APPENDIX B

Causes and Effects of Nutrient Conditions in the Upper Klamath River

CAUSES AND EFFECTS OF NUTRIENT CONDITIONS IN THE UPPER KLAMATH RIVER

Klamath Hydroelectric Project
(FERC Project No. 2082)

PacifiCorp
Portland, Oregon

November 2006

CONTENTS

ATTACHMENTS

1.0 EXECUTIVE SUMMARY

The purpose of this document is to summarize information on the causes and effects of nutrient conditions in the upper Klamath River in the vicinity of the Klamath Hydroelectric Project (Project). The information in this document focuses in particular on the likely effect of the Project on nutrient loads in the river – loads known to be very large as a result of releases from hypereutrophic (highly enriched) Upper Klamath Lake, the principal source of flows to the upper Klamath River.

The Klamath River system is complex and unique, particularly because water quality generally improves as water flows from its source at Upper Klamath Lake towards the estuary. In most river systems, water quality is highest at the source and degrades as water flows downstream. Upper Klamath Lake is a substantial source of both phosphorus and nitrogen to the Klamath River, particularly during the months June through October.

Owing to its hypereutrophic state, Upper Klamath Lake has been the subject of scientific investigation dating back to the 1950s. Concerns about the quality of water in the Upper Klamath Lake date back to the earliest recorded contacts with the lake. Although the lake has probably been naturally enriched with nutrients (eutrophic) since before settlement of the basin by non-Native Americans, it has apparently changed substantially over the past several decades concurrent with dramatic changes in the basin as a result of agricultural modifications, and diking and draining of large areas of marsh surrounding the lake.

High algal productivity in Upper Klamath Lake has been accompanied by violations of Oregon's water quality standards for dissolved oxygen, pH, and free ammonia. In May of 2002, ODEQ established a total maximum daily load (TMDL) for the Upper Klamath Lake drainage to define "the maximum amount of pollution [from all sources] that a water body can receive without violating water quality standards". To address the high productivity issue, the TMDL called for a 40 percent reduction of total phosphorous loading to Upper Klamath Lake.

In 2004, the National Research Council's Committee on Endangered and Threatened Fishes in the Klamath River Basin issued a report concluding that even if the TMDL's targeted 40 percent reduction in external phosphorus loading could be achieved, it would "probably be ineffectual without suppression of internal phosphorus loadings, given that internal phosphorus loading is very large for Upper Klamath Lake" and that "available evidence indicated that … internal loading appeared sufficient to maintain algal populations".

In March 2004, PacifiCorp submitted a Final License Application (FLA) to the Federal Energy Regulatory Commission for relicensing of the Klamath Hydroelectric Project. In March 2006, PacifiCorp submitted applications for Section 401 water quality certification to ODEQ for the Oregon portion of the Project and the State Water Resources Control Board (SWRCB) for the California portion of the Project. Based on these previously-reported analyses, PacifiCorp concluded that the Project does not contribute to excess concentration of nutrients in the Klamath River. The abundance of chlorophyll *a*, and the growth of phytoplankton are a natural consequence of the occurrence of excess nutrients from upstream sources, notably Upper Klamath Lake. Nevertheless, PacifiCorp proposed Reservoir Management Plans to help address primary production in Project reservoirs resulting from nutrient loading from upstream sources. The Reservoir Management Plans will have the effect of reducing algae growth and thus reducing chlorophyll concentrations within the reservoirs, as well as benefiting water quality in general.

In July 2005, Kann and Asarian (2005) issued a report of their analysis of 2002 nutrient loading to Copco and Iron Gate reservoirs. They concluded that the “reservoirs can act as a nutrient source during critical periods” and that their analysis does not support PacifiCorp’s conclusion that the reservoirs benefit water quality by processing organic matter and nutrients from upstream sources. Subsequently, in July 2006, Asarian and Kann (2006) issued a report of their analysis of nitrogen loading and retention in Copco and Iron Gate reservoirs and for the river reaches below Iron Gate dam. On the basis of this analysis, Asarian and Kann (2006) concluded that “the river consistently provides moderate positive retention, while the combined retention of Iron Gate and Copco reservoirs alternates between positive and negative values”, and further concluded that “the reservoir effect on retention was minimal (4.6% of incoming load) or even negative (-3.3% of incoming load) for the periods evaluated.”

As discussed in this document, the Kann and Asarian (2005) and Asarian and Kann (2006) analyses have substantial flaws. Notwithstanding these flaws, Kann and Asarian’s (2005) analysis itself clearly shows that Copco and Iron Gate reservoirs act as net sinks for P and N over the longer term – the same basic conclusion reached by PacifiCorp as noted above. Despite the wording of their stated conclusion to the contrary, this net retention of nutrients indicates that the reservoirs help to store and process the very large amounts of organic matter and nutrients from upstream sources. In addition, contrary to Asarian and Kann’s (2006) stated conclusions, the analyses described below in this document indicate that Iron Gate and Copco reservoirs consistently provide net positive retention, while the river reaches do not.

The very large loads of algae biomass that are discharged to the upper Klamath River from Upper Klamath Lake, particularly during summer, diminish in consistent fashion with distance from Keno reservoir through the Project area reservoirs and river reaches downstream to near the mouth of the Shasta River. The decomposition of these very large algae loads during downriver transit is not only a large potential source of nitrogen (via mineralization) but also of biochemical oxygen demand (BOD) imposed on the water’s dissolved oxygen (DO) content.

Research has shown that mineralization of inorganic nitrogen and short-term oxygen demand from blue-green and other algae decay approximately follows a first-order decay rate. As such, decay is quite rapid during the initial stages of the decomposition process (e.g., about ¾ of the oxygen demand present would on average be expended within about 10 days). The analyses described below in this document indicate that, under existing conditions, the processing of the loads to the upper Klamath River of upstream organic matter is largely completed by the time water travels past Iron Gate dam.

By contrast, under hypothetical without-Project conditions, about 50 percent or more of the load of upstream organic matter would still be present as water travels past Iron Gate dam. This indicates that, in the absence of Project reservoirs, a substantial amount of organic matter would remain available throughout the lower Klamath River downstream of Iron Gate dam, acting as a source of inorganic nitrogen, phosphorus, and BOD from ongoing decay. This substantial remaining organic matter would exacerbate water quality impairment in the river downstream of

Iron Gate dam to the estuary by increasing BOD, reducing DO, and further promoting growth of benthic algae (periphyton).

As described in this document, the total annual net retention of nutrients by Copco and Iron Gate reservoirs is substantial, particularly when both reservoirs are considered in combination. The observed concentrations of total inorganic nitrogen (TIN) and total nitrogen (TN) in particular are consistently lower in water released from Iron Gate reservoir than in the water entering Copco reservoir. These observations support the conclusion that Iron Gate and Copco reservoirs act as a net sink for both total nitrogen and total phosphorous over the long term (i.e., on a seasonal or annual basis).

Overall, the monthly nitrogen retention values summarized in this document indicate that the reservoirs acted to retain a significant percentage of inflowing TN (21 percent) and TIN (42 percent) over the entire evaluation period of March-November 2002. This generally corresponds to previous conclusions from PacifiCorp's FLA analysis. Given the large inflowing nitrogen load of nearly 600 metric tons to Copco reservoir over the entire evaluation period of March-November 2002, the substantial net retention provided by Copco and Iron Gate reservoir is an important process for reducing downstream loads to the Klamath River below Iron Gate dam.

It is important to note that the effect of Copco and Iron Gate reservoirs on upstream-downstream nutrient flux does not occur instantly, but rather over several days or weeks due to both the duration of the upstream conditions and the extended residence time of the reservoirs. Evidence of this lag effect is examined in this document. Because of this lag, it is expected that at times the nutrient concentration in release waters from Iron Gate reservoir on a given day may be greater than in the inflowing waters to Copco reservoir on the same day, even though the reservoirs act to retain and reduce the loads from these nutrient "events" as they move through the reservoirs. This lag effect was not recognized and accounted for in the analyses of Kann and Asarian (2005) and Asarian and Kann (2006).

2.0 INTRODUCTION

The purpose of this document is to summarize information on the causes and effects of nutrient conditions in the upper Klamath River in the vicinity of the Klamath Hydroelectric Project (Project). The information in this document focuses in particular on the likely effect of the Project on nutrient loads in the river – loads known to be very large as a result of releases from hypereutrophic (highly enriched) Upper Klamath Lake, the principal source of flows to the upper Klamath River.

PacifiCorp has prepared this document in part to respond to reports recently prepared by Kann and Asarian (2005) and Asarian and Kann (2006), in which the effects of Project reservoirs on nutrients are inaccurately characterized. As explained in this document, the Kann and Asarian (2005) and Asarian and Kann (2006) reports use a flawed analysis leading to inaccurate conclusions that: (1) the Project reservoirs are a "nutrient source during critical times for growth or algae and macrophytes" (Kann and Asarian 2005); and (2) that river reaches in the absence of Project reservoirs would provide a comparable or even greater level of nutrient retention as the reservoirs now provide (Asarian and Kann 2006).

PacifiCorp also has prepared this document in part to provide information in response to the FERC Draft Environmental Impact Statement (DEIS) on the Project issued September 25, 2006. In particular, an important assumption made by FERC Staff in the DEIS is that the Project reservoirs cause an increase in nutrients, leading to an increase in periphyton in the river downstream (*Cladaphora*) which in turn provides an increase in habitat for the polychaete host for the fish disease *Ceratomyxa shasta*. As explained in this document, the Project reservoirs help to process the high nutrient loads coming in upstream of the Project, and the potential for increases in periphyton (*Cladaphora*) would be appreciably greater in the absence of Project reservoirs.

The document proceeds in the next section with a discussion of the background of nutrient issues in the upper Klamath River. This background context is essential given that water quality in the upper Klamath River in the vicinity of the Project is driven by the very large amount of nutrients and algae entering the river from hypereutrophic Upper Klamath Lake. The next section describes what empirical nutrient data indicates about nutrient changes in reservoir and river reaches in the upper Klamath River, particularly in the Project area. Subsequent sections of this document present analyses that illustrate the processing of organic matter and retention of nitrogen (the key limiting nutrient) in the Project area, including under both existing conditions and a hypothetical without-Project scenario. The final section of this document summarizes key conclusions from the information presented.

3.0 BACKGROUND ON NUTRIENT ISSUES

3.1 UPPER KLAMATH LAKE AND ITS INPUT TO THE UPPER KLAMATH BASIN – A LONG HISTORY OF NUTRIENT ENRICHMENT AND WATER QUALITY IMPAIRMENT

Water quality in the upper Klamath River in the vicinity of the Klamath Hydroelectric Project is strongly influenced by the abundance of nutrients (particularly nitrogen and phosphorous), organic matter, and algae entering the river from Upper Klamath Lake. Upper Klamath Lake is a large (121 mi^2), shallow (mean depth about 8 feet) lake that is geologically old and classified as hypereutrophic (highly enriched with nutrients and supporting high abundance of suspended algae) (Johnson et al. 1985).

Concerns about the quality of water in the Upper Klamath Lake date back to the earliest recorded contacts with that body of water. Bortleson and Fretwell (1993) suggest that the lake has probably been naturally enriched with nutrients (eutrophic) since before settlement of the basin by non-Native Americans. A paleolimnological study by Eilers et al. (2001) revealed that Upper Klamath Lake has been a very productive lake, with high nutrient concentrations and blue-green algae, for at least the period of record represented by the study (about 1,000 years). However, recent lake sediments showed that the water quality of Upper Klamath Lake has apparently changed substantially over the past several decades. The most dramatic changes in the basin during the 20th century were the result of agricultural modifications. Since the 1930's, large areas of marsh surrounding the lake have been diked, ditched, and drained for agricultural use, leading to the decomposition of organic soils. Riparian vegetation has been degraded or completely eliminated.

Owing to its hypereutrophic state, Upper Klamath Lake has been the subject of scientific investigation dating back to the 1950s. A detailed history of scientific investigations of water quality in Upper Klamath Lake is provided by Wee and Herrick (2005). Wee and Herrick state that despite these investigations, no viable solutions to remedy the lake's hypereutrophic condition have been identified by these studies.

The following is a brief summary of the long history of the nutrient enrichment and water quality impairment in Upper Klamath Lake and the input to the Klamath River. See Attachment A for more detail.

