bureau of Reclamation. 1987 Quality Assurance Plan - Soil and Water Quality Laboratory. Pacific Northwest Region, Boise, Idaho. 13 pp.

U.S. Environmental Protection Agency. 1983. Water Quality Monitoring Handbook. USEPA 312/46/5-82-003. 182 pp.

U.S. Environmental Protection Agency. 1986. Quality Criteria for Water - 1986. USEPA 440/5-86-001. 398 pp.

U.S. Environmental Protection Agency. 1992. Managing nonpoint source pollution. Office of Water, Washington, D.C.

U.S. Fish and Wildlife Service. 1997. Klamath River (Iron Gate Dam to Seiad Creek) Life State Periodicities for Chinook, Coho and Steelhead. Coastal California Fish and Wildlife Office, Arcata, CA. 54 pp.

U.S. Geological Survey. 1993. A Review of Possible Causes of Nutrient Enrichment and Decline of Endangered Sucker Populations in Upper Klamath Lake, Oregon. Water-Resources Investigations Report 93-4087. 24 pp.

U.S. Geological Survey. 1998. Upper Klamath Lake Basin Nutrient-Loading Study - Assessment of Historic Flows in the Williamson and Sprague Rivers. Water-Resources Investigations Report 98-4198. 22 pp.

Wetzel, R. G. 1983. *Limnology*, Second Edition. Saunders College Publishing, Harcourt Brace College Publishers, Orlando, FL. 767 pp.

Willamson, J.D., and J. S. Footte. 1998. FY98 Investigational Report: Diagnostic Evaluation of Moribund Juvenile Salmonids in the Trinity and Klamath Rivers (June - September 1998). U.S. Fish and Wildlife Service, California-Nevada Fish Health Center, Anderson, CA. December, 1998. 13 pp. + appendices.

William M. Keir Associates. 1991. Long Range Plan for the Klamath River Basin Conservation Area Fishery Restoration Plan. Prepared for the Klamath River Basin Fisheries Task Force.