3.1.1 <u>Early Observations and Studies</u>

The earliest recorded statement regarding Upper Klamath Lake's water quality was made on August 14, 1855 by Lieutenant Henry L. Abbot, who led an exploration party that surveyed a line for a proposed railroad running north from the Sacramento River to the Columbia River. Lt. Abbot commented upon the "dark color" and "disagreeable taste" of the waters of Klamath Lake, attributing these characteristics to decaying tule growth. Abbott's party spent a few days at the lake and camped in the vicinity of Cove Point. He reported that his party had difficulty drinking water from the lake: "The taste of the water was so disagreeable that several vain attempts were made to discover a spring in the vicinity."

The "impurities" of Upper Klamath Lake's water became the focus of a 1905 controversy in Klamath Falls regarding possible "disease laden ice." One Klamath Falls citizen commented "there is no pure ice in Klamath county … the waters of the lake are not fit to drink …" while another held that "the ice on the Upper [Klamath] Lake runs a chance of being infected with the flotsam and jetsam of that great body of water. A great many fish of the sucker species die and float into the waters of the lake, which give a chance for impurity…"

The first report of the bloom-forming blue-green algae species *Aphanizomenon flos-aquae* in Upper Klamath Lake was made by Ethel Ida Sanborn of Oregon State College in the summer of 1933. Sanborn found other algal varieties as well, including the additional blue-green forms *Anabaena* and *Microcystis*; diatoms *Melosira* and *Navicula*; and the green algae *Pediastrum*. In the late 1930s, researchers from the Department of Entomology at Oregon State College, D. E. Bonnell and D. C. Mote, found *Aphanizomenon flos-aquae* to be "abundant," but not always the predominant form of algae. They reported that the vast masses of suspended blue-green algae were "filamentous in form (*Aphanizomenon*) and during the summer so dense as to give the water only a quasi-liquid appearance". By 1957, *Aphanizomenon* populations had reached levels ten times those recorded by Bonnell and Mote less than two decades earlier.

3.1.2 The 1950s: Beginning of Scientific Studies

By the 1950s, recurring blooms of algae in the Upper Klamath Basin had become a matter of greater concern for Klamath County residents, particularly to the increasing number of residents with property riparian to the waterways of the basin. Fish and wildlife kills within the basin had increased in frequency. Dead waterfowl were found in the Link River during several successive springs. Fish kills reported in the Klamath River near Keno in 1928, 1938, 1944, 1950, and 1951 also caused apprehension regarding the state of the watershed. The Oregon State Game Commission's Fishery Division attributed the 1950 and 1951 fish kills on the Klamath River to a lack of dissolved oxygen.

In 1953, the Oregon State Game Commission undertook a study to learn about the causes and development of the lake's algal blooms, and their effects upon water quality in the upper Klamath River. The 1953 study found that the algal bloom for that year, composed almost entirely of *Aphanizomenon flos-aquae*, began to appear "in appreciable concentrations in late May and started to decline in October." The decomposition of this mass of organic material reduced the dissolved oxygen content of the Klamath River at Keno to a minimum of 0.4 parts per million (ppm), far below the minimum to sustain fish life. In order for dissolved oxygen to be depleted to such low levels, the researchers estimated that the Klamath River would have to contain a level of pollution equal to the raw sewage produced by a population of more than 240,000 persons. Since an inventory of the sewage and industrial wastes of the area indicated a total population equivalent to only 14,200 persons, researchers concluded that about 94 per cent of the biochemical oxygen demand is derived from "natural causes".

Starting in 1955, Dr. Harry Phinney of Oregon State College conducted a three-year study of algae in Upper Klamath Lake. In a summary of his findings submitted to the supporting agencies in about 1959, Phinney stated that the "organisms responsible for the nuisance condition in Klamath Lake are all members of the blue-green algal group (*Cyanophyta*)," although other species of algae were found in the lake. Phinney attempted to explain the presence of high levels of algae blooms in the lake. He observed that the shallow configuration of Upper Klamath Lake provides not only for rapid decomposition of dead organic material, but also puts the lake into almost constant circulation. Therefore, recirculation of the nutrients released through decomposition "is essentially immediate," making the nutrients quickly available to organisms at the surface as well as the bottom of the lake.

3.1.3 The 1960s through 1980s: Federal and State Government Investigations

Fish kills continued during the 1960s, most notably in the Klamath River Straits and in Lake Ewauna during 1966 and 1968, respectively. Oregon State Game Commission fish biologists attributed both of these fish kills to a lack of dissolved oxygen. These fish kills helped keep Klamath Basin water quality issues at the forefront of the minds of residents and government officials alike. Several studies were conducted in the 1960s regarding Klamath Basin water quality in general and algae in particular. Despite these efforts, however, researchers appeared no closer to a solution to the algae problem than when Phinney conducted his investigations in the 1950s.

By the mid-1970s, frustration on the part of Klamath County citizens became more evident as scientific study after scientific study was completed but none had found a viable solution to the algae problems of Upper Klamath Lake. In 1977, the U. S. Congress authorized that the Army Corps of Engineers (Corps) undertake a study to "review the existing situation in the Klamath River Basin, Oregon, with the purpose of determining whether modifications to existing policies regarding the development, management, conservation, and environmental enhancement of water, land, and related reservoirs are presently advisable". The Corps released a preliminary "Reconnaissance Report" regarding the Klamath River Basin in Oregon in September 1979. This "Reconnaissance Report" reviewed and briefly related the findings of previous studies; identified the problems to be addressed by further study; provided potential solutions and alternative plans in response to the problems; and established planning objectives and a course of action for the remainder of the study. The Corps stated that review of previous studies and visual observations of the lake "has shown the problems to be obvious" and "the lake is hyper-eutrophic with extremely dense blue-green algal blooms, abundant midge flies and encroaching macrophytes". Additionally, the Corps found "the causes of the problems" to be "equally obvious":

> "High nutrient loadings and associated sedimentation of organic matter have produced an ideal habitat for the abundant growth of algae, benthic animals, and macrophytes. If no restorative action is taken, it is reasonable to expect continued sedimentation, high algal densities and encroachment of macrophytes."

In 1982, the Corps produced a second report that described research methods and data collection in Upper Klamath Lake, including water quality monitoring of major tributaries to Upper Klamath Lake; the collection of benthic invertebrates and adult midges; examination of the composition, nutrient, and metal profiles of lake sediment cores; and analysis of nutrients released from the lake's bottom sediments. After examination of this data in light of the potential restoration methods suggested in the "Reconnaissance Report," the Corps concluded that "… the feasibility of full-scale phosphorus limitation in the lake is highly questionable":

> "The lake receives high external loading as well as internal cycling from shallow nutrient-rich bottom sediments due to frequent wind-generated resuspension. From loading models, it is estimated that an 88 percent reduction of the present annual

> phosphorus loading of 505 tons would be necessary to avert eutrophic lake conditions. Such a reduction on a lake-scale basis is not deemed possible given technical unfeasibility and excessive sustained costs."

3.1.4 Recent Renewal of Scientific Investigation

Less than a decade later, problems in Upper Klamath Lake once again received increased scrutiny, and investigations have continued until the present time. The U. S. Geological Survey (USGS), in cooperation with the several local, state and federal agencies including the U. S. Bureau of Reclamation and the Klamath Tribes, initiated a phased program of research regarding eutrophication in Upper Klamath Lake, focusing on possible causes of the excessive nutrient enrichment of its waters as well as the reasons for sucker population decline. These studies, undertaken throughout the 1990s, resulted in several publications, including further reports regarding bottom sediments and their relation to nutrients in the lake, as well as nitrogen and phosphorus loading of the lake from inflowing waters. See Attachment A for more detail.

3.1.5 Upper Klamath Lake TMDL

High algal productivity in Upper Klamath Lake has been accompanied by violations of Oregon's water quality standards for dissolved oxygen, pH, and free ammonia. Such water quality violations led to 303(d) listing of UKL in 1998 by ODEQ. In May of 2002, ODEQ established a total maximum daily load (TMDL) for the Upper Klamath Lake drainage to define "the maximum amount of pollution [from all sources] that a water body can receive without violating water quality standards". The Upper Klamath Lake TMDL for nutrient-related pollution identified controlling total phosphorous loading as the "primary and most practical mechanism to reduce algal biomass and attain water quality standards for pH and dissolved oxygen." The TMDL stated that "mobilization of phosphorus from agriculture and other nonpoint sources … appears to have pushed the lake into an exaggerated state of eutrophication".

The TMDL estimated that of the total phosphorus loading in the lake, only 39 percent could be attributed to external loading, while approximately 61 percent was generated by internal loading mechanisms such as sediment-water nutrient exchange. Further, the release of phosphorus from sediment into lake waters is facilitated by increased pH levels. Evidence gathered by previous studies suggested that as the *Aphanizomenon flos-aquae* population increases, pH levels increase. The increased pH levels then help release more phosphorus into the water, further elevating the blue-green algae population and pH levels, and thereby "setting up a positive feedback loop." To address the phosphorus issue, the TMDL called for a 40 percent reduction of total phosphorous loading to Upper Klamath Lake.

This 40 percent reduction in total phosphorus loading could be achieved, stated the TMDL, through wetlands restoration, changes in hydrology along the watercourses flowing into the lake as discussed above, and reducing phosphorus discharge levels from two point sources, Chiloquin Sewage Treatment Plant and Crooked Creek Hatchery (although these two point sources combined supplied only an estimated 2.5 metric tons of phosphorus to the lake per year, a relatively minor phosphorus source when compared to the 179.2 metric tons estimated to be supplied by non-point external sources). The TMDL estimated that up to 29 percent of the external phosphorus load could possibly be attributed to the drainage of wetlands adjacent to the lake, and that restoration of the wetlands could reduce the external phosphorus loading of Upper

Klamath Lake by that 29 percent. An additional 18 percent reduction in external phosphorus loading could be achieved, according to the TMDL, through restoring land cover to areas cleared by timber harvesting or livestock grazing, and also changing the hydrology of upland agricultural and drainage systems along the Williamson, Sprague, and Wood rivers.

In order to implement the load allocations stipulated by the TMDL, and achieve the targeted 40 percent reduction in total phosphorus loading, the "first iteration" of a water quality management plan was included in the TMDL document. This water quality management plan "is the overall framework describing the management efforts to implement TMDLs in the UKLDB [Upper Klamath Lake Drainage Basin]." The proposed water quality management plan did not specify specific remedial measures that would attain the necessary load reductions (internal and external) to resolve water quality problems in Upper Klamath Lake, rather the intent was to provide a foundation for more specific implementation plans. The water quality management plan listed various management measures ranging from public outreach and education to erosion control, wetlands restoration to enforcement of trash dumping and pollution discharge, and riparian forest management to proper road construction and repair. Recent TMDL efforts for downstream Klamath River reaches have identified additional questions for the existing Upper Klamath Lake TMDL, including the fact that the Upper Klamath Lake TMDL only addresses phosphorous and not nitrogen.

3.1.6 The 2004 Report of the National Research Council

In 2004, the National Research Council's Committee on Endangered and Threatened Fishes in the Klamath River Basin issued a report regarding endangered and threatened fishes in the Klamath Basin, including sucker and salmonid species to "evaluate the strength of scientific support for the biological assessments and biological opinions on the three listed species, and to identify requirements for recovery of the species." The committee had a primary interest in regard to Upper Klamath Lake as a factor influencing the health and survival of endangered sucker species. In this regard, the committee studied the various proposed causes of Upper Klamath Lake's hypereutrophic status, which have the potential to cause direct or indirect harm to sucker populations. These factors, now familiar to the reader, include the various roles played by the nutrients nitrogen and phosphorus, pH levels, dissolved oxygen levels, and the predominance of *Aphanizomenon flos-aquae* in the lake's algal populations.

In evaluating the scientific research conducted regarding Upper Klamath Lake, the National Research Council committee found four hypotheses regarding the lake's water quality to be "well supported" by the available evidence:

- That "algal abundance as measured by chlorophyll is positively related to total phosphorus in the water column."
- That algal population levels are "positively related to daytime pH."
- That the rate of development of the algal population in early spring is "positively related to the rate of warming in the water column."

- That large amounts of the phosphorus present in the lake's waters during the algal growing season (spring, summer, and early fall) originate in the lake's bottom sediments, being transferred to the overlying water through internal loading mechanisms.

While the committee acknowledged that typically the most effective way to limit algal growth is to restrict phosphorus loading, Upper Klamath Lake did not seem to lend itself to this technique, contrary to the conclusions of ODEQ's Upper Klamath Lake TMDL. The committee noted that approximately 60 percent of the external phosphorus load derived from natural sources rather than artificial ones. In addition, most of that portion of the phosphorus load stemming from artificial sources originates from non-point sources such as agricultural and other land use practices rather than point sources, which are easier to control and regulate. The implementation of regulations regarding non-point sources, stated the committee, would involve major changes in land use upon privately-held land, a difficult proposition at best and one that seemed to make "even a reduction of 20%" in external phosphorus loading," half of what the TMDL recommended, "ambitious and potentially infeasible…"

Even if the TMDL's targeted 40 percent reduction in external phosphorus loading could be achieved, the committee held that it would "probably be ineffectual without suppression of internal phosphorus loadings, given that internal phosphorus loading is very large for Upper Klamath Lake" and that "available evidence indicated that … internal loading appeared sufficient to maintain algal populations".

The committee perceived another deficiency in ODEQ's Upper Klamath Lake TMDL document as well: the TMDL document failed to satisfactorily explain why *Aphanizomenon* had become the dominant algae species during the latter portion of the 20th century. The committee postulated that organic acids (called "limnohumic" acids) present in wetland sediments could have played a part in inhibiting the growth of blue-green algae species before diking and subsequent drainage of wetlands adjacent to the lake. The influx of these limnohumic acids into the lake's waters was probably high, and could have inhibited algal growth through either preventing light penetration of the lake waters, or even having a toxicity to certain types of algae. When the levels of these acids dropped after development of the wetlands for agricultural purposes, according to this hypothesis, *Aphanizomenon* would have been "released from suppression by weak light availability or chemical inhibition," and thereby begun its ascension to its current dominant role. This hypothesis was more attractive to the committee than the phosphorus-loading hypothesis for its ability to explain both the change in the composition of algal population (to a population dominated by *Aphanizomenon*), and also the increase in the amount of algae in the water.

3.2 PREVIOUSLY-REPORTED PACIFICORP ANALYSES WITH REGARD TO THE EFFECTS OF THE KLAMATH HYDROELECTRIC PROJECT ON NUTRIENTS

In March 2004, PacifiCorp submitted a Final License Application (FLA) to the Federal Energy Regulatory Commission for relicensing of the Klamath Hydroelectric Project. In March 2006, PacifiCorp submitted applications for Section 401 water quality certification to ODEQ for the Oregon portion of the Project and the State Water Resources Control Board (SWRCB) for the California portion of the Project. As part of the FLA and the 401 applications, PacifiCorp provided a detailed evaluation of water quality conditions and effects in the Project area, based on analysis of water quality monitoring data and the results of comprehensive water quality modeling. The water quality studies used to support this evaluation, including the collection of water quality monitoring data and development of the comprehensive water quality model, was done in extensive multi-year collaboration with a Water Quality Working Group comprised of representatives from interested agencies, tribes, and other organizations.

An initial task performed by PacifiCorp as reported in the FLA was to compile available historic water quality data and information for the Project into a computerized database. The database contains 57,378 records with measurements for 66 distinct constituents from 175 sites in the Klamath River basin sampled on 2,180 different dates between October 12, 1950, and June 20, 2001. The historical data provided the opportunity to compare water quality among sites along the Klamath River. However, not all sites had sufficient data to make adequate comparisons. Likewise, not all constituents were measured frequently enough at the most sampled sites to provide sufficient data for comparison. Nevertheless, the pattern of differences provided some insight into the dynamics of water quality in the Klamath River.

The overall picture of the Klamath River that emerges from the historical data is one of higher production and organic matter in the upper reaches of the river (Lake Ewauna and Keno reservoir), changing to lower production and lesser organic matter in the lower reaches of the river. The available historical data indicate as expected that Upper Klamath Lake and Klamath Straits Drain are prolific sources of BOD, organic nitrogen, dissolved solids, turbidity (suspended solids), and phosphorus to the Klamath River.

A subsequent task performed by PacifiCorp as reported in the FLA and the 401 applications was an assessment of current water quality conditions in the Klamath River between Link River dam and the Shasta River based on grab sample data collected by PacifiCorp from 2000 through 2004. As expected, these data showed that the driving force influencing water quality in the Project area is the quality of water entering the Project from Upper Klamath Lake and Klamath Straits Drain. The data show that the entire Klamath River system upstream and within the Project area is high in phosphorus, including the tributary streams, with median total phosphorus concentration (0.21 mg/L) well above values commonly considered to indicate a eutrophic system (0.08 mg/L; Wetzel, 2001, p. 283). In addition to Upper Klamath Lake, the Klamath Straits Drain provides an abundant source of phosphorus (median total phosphorus = 0.43 mg/L). The contribution of the Klamath Straits Drain to the Klamath River can be observed as a noticeable increase in total phosphorus concentration in Keno reservoir below Klamath Straits Drain.

Water entering Lake Ewauna from Link River carries a high load of organic nitrogen and other organic matter and is well seeded with algae, as evidenced by an average chlorophyll *a* concentration greater than 50 ug/L. The abundant algae delivered from Upper Klamath Lake continue to grow in Lake Ewauna and achieve chlorophyll *a* concentrations that average between 20 and 40 ug/L, and peak near 300 ug/L during bloom conditions which may occur multiple times during the late spring-to-early fall growing season. The respiration demands of such abundant algal production combine with BOD to consume much of the oxygen in the water. BOD demand in the water is the major cause of dissolved oxygen depletion in Lake Ewauna, including complete anoxia during certain periods of the summer and early fall.

There is no process or discharge associated with the Klamath Hydroelectric Project that contributes nutrients to the Klamath River. The nutrient concentrations observed in the Project area are the result of input from upstream sources, particularly Upper Klamath Lake, and as modified by physical and biological processes in the river and reservoirs during transit. Copco and Iron Gate reservoirs act as net sinks to retain and process nutrients exported from upstream on an annual basis. The total annual net retention of nutrients in the project reservoirs is presented in Table 3-1 based on the analysis of Kann and Asarian (2005) using predominantly PacifiCorp 2002 nutrient data. The cumulative retention of nutrients, especially for total nitrogen, is substantial. Also, as Figure 3-1 indicates, cumulative monthly nutrient loading through the year to the Klamath River below Iron Gate dam is less than cumulative nutrient loading to Copco reservoir.

When looked at individually without regard to the timing of inflows and discharges and internal processing, each reservoir at times may appear to be a source of nutrients during some portions of the year. For example, Kann and Asarian (2005) estimated that total N load was higher below Iron Gate reservoir than above Copco reservoir in August 2002. However, as described in section 4.5 of this document, the extended residence time of the reservoirs introduces a time lag that offsets the output conditions from the input conditions. Therefore, nutrient concentrations in water released from Iron Gate reservoir may on occasion be greater than in the concurrent inflowing waters to Copco reservoir, even though the reservoirs act to retain and reduce the loads, because they are reflecting conditions above Copco from an earlier time.

Nitrogen and phosphorus, in the forms of nitrate and phosphate, are common nutrients within the Klamath River basin that stimulate phytoplankton production and contribute to eutrophic conditions. High phytoplankton production within the system contributes to a variety of water quality changes that affect habitat for salmonids and other fish and invertebrates. Phytoplankton contribute to local and seasonal changes in dissolved oxygen concentrations, pH, biological oxygen demand, and organic loading. Because the Klamath River is weakly-buffered, algal production processes can cause notable diurnal variations in pH; it is not uncommon for pH values to exceed 9.0 in the warmest parts of the day.

Table 3-1. Total annual net retention of nutrients by Copco and Iron Gate reservoirs (based on data from Kann and Asarian [2005] using predominantly PacifiCorp 2002 nutrient data).

Constituent	**Net Retention (tons)**
Total Phosphorus	23
Orthophosphate	14
Total Nitrogen	127
Total Inorganic Nitrogen	95

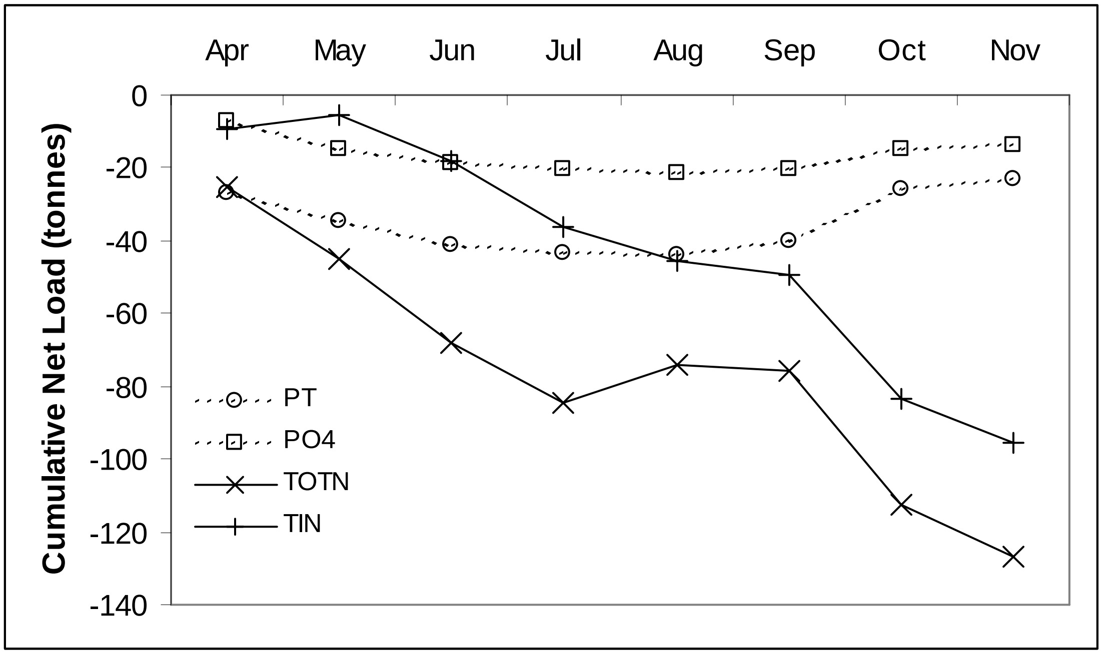


Figure 3-1. The cumulative difference in nutrient load (tons) between the Klamath River above Copco and the Klamath River below Iron Gate Dam. A negative value indicates that the load at Iron Gate is less than the load above Copco. (Data from Kann and Asarian 2005).

Based on these previously-reported analyses, PacifiCorp concluded that the Project does not contribute to excess concentration of nutrients in the Klamath River. The abundance of chlorophyll *a*, and the growth of phytoplankton are a natural consequence of the occurrence of excess nutrients from upstream sources. The appropriate means to control the load of nutrients in the Project area is implementation of TMDLs established by ODEQ and the SWRCB. Nevertheless, PacifiCorp has proposed Reservoir Management Plans to address primary production in Project reservoirs resulting from nutrient loading from upstream sources. The Reservoir Management Plans will have the effect of reducing algae growth and thus reducing chlorophyll concentrations within the reservoirs, as well as benefiting water quality in general.

3.3 RECENT ANALYSES BY KANN AND ASARIAN ON NUTRIENT RETENTION IN COPCO AND IRON GATE RESERVOIRS AND IN THE KLAMATH RIVER BELOW IRON GATE DAM

3.3.1 Kann and Asarian (2005)

In July 2005, Kann and Asarian (2005) issued a report of their analysis of 2002 nutrient loading to Copco and Iron Gate reservoirs based on nutrient data collected by PacifiCorp during March to November 2002, with some supplemental data from USFWS from early June through mid-September, 2002. On the basis of their analysis, Kann and Asarian (2005) concluded that:

> "Despite acting as sinks for P and N over the entire Apr-Nov period, both Copco and Iron Gate reservoirs can act as a nutrient source during critical periods (e.g., June through September), making nutrients available at such periods for downstream growth of algae and macrophytes."

Kann and Asarian (2005) further concluded that:

> 'The more robust seasonal analysis presented here does not support an earlier PacifiCorp (2004a, 2005b) broad postulation that the reservoirs benefit water quality by processing organic matter and nutrients from upstream sources. Within the given data set, there is clear indication that the reservoirs periodically increase nutrient loading downstream."

As described below, the Kann and Asarian (2005) analysis has important flaws. Notwithstanding these flaws, Kann and Asarian's (2005) analysis itself clearly shows that Copco and Iron Gate reservoirs act as net sinks for P and N over the longer term (Table 3-1) – the same basic conclusion reached by PacifiCorp as summarized above. Despite the wording of their stated conclusion to the contrary, this net retention of nutrients indicates that the reservoirs help to store and process the very large amounts of organic matter and nutrients from upstream sources.

In addition, Kann and Asarian's (2005) conclusion that Copco and Iron Gate may act as nutrient source at times is also similar to PacifiCorp's conclusion as summarized above, i.e., that when looked at individually without regard to the timing of inflows and discharges and internal processing, each reservoir at times may appear to be a source of nutrients during some portions of the year. However, as described in section 4.5 of this document, the extended residence time of Copco and Iron Gate reservoirs creates a time lag whereby nutrient concentrations in release waters from Iron Gate reservoir may at times be greater than in the inflowing waters to Copco reservoir, even though the reservoirs act to retain and reduce the loads from nutrient "events" (e.g., phytoplankton blooms and die-offs) originating from Upper Klamath Lake as they move through the upper Klamath River.

A basic flaw of the Kann and Asarian (2005) analysis is that they derive a nutrient budget by extrapolating a *daily* time-series of "nutrient loadings" from approximately *monthly* nutrient sample data. Such extrapolation is not only unacceptable as a basic analytical technique, but is particularly inappropriate for nutrients that are known to be dynamic and vary widely through time in this system. To their credit, Kann and Asarian (2005) raise caveats with respect to this sampling frequency, stating that "…a minimum of biweekly sampling is recommended to determine … nutrient sources and sinks." The daily loading extrapolations made by Kann and Asarian (2005) give the misleading impression of "data" availability and detail that do not exist. The Kann and Asarian (2005) report presents many detailed graphs and make conclusions about nutrient conditions in the reservoirs using this inferred pseudo-daily data – all based on only *monthly* nutrient data; for example:

> "Reservoir TN storage declines with inflow loading through mid-May, and then increases or remains steady through November. The retention pattern is one of positive retention between April and late May, and then alternating periods of negative and positive retention through November."

Kann and Asarian (2005) go on to make conclusions based on the pseudo-daily data, such as the reservoirs "act as a nutrient source during critical times for growth of algae and macropyhtes" and "net negative retention of nitrogen may reflect input to the reservoirs from nitrogen fixing cyanobacteria".

Interestingly, there are *monthly* "nutrient loading" values listed in Kann and Asarian's (2005) Tables 5 and 6 that are not discussed by the report's authors, but upon which a reviewer of the report can reach different conclusions. These monthly values indicate that Copco reservoir acts to positively retain TP in 6 of the 9 months assessed, and that the net negative retention months were September, October, and November (Table 3-2). Iron Gate reservoir retains TP in 7 of the 9 months assessed, and the net negative retention months were October and November. Copco reservoir acts to retain TN in 8 of the 9 months assessed, and the net negative retention month was September. Iron Gate reservoir retains TN in 8 of the 9 months assessed, and the net negative retention month was August.

Table 3-2. Summary of total phosphorus (TP) and total nitrogen (TN) retention in Copco and Iron Gate reservoir (in metric tons) as reported by Kann and Asarian (2005) based on 2002 nutrient data.

	Klamath above Copco Reservoir	**Klamath below Copco Reservoir**	**Klamath below Iron Gate Reservoir**	**Copco Net Retention**	**Iron Gate Net Retention**
TP					
April	48	30	22	18	12
May	23	16	16	7	0
June	17	15	11	2	4
July	14	13	12	1	1
August	10	10	9	0	1
September	11	15	14	-4	1
October	8	15	22	-7	-7
November	3	4	6	-1	-2
Total	*134*	*118*	*112*	*16*	*6*
TN					
April	114	100	89	14	11
May	85	71	65	14	6
June	71	69	48	2	21
July	75	67	59	8	8
August	48	40	58	8	-18
September	58	77	56	-19	21
October	104	78	67	26	11
November	41	31	27	10	4
Total	*597*	*531*	*470*	*66*	*61*

These monthly results indicate that Copco and Iron Gate reservoirs act to retain nutrients in most months, and in most cases the months of net negative retention month do not occur during "critical times for growth of algae and macrophytes" as Kann and Asarian (2005) contend. Kann and Asarian (2005) also do not acknowledge the important tandem effect of these two reservoirs. For example, as mentioned above, the monthly values suggest that September was the net negative retention month in Copco reservoir for TN (Table 3-2). However, in tandem Copco and Iron Gate acted to retain TN in September.

Overall, the monthly "nutrient loading" values listed in Kann and Asarian's (2005) Tables 5 and 6 indicate that the reservoirs acted to retain a significant percentage of inflowing TP (26 percent in Copco, 26 percent in Iron Gate) and TN (8 percent in Copco, 12 percent in Iron Gate) over the entire evaluation period of March-November 2002. This generally corresponds to previous conclusions from PacifiCorp's FLA analysis. Interestingly, Kann and Asarian (2005) make little mention of the very large inflowing nutrient loads to the reservoirs from the upstream Klamath River and Upper Klamath Lake. Little mention of this is made despite Kann and Asarian's (2005) own findings that the Klamath River entering Copco reservoir contributes 98 percent of the TP load of 138 metric tons and nearly 100 percent of the TN load of 600 metric tons to Copco reservoir – both very large quantities.

3.3.2 Asarian and Kann (2006)

In July 2006, Asarian and Kann (2006) issued a report of their analysis of nitrogen loading and retention in Copco and Iron Gate reservoirs and for the river reaches below Iron Gate dam. Asarian and Kann (2006) considered nitrogen data collected by PacifiCorp, USFWS, USBR, ODEQ, and USGS during 1996 to 2004. However, they base their conclusions mostly on data for 2002, ostensibly because 2002 contained the most overlapping data for both reservoirs and for the river reaches below Iron Gate dam. On the basis of their analysis, Asarian and Kann (2006) concluded that:

> "A comparison of temporal variability of river retention to reservoir retention showed that the river consistently provides moderate positive retention, while the combined retention of Iron Gate and Copco reservoirs alternates between positive and negative values. Thus, although overall reservoir nitrogen retention was positive for the entire evaluated period there were two significant periods in 2002 when the reservoirs were releasing nitrogen (i.e., retention was negative)."

Asarian and Kann (2006) further concluded that:

> "Thus, this exercise indicates that when retention due to pre-reservoir natural river processes is factored into the reservoir retention estimated in Kann and Asarian (2005), the reservoir effect on retention was minimal (4.6% of incoming load) or even negative (-3.3% of incoming load) for the periods evaluated."

> "Overall these analyses confirm the importance of natural riverine nitrogen retention processes in the Klamath River system, and they underscore the need to factor these processes into evaluation of the hydrologic alterations attributable to the Klamath Hydroelectric Project."

As with the Kann and Asarian (2005) analysis described above, the Asarian and Kann (2006) report contains basic flaws. As in their 2005 report, Asarian and Kann (2006) derive a *daily* "TN budget" from *monthly* or *bimonthly* nitrogen data. Asarian and Kann (2006) derive these daily values by interpolating between dates of actual samples that were typically separated by a gap of 15 to 30 days, and up to as many as 45 days. These derived daily values again give the misleading impression of "data" availability and detail that do not exist. In fact, Asarian and Kann (2006) inappropriately refer to the pseudo-daily load values they derive in this manner as "observed load" and "measured load" (see page 16 of Asarian and Kann [2006]). Asarian and Kann (2006) present many detailed graphs and go on to make conclusions about nutrient conditions in the reservoirs using these derived pseudo-daily data, including conclusions about "negative retention pulses" and "patterns", and "shorter-term variations of ecological significance".

Asarian and Kann (2006) calculated their TN "retention" values by subtracting their derived load for the upstream end of the reach from their derived load for the downstream end of the reach *for each day*. Comparisons are then made of such daily retention values in Copco and Iron Gate reservoirs with derived daily retention values in the river reach from Iron Gate to Seiad Valley for the year 2002. Based on this comparison, Asarian and Kann (2006) conclude that "the river consistently provided moderate positive retention, while the reservoirs alternate between highly positive and highly negative retention", and that "the negative retention for the reservoir-only effect during this period indicates that when river retention is accounted for, the reservoirs may actually cause a net release of nutrients". However, these conclusions are based on information that is erroneous for two key reasons: (1) the calculated daily retention values are based not on real data, but on derived pseudo-daily data as explained above; and (2) the calculated daily retention values are based on same-day subtractions that do not account for water residence or travel times which is on the order of days in the Iron Gate to Seiad Valley reach and several weeks in Copco and Iron Gate reservoirs.

Moreover, these faults point out that the analysis of reservoir nutrient loading and retention using the available measured data is only really appropriately applicable at a *seasonal to annual* time scale, and must account for the time-lag effect of water residence and travel time through the system. In section 4.5 of this document, PacifiCorp presents an analysis of nutrient conditions and effects in the Project area that demonstrates the importance of taking into account water residence and travel time through river and reservoir reaches.

Throughout their report, Asarian and Kann (2006) use a "standardized" metric of "percent retention" or "percent retention per mile" (calculated as the percent reduction between upstream and downstream loads for each day). However, this is misleading when comparing nutrient retention in different segments of the river because it does not consider the total mass of nutrients retained (TN in this case). For example, a net retention of 4 percent per mile at 1000 cfs would remove 115 kg per mile at Link River, 77 kg per mile at Keno dam, and only 45 kg per mile at Iron Gate based on average TN values at each site.

It is particularly important to consider nutrient mass or quantity when reviewing Asarian and Kann's (2006) comparison of their information to the empirical relationship developed by Seitzinger et al. (2002). The Seitzinger et al. (2002) empirical relationship is based on river and stream systems that are less nutrient-enriched and generally smaller than the Klamath River, and that are located in the northeastern United States. In a comprehensive review of the literature on nitrogen retention in river ecosystems, Bernot and Dodds (2005) indicate that long term data sets have shown that the capacity of rivers to remove instream nitrogen loads decreases as river size increases – that is, the larger the river, the greater the amount of nitrogen delivered downstream. Bernot and Dodds (2005) also report that in systems where baseline N loads and concentrations are high, uptake of nitrogen is limited – that is, with chronic N loading, N export in rivers increases and the rate of increase is proportional to the load.

Additionally, Asarian and Kann's (2006) comparisons of river N retention use only certain selected values they calculated for the Iron Gate to Seiad Valley reach. Values from other reaches calculated by Asarian and Kann (2006), including for the river downstream of Seiad Valley, show different and more variable results (including negative retention in many cases). If included in the comparison, such values would show a substantial deviation of Asarian and Kann's (2006) derived values from the Seitzinger et al. (2002) empirical relationship.

Asarian and Kann's (2006) selective presentation of their derived river N retention values is also evident in their erroneous conclusion that "the river consistently provides moderate positive retention" of nitrogen. This conclusion is drawn from only the values derived from the data for the Iron Gate to Seiad Valley reach. There are clear cases where Asarian and Kann's (2006) derived retention values show consistent negative retention of nitrogen in river reaches, such as Seiad Valley to Happy Camp based on 2002 data, Orleans to Martins Ferry based on 2001 and 2002 data, and Martins Ferry to Klamath Glen based on 2001 data (Table 3-3).

Asarian and Kann's (2006) selective presentation of their derived river N retention values is also evident in their erroneous conclusion that "the reservoir effect on retention was minimal (4.6% of incoming load) or even negative (-3.3% of incoming load) for the periods evaluated." For example, if all river reaches are considered, the overall total of the net TN retention calculated by Asarian and Kann (2006) for the 184 miles of the Klamath River from Klamath Glen to Iron Gate (RM 5.8 to 190) equals about 116 metric tons or 0.6 metric tons per mile for the June-October period based on 2002 nutrient data (Table 3-3). By comparison, information presented in Kann and Asarian (2005) indicates the overall total of the net TN retention in Copco and Iron Gate reservoirs during the same June-October 2002 period equals about 68 metric tons (see Table 3-2 for component values) or 4.3 metric tons per mile[1]. Comparison of these values indicates that the reservoirs have a substantial positive effect on TN retention when compared to the lower Klamath River as a whole.

[1] The combined length of Copco and Iron Gate reservoirs is about 16 miles.

Table 3-3. Summary of net total nitrogen (TN) retention in reaches of the Klamath River below Iron Gate dam (in metric tons) for the June-October period as reported by Asarian and Kann (2006) based on 2001-2002 nutrient data.

	Iron Gate to Seiad Valley	**Seiad Valley to Happy Camp**	**Happy Camp to Orleans**	**Orleans to Martins Ferry**	**Martins Ferry to Klamath Glen**	**Total**
Length (RM)	RM 190 to 129	RM 129 to 101	RM 101 to 59	RM 59 to 40	RM 40 to 5.8	RM 190 to 5.8
Length (miles)	61	28	42	19	34	184
***TN Retention* (metric tons)**						
2001	104	28	115	**-38**	**-92**	117
2002	80	**-37**	87	**-76**	62	116
***TN Retention* (metric tons per mile)**						
2001	1.7	1.0	2.7	**-2.0**	**-2.7**	0.6
2002	1.3	**-1.3**	2.1	**-4.0**	1.8	0.6

4.0 NUTRIENT CHANGES IN RESERVOIR AND RIVER REACHES IN THE UPPER KLAMATH RIVER

This section provides an analysis of nutrient changes in the reservoir and river reaches of the upper Klamath River. As previously described in section 3.0, the Klamath River upstream of the Klamath Hydroelectric Project receives very large loads of nutrients and organic matter from Upper Klamath Lake and other upstream sources such as the Klamath Straits Drain. These very large loads of nutrients and organic matter are the “drivers” that dictate the water quality conditions in the river and reservoir reaches in the Project area and downstream of Iron Gate dam.

The Klamath River system is complex and unique, particularly because water quality generally improves as water flows from its source at Upper Klamath Lake towards the estuary. In most river systems, water quality is highest at the source and degrades as water flows downstream. Upper Klamath Lake is a substantial source of both phosphorus and nitrogen, particularly during the months June through October (ODEQ 2002). For example, total phosphorus concentrations in Upper Klamath Lake and its outflow to the Klamath River nearly always exceeds 50 µg/L (or ppb) and can seasonally exceed 300 µg/L. These values frequently exceed the total phosphorus level of 200 µg/L established by the Organization for Economic Cooperation and Development (OECD) for classifying lakes as hypereutrophic (Philip Williams & Associates 2001) and nearly always exceed the 50 µg/L threshold reported by Welch (1992) for nutrient enrichment impairment of rivers and streams.

4.1 PROCESSING OF ORGANIC MATTER AND NITROGEN IN THE KLAMATH RIVER

Upper Klamath Lake is also a substantial source of organic matter, principally in the form of large amounts of discharged algae matter whose growth in the lake is fueled by the abundant nutrient conditions. Upper Klamath Lake is subject to abundant and persistent blooms of phytoplankton (Figure 4-1), and the lake’s outflow exports large quantities of algae, organic matter, and algal nutrients to the upper Klamath River (into Link River and Keno reservoir).

In general, the Klamath River exhibits higher algae production and organic matter in the upper reaches of the river (Upper Klamath Lake outlet and Keno reservoir), changing to lower production and lesser organic matter in the lower reaches of the river. There is no process or discharge associated with the Project that directly contributes nutrients to the Klamath River. The nutrient concentrations observed in the Project area are the result of input from upstream sources, particularly Upper Klamath Lake, as modified by physical and biological processes in the river and reservoirs during transit. Chlorophyll *a* data, a surrogate for algae biomass, were collected approximately monthly between March and November 2000 through 2005, and are presented in Figure 4-2. These data reflect the very large loading of algae and organic matter to the river from hypereutrophic Upper Klamath Lake (left side of the plot), and the consistent reduction in algae biomass with distance from Keno reservoir through the Project area reservoirs and river reaches downstream to near the mouth of the Shasta River (right side of the plot).

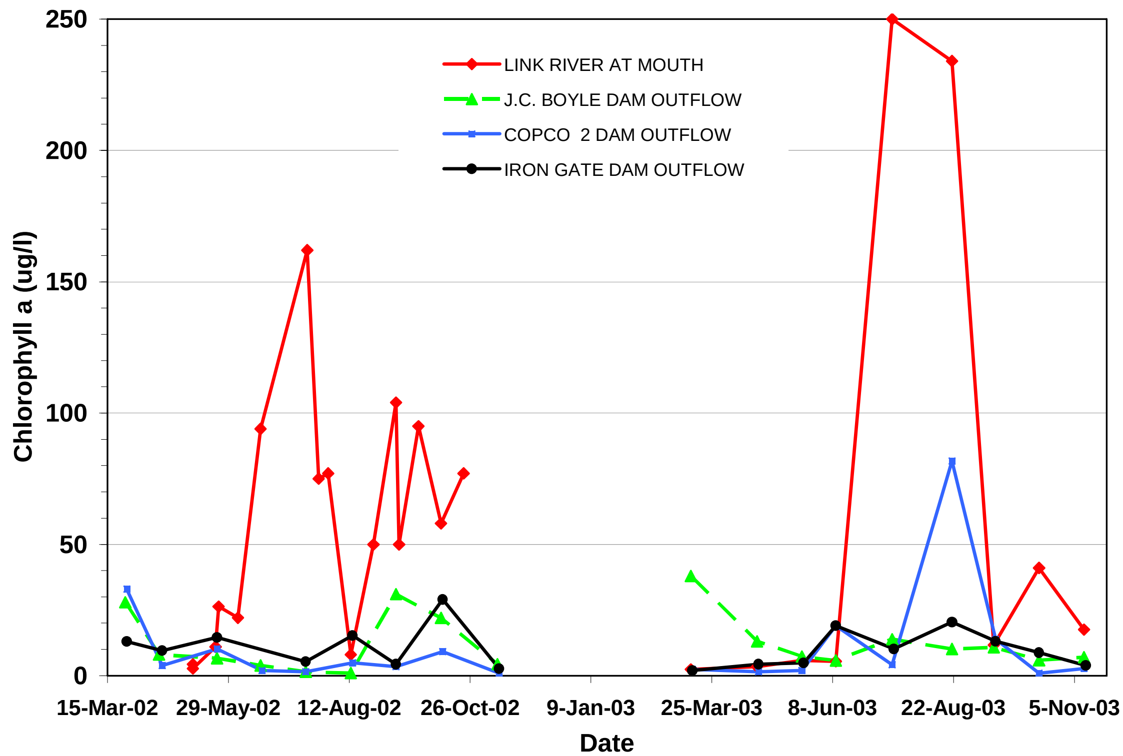


Figure 4-1. Observed chlorophyll *a* concentrations collected during 2002 and 2004 at the outflows from Upper Klamath Lake (near the mouth of Link River), J.C. Boyle dam, Copco 2 dam, and Iron Gate dam.

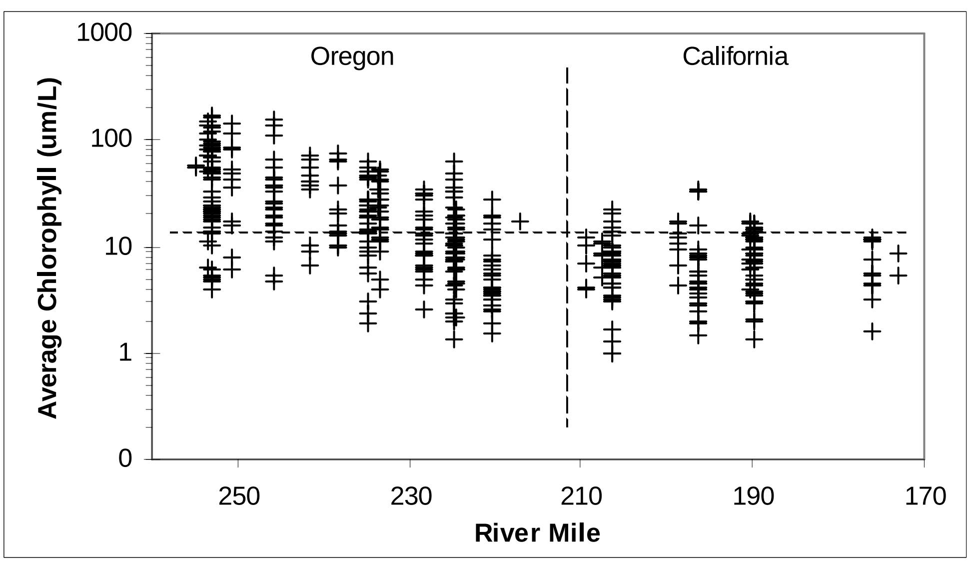


Figure 4-2. Average chlorophyll *a* concentration of sequential sets of three consecutive monthly values for data collected from 2000 through 2005 at various locations in the Klamath River. Note the logarithmic scale on the Y axis. The horizontal dashed line marks a concentration of 15 ug/L (equal to the Oregon Department of Environmental Quality action level for phytoplankton control strategies), and the vertical dashed line marks the approximate location of the Oregon-California border.

As water moves downstream from Upper Klamath Lake through the Klamath River, biological and physical processes act on the nutrients and organic matter, converting particulate organic matter to dissolved nutrients, sequestering inorganic nutrients in organic plant matter, and altering the form of some nutrients – for example, ammonia nitrogen to nitrate nitrogen. In the free-flowing river segments, these processes may be limited by high velocity, short residence time, and limited light availability because of the high light extinction coefficient of the Klamath River. Despite these processes, however, the Klamath River flows downstream abundantly supplied with nutrients that promote algal growth.

The loads to the upper Klamath River of both nitrogen and phosphorus are large, and both nutrients are essential for fueling algae growth. However, the data suggest that phytoplankton growth in the Klamath River is nitrogen-limited. The ratio of nitrogen to phosphorus in algal cells (Redfield ratio) is relatively constant at about 7:1 by weight. Reference to this ratio has been used as an approximate indicator of relative nutrient limitation of phytoplankton in lakes. A ratio of N:P greater than about 10:1 (by weight) is generally considered to indicate phosphorus limitation. The median N:P ratio in the Klamath River system is 6.6:1, with only about 20 percent of all values greater than 10:1. This condition holds from Link dam to Iron Gate dam, which suggests that phytoplankton growth in the Klamath River is nitrogen-limited.

The nitrogen contained in the very large loads of organic matter to the upper Klamath River, primarily from Upper Klamath Lake, is subject to various mechanisms of nitrogen retention and removal. The cycle of N in aquatic ecosystems is complex. Mechanisms for N retention include adsorption, biotic uptake, and settling which stores N in the sediment (Figure 4-3). Mechanisms for removal include denitrification, ammonia volatilization, and export downstream as described below.

Factors that influence forms and concentrations of water column N are essential to determining N retention. Nutrients dissolved in the water column move downstream much more rapidly than those in the particulate phase (Bernot and Dodds 2005). Processes that influence the forms of nitrogen include biotic uptake, organic matter mineralization, nitrification, denitrification, and nitrogen fixation.

4.1.1 Biotic Uptake and Organic Matter Mineralization

In the reservoirs and river reaches of the upper Klamath River, phytoplankton (in the reservoirs) and periphyton and macrophytes (in river reaches) remove nutrients from the water column via uptake for tissue production. After nitrogen is incorporated into organic matter, it can be converted back into inorganic nitrogen by mineralization, or decay, mediated by bacteria and fungi.

During mineralization, a significant amount of the nitrogen contained within the dead organism is converted to ammonium. Once in the form of ammonium, nitrogen is available for use by plants or for further transformation into nitrate ($NO3^-$) through the process called nitrification. Several factors, such as grazing, sloughing, flow disturbance, light limitation, and diffusion ultimately limit the total amount of N that can be retained in algae matter

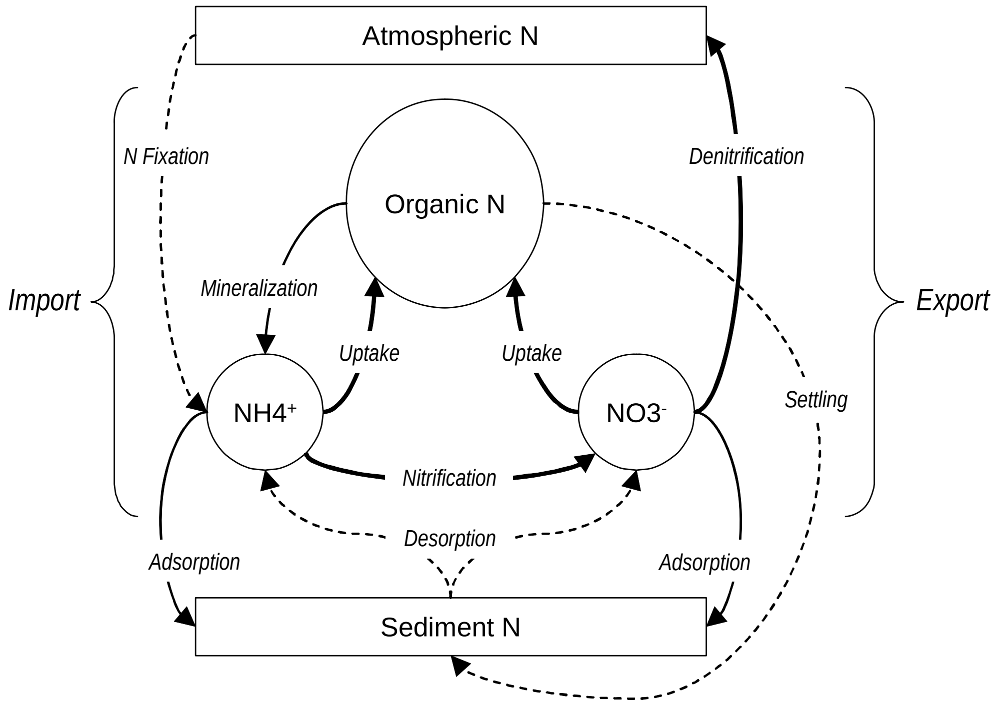


Figure 4-3. Conceptual model of mechanisms for nitrogen retention and removal in the reservoir and river reaches of the upper Klamath River.

Decomposition of algae can be described as a first-order process, and blue green algae are particularly susceptible to rapid decomposition (Fallon and Brock 1979). Kinetic data suggest that mineralization of nitrogen from algae material is most rapid during the initial stage of the decomposition process, and appears to be faster under aerobic than anaerobic conditions (Fallon and Brock 1979).

4.1.2 Nitrification

Some of the ammonium produced by decomposition is converted to nitrate through nitrification, mediated by bacteria. Nitrification requires the presence of oxygen, and occurs only in oxygen-rich environments like circulating or flowing waters and the surface layers of soils and sediments.

Nitrification produces nitrate from ammonium, and nitrate is more easily transported downstream and less likely to be immobilized. Therefore, understanding what controls rates of nitrification, and subsequently denitrification, is crucial to building a mechanistic view of N retention in aquatic ecosystems (Bernot and Dodds 2005).

In river reaches, nitrification occurs primarily in the oxidized surface of the bottom sediment and only minimally in the overlying water (DeLaune et al. 1991; Kemp and Dodds 2001). The efficiency of nitrifying bacteria is highest when dissolved oxygen penetration into the sediment is greatest, and may also depend upon N delivered from the water column (Kemp and Dodds 2001).

4.1.3 Denitrification

Through denitrification, oxidized forms of nitrogen such as nitrate and nitrite ($NO2^-$) are converted to dinitrogen (N2) and, to a lesser extent, nitrous oxide gas. The process is carried out in the absence or near-absence of oxygen by denitrifying bacteria. Once converted to dinitrogen, nitrogen is unlikely to be reconverted to a biologically available form because it is a gas and is rapidly lost to the atmosphere. Denitrification is the only nitrogen transformation that removes nitrogen from ecosystems (essentially irreversibly).

Review of the controlling factors identified above suggests that higher potential denitrification rates would occur in the reservoirs than in the river reaches. In the reservoirs, settling organic matter is in contact with waters that seasonally reach low oxygen levels, which would allow denitrification. By comparison, the river reaches are typically oxygenated and lack appreciable accumulations of settled organic matter. The river reaches are typically turbulent, and because organic matter has a very low shear stress, sedimentation of organic matter in these reaches is minimized.

4.1.4 Nitrogen Fixation

Nitrogen fixation is an energy-consuming aerobic process wherein N2 is converted to $NH4^+$. It is a potentially important process, particularly in N-limited systems, because it is the only way that organisms can attain nitrogen directly from the atmosphere. In aquatic environments, blue-green algae (Cyanobacteria) are nitrogen fixers. In Upper Klamath Lake and the Project reservoirs, *Aphanizomenon* is the most prevalent blue-green algae (during summer) that has the ability to fix nitrogen.

N fixation is performed in the heterocysts of blue-green algae. The abundance of these extra long heterocyst cells in the filaments of N-fixing blue-green algae, like *Aphanizomenon*, usually increases with $NO3^-$ depletion. Because N-fixation is an energy-consuming process, it becomes advantageous only when $NO3^-$ and $NH4^+$ are no longer available (Welch 1992). Although *Aphanizomenon* is prevalent during summer in the Project reservoirs, ample concentrations of $NO3^-$ and $NH4^+$ are nearly always available (for example, see TIN values in Figures 4-4, 4-5, and 4-6), which suggests that N fixation is likely not a substantial source of nitrogen as Kann and Asarian (2005) suggest.

4.2 UPSTREAM-DOWNSTREAM COMPARISONS OF NUTRIENT DATA FROM PROJECT RESERVOIRS AND RIVER REACHES

What do empirical data indicate about nutrient changes in reservoir and river reaches in the Project area once these large loads of nutrient and organic matter are released to the upper Klamath River from Upper Klamath Lake and other upstream sources (such as the Klamath Straits Drain)? The following sections compare upstream-downstream time-series plots of nutrient data collected by PacifiCorp during 2002-2004 for the three Project reservoirs (J.C. Boyle, Copco, and Iron Gate reservoirs) and four river reaches (Keno reach from Keno Dam to J.C. Boyle reservoir headwaters, J.C. Boyle bypass reach from J.C. Boyle dam to powerhouse, J.C. Boyle peaking reach from J.C. Boyle powerhouse to Copco reservoir headwaters, and the Klamath River from Iron Gate dam to the Shasta River). The comparisons of nutrient data in these plots provide an indication of potential nutrient retention and conversion in the river and reservoirs during transit of river flows.

4.2.1 Nutrient Data from Project Reservoirs

4.2.1.1 J.C. Boyle Reservoir

J.C. Boyle reservoir extends from the reservoir's headwaters (the end of the Keno reach at RM 228.2) to J.C. Boyle dam (RM 224.6). Total storage capacity is approximately 3,500 acre-feet with a maximum depth of about 25 feet. Reservoir residence time ranges from less than half a day to over two days depending on flow regime.

Because of the short residence time, lack of stratification, and limited photic zone, the observed concentrations of total inorganic nitrogen (TIN), total nitrogen (TN), orthophosphate (PO4), and total phosphorus (TP) in outflowing waters from the reservoir are similar to those in inflowing waters (Figure 4-4), indicating the J.C. Boyle reservoir has no substantial effect on nutrients. The fact that the reservoir does not strongly stratify (and is in a fairly windy region), allows the inflowing waters and the nutrients they carry to mix throughout the depth of the reservoir. As a result, a significant portion of the vertically-distributed nutrient loads pass through the reservoir because the nutrient uptake by primary production in the photic zone is restricted to the nearer-surface waters within the reservoir.

4.2.1.2 Copco Reservoir

Copco reservoir extends from the reservoir headwaters (RM 203.1) to Copco dam (RM 198.6). The reservoir has a storage capacity of approximately 40,000 acre-feet and is approximately 115 feet deep near the dam. The reservoir's hydraulic residence times range from a few days under winter high flow events to approximately two to three weeks under typical lower flow conditions during summer.

During the warmer periods of the year when the reservoir stratifies, the deeper waters of the reservoir have a longer residence time than the intermediate surface waters. Reservoir profiles suggest density dependent interflow or intrusion occurs within the reservoir, affecting residence time estimations. Because of these density driven flows, the surface waters may have a residence time that is considerably longer than two to three weeks. These conditions allow the primary production in the photic zone to affect the flux of nutrients during transit through the reservoir. As a result, the observed concentrations of TIN, TN, PO4, and TP are generally lower in release waters than reservoir inflows (Figure 4-5).

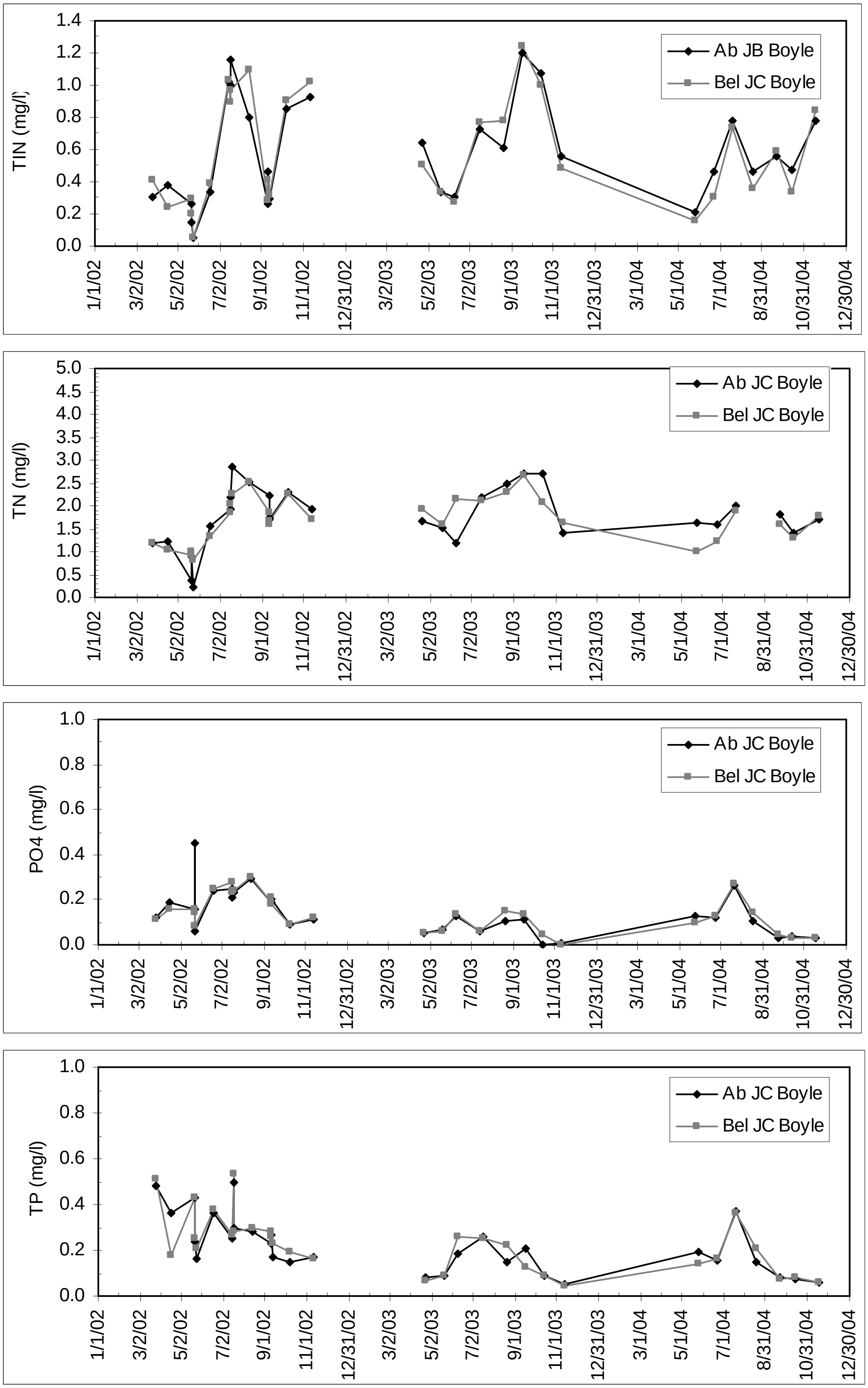


Figure 4-4. Observed total inorganic nitrogen (TIN), total nitrogen (TN), orthophosphate (PO4), and total phosphorus (TP) in the Klamath River above and below J.C. Boyle reservoir, 2002-2004.

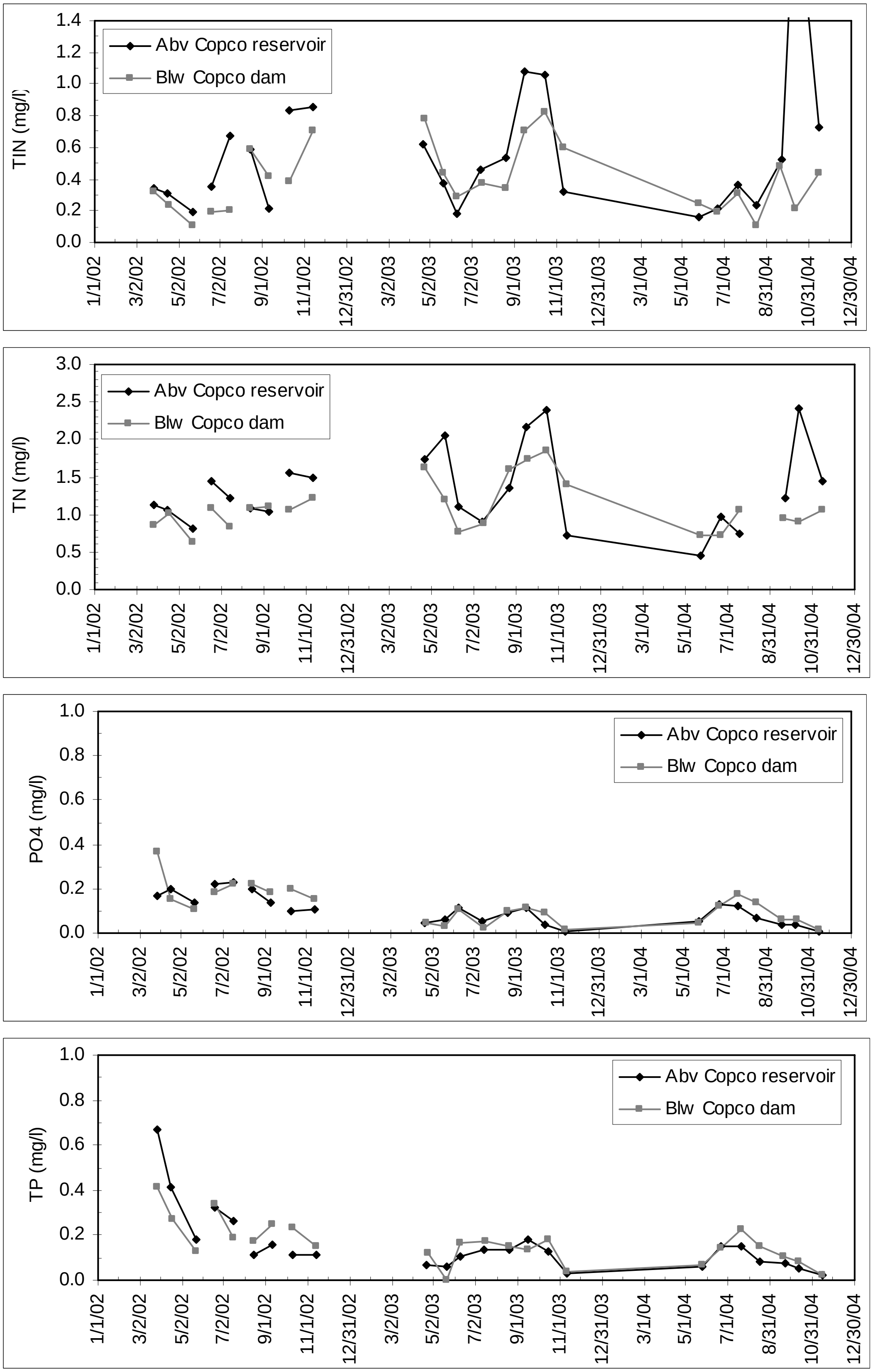


Figure 4-5. Observed total inorganic nitrogen (TIN), total nitrogen (TN), orthophosphate (PO4), and total phosphorus (TP) in the Klamath River above and below Copco reservoir, 2002-2004.

4.2.1.3 Iron Gate Reservoir

Iron Gate reservoir extends from the reservoir's headwaters (RM 197) to Iron Gate dam (RM 190.1). The reservoir has a storage capacity of approximately 50,000 acre-feet, and a maximum depth of approximately 160 feet near the dam. The reservoir's hydraulic residence times range from a few days under winter high flow events to approximately three to four weeks under typical lower flow conditions during summer.

Like Copco reservoir, Iron Gate reservoir stratifies during the warmer periods of the year, and reservoir profiles suggest density dependent interflow or intrusion occurs within the reservoir. Because of these density driven flow conditions, the surface waters may have a residence time that is considerably longer than two to three weeks. These conditions allow the primary production in the photic zone to affect the flux of nutrients during transit through the reservoir. As a result, the observed concentrations of TIN, TN, PO4, and TP are generally lower in release waters than reservoir inflows (Figure 4-6).

4.2.1.4 Copco and Iron Gate Reservoirs in Tandem

Iron Gate reservoir is located only about 1.5 miles below Copco dam, and the two reservoirs essentially act in series because the Copco powerhouse essentially discharges waters directly into the Iron Gate reservoir headwaters. The orientation of these two reservoirs in series has an important added effect on the fate of nutrients during transit through the reservoirs. As discussed in section 3.2, the total annual net retention of nutrients by Copco and Iron Gate reservoirs is substantial when both reservoirs are considered in combination (Figure 3-1). The observed concentrations of TIN and TN in particular are consistently lower in water released from Iron Gate reservoir than in the water entering Copco reservoir (Figure 4-7). These observations support the conclusion that Iron Gate and Copco reservoirs act as a net sink for both total nitrogen and total phosphorous over the long term (i.e., on a seasonal or annual basis).

It is important to note that the tandem effect of Copco and Iron Gate reservoirs on upstream-downstream nutrient flux does not occur instantly, but rather over several days or weeks due to both the duration of the upstream conditions and the extended residence time of the reservoirs. For example, such a lag is evident in the observed TIN data for 2003 in Figure 4-7. Further evidence of this lag effect is examined in section 4.5 of this document based on modeling results. Because of this lag, it is expected that at times the nutrient concentration in release waters from Iron Gate reservoir on a given day may be greater than in the inflowing waters to Copco reservoir on the same day, even though the reservoirs act to retain and reduce the loads from these nutrient "events" as they move through the reservoirs.

Copco and Iron Gate reservoirs are productive during summer months, and can produce large nuisance algal blooms if the influx of nutrients via the inflow increases in response to upstream conditions (e.g., large algal blooms, severely impaired water quality conditions in Upper Klamath Lake and Keno reservoir). The hydraulic residence (or transit) times of Copco and Iron Gate reservoirs play an important role in the processing of the substantial loads of nutrient and organic matter from upstream sources, notably Upper Klamath Lake. Water travel times, and corresponding interflow or intrusion characteristics within these reservoirs are important to determining how the short-term fluxes of nutrients and organic matter changes in reaches of the

Klamath River in the Project area and downstream of Iron Gate dam. Further analysis of these effects, based on modeling results, is provided in the section 4.3 of this document.

4.2.2 Nutrient Data from River Reaches in the Project Area

4.2.2.1 Keno Reach

The Keno reach of the Klamath River extends from Keno dam (RM 233.3) to the headwaters of J.C. Boyle reservoir (RM 228.2). Mean annual flow in the reach is on the order of 1.12 MAF. The reach is characterized by a steep, bedrock canyon, and has no appreciable tributaries or diversions. The hydraulic residence time in the reach varies based on flow (which can vary considerably over the period of a few days), but is approximately 5 hours under typical summer flow conditions.

Observed concentrations of TN, PO4, and TP in inflowing waters to the reach (from Keno dam) are similar to those exiting the reach (to J.C. Boyle reservoir) (Figure 4-8). Although TN is almost unchanged in the reach, TIN is consistently higher at the downstream end of the reach, the result of the conversion of organic matter from Keno reservoir to inorganic nitrogen enroute to J.C. Boyle reservoir. The ability of river reaches like the Keno reach to process organic matter and nutrients is a function of many factors including flow volume, flow velocity and travel time, reach morphology, light extinction characteristics, water quality of reach inflows (upstream and tributaries) – issues that vary in space and time. The Keno reach appears to provide conditions for mineralization (decay) of some organic matter to inorganic nitrogen. However, observed concentrations of TN and TP stay consistent through the Keno reach (Figure 4-8), suggesting that this 5-mile river reach is doing little to reduce total nutrient levels under typical conditions. The effects of nutrient retention in river reaches and reservoirs on production of attached algae are further examined in the section 4.4 of this document.

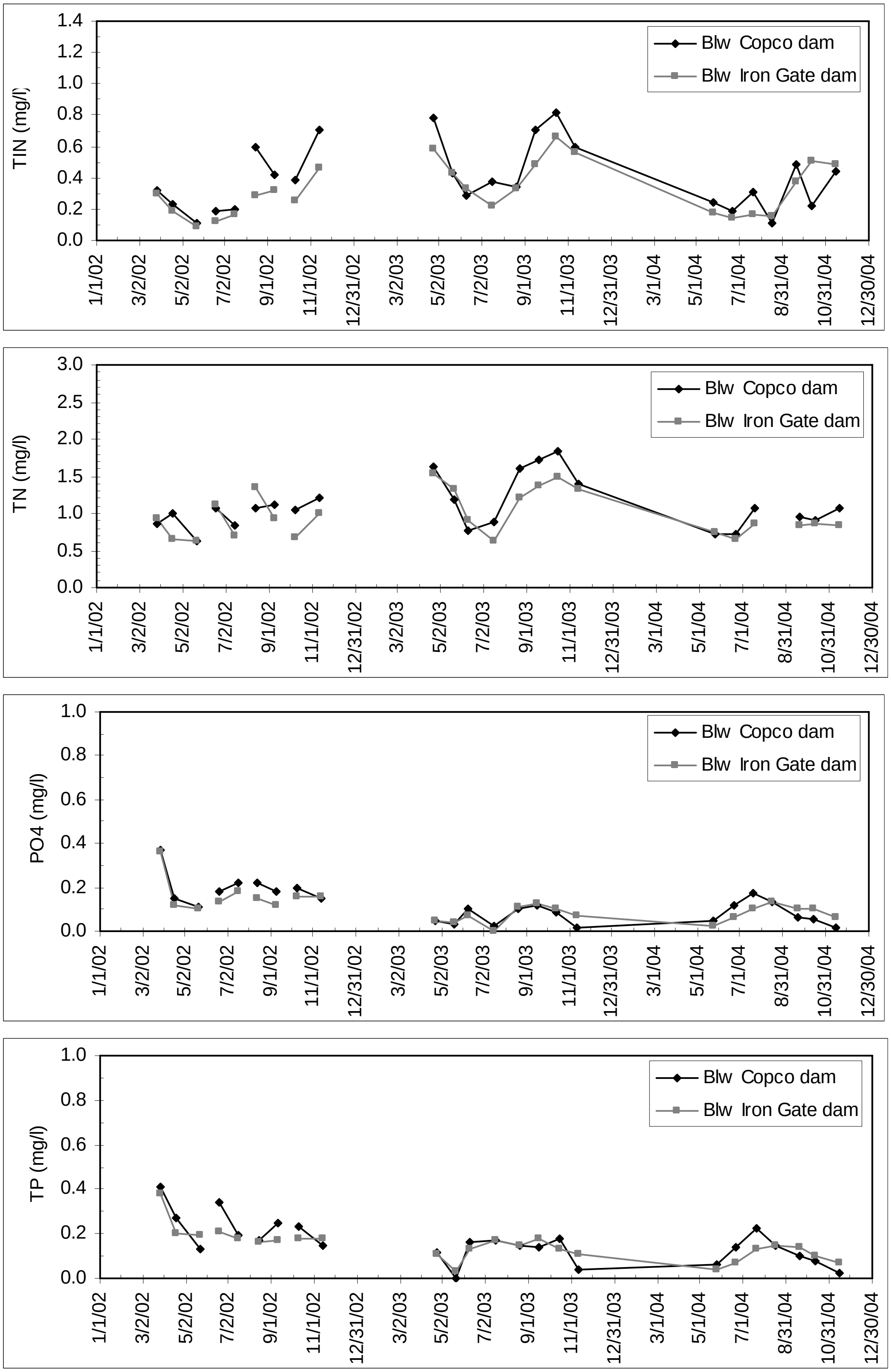


Figure 4-6. Observed total inorganic nitrogen (TIN), total nitrogen (TN), orthophosphate (PO4), and total phosphorus (TP) in the Klamath River above and below Iron Gate reservoir, 2002-2004.

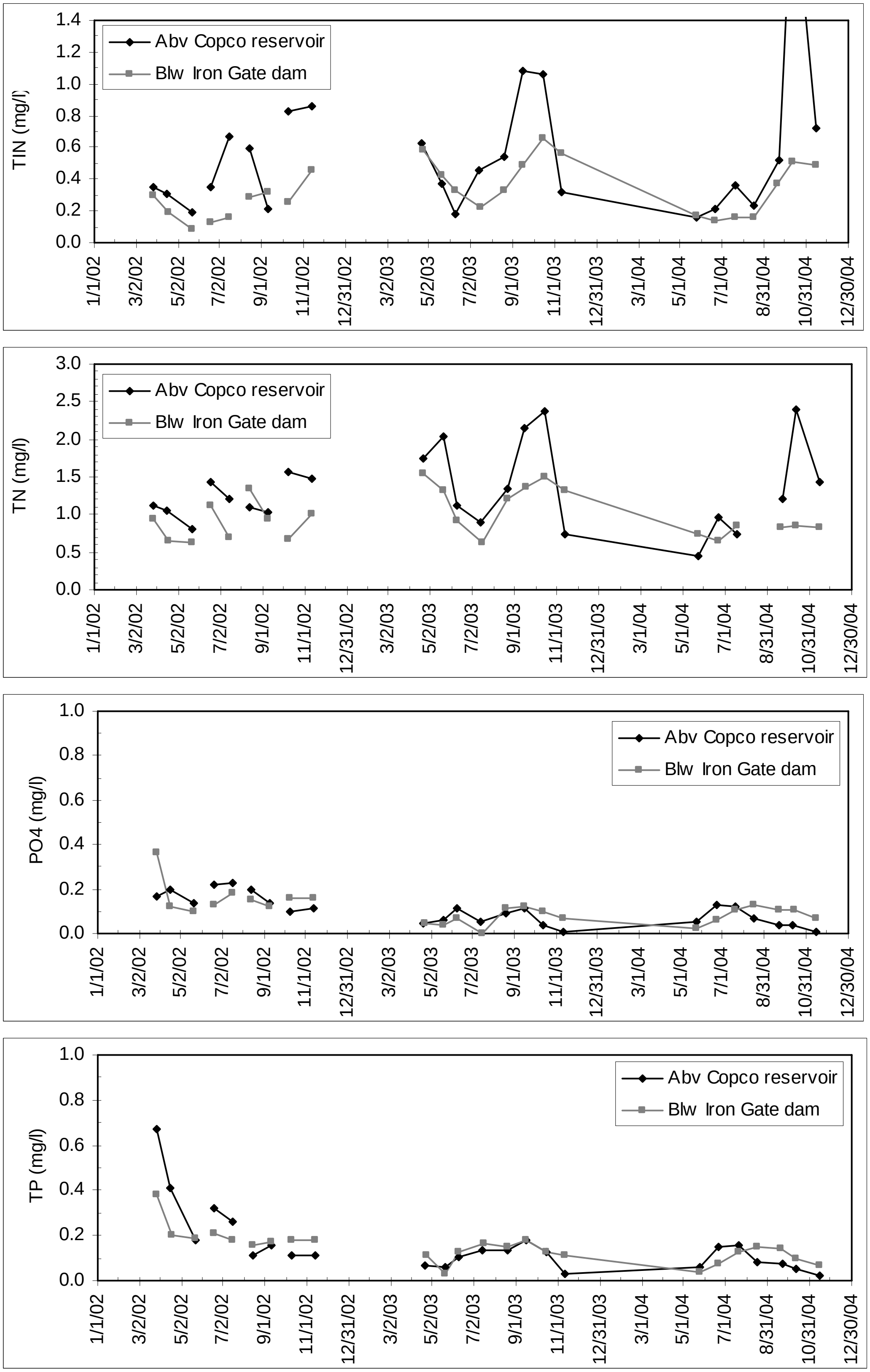


Figure 4-7. Observed total inorganic nitrogen (TIN), total nitrogen (TN), orthophosphate (PO4), and total phosphorus (TP) in the Klamath River above Copco reservoir and below Iron Gate reservoir, 2002-2004.

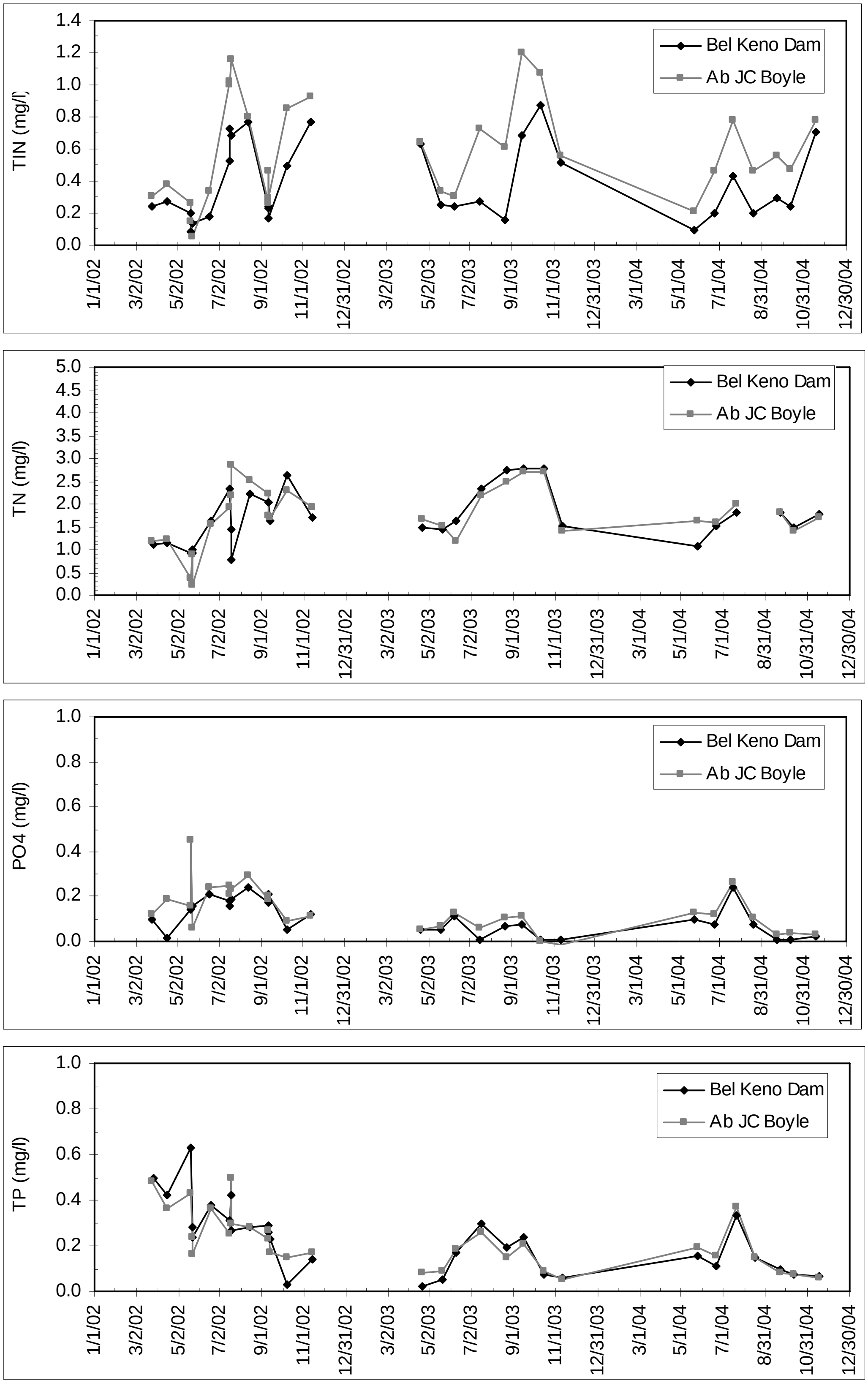


Figure 4-8. Observed total inorganic nitrogen (TIN), total nitrogen (TN), orthophosphate (PO4), and total phosphorus (TP) in the upper and lower end of Keno reach, 2002-2004.

4.2.2.2 J.C. Boyle Bypass and Peaking Reaches

The J.C. Boyle bypass and peaking reaches extends from J.C. Boyle dam (RM 224.6) to the headwaters of Copco reservoir (RM 203.1) – a distance of 21.5 miles. The J.C. Boyle bypass reach extends from J.C. Boyle dam (RM 224.6) to J.C. Boyle powerhouse (RM 220.4) – a distance of approximately four miles. Approximately ½ mile downstream of J.C. Boyle dam, large springs enter the river, allowing the river to gain 220 to 250 cfs of spring input – resulting in a base flow of approximately 300 to 350 cfs in the reach. The hydraulic residence time in the steep bypass reach is on the order of hours under base flow conditions, but can be considerably less during larger flow events (i.e., during spill at the dam).

The J.C. Boyle peaking reach extends from J.C. Boyle powerhouse (RM 220.4) to the headwaters of Copco reservoir (RM 203.1). This reach often experiences daily flow fluctuation as a result of peaking operations at J.C. Boyle powerhouse. Under non-generation flow conditions (powerplant off-line) of about 350 cfs, the reach is dominated by bypass reach waters. Under peaking operations, flows increase over the span of a few hours to about 1,500 cfs (one unit peaking) or about 3,000 cfs (two-unit peaking), and continue until operations are ramped down later in the day. Residence time through the peaking reach varies depending on flow conditions; during peaking operations transit time may range from 8 to 10 hours, while under low flow conditions the transit time may be twice as long.

The nutrient data suggests that the primary “process” in the J.C. Boyle bypass and peaking reaches is dilution from spring inflows. The ratio of release from J.C. Boyle dam to spring inflows is approximately 1:2. Comparisons of TN and TP concentrations at the top and bottom of the bypass reach indicate that in almost all instances concentrations are reduced consistent with this ratio, i.e., concentrations are reduced by approximately two-thirds (Figure 4-9). TIN and PO4 are also often reduced consistent with this ratio, but there are instances when TIN and PO4 are more equal at the bottom of the reach than at the top. We presume that the steep and turbulent conditions in the J.C. Boyle bypass reach create sufficient conditions to support some oxidation of organic and inorganic forms.

Because of peaking operations, monitoring data in the peaking reach are collected under different flow regimes. Samples may be collected under full peaking flows, under non-peaking operations, or during transition between high and low or low and high flows. As a result, estimates of changes in nutrient fluxes between the upper end of the bypass reach and the lower end of the peaking reach include the combined effects of changing operations, dilution from spring inflows, and possibly some processing (oxidation of organic and inorganic forms) (Figure 4-10). For example, Figure 4-10 shows a general reduction in concentration that reflects the dilution from spring inflows in the bypass reach. However, in contrast to Figure 4-9, Figure 4-10 shows spikes in concentration that reflect the discharge from the J.C. Boyle powerhouse of nutrient-enriched waters from the river upstream. Nonetheless, when compared to the river upstream (Figure 4-8), it appears that only modest change in nutrients occurs during the relatively short residence time through the J.C. Boyle bypass and peaking reaches. The bulk of the water transits this reach with the peaking flows, resulting in increased depth, velocity, and light extinction. Phytoplankton generally perform poorly in such river conditions, and the substrate in this steep rocky canyon further limits attached algae forms, thus limiting the ability of nutrients to be acquired by aquatic plants.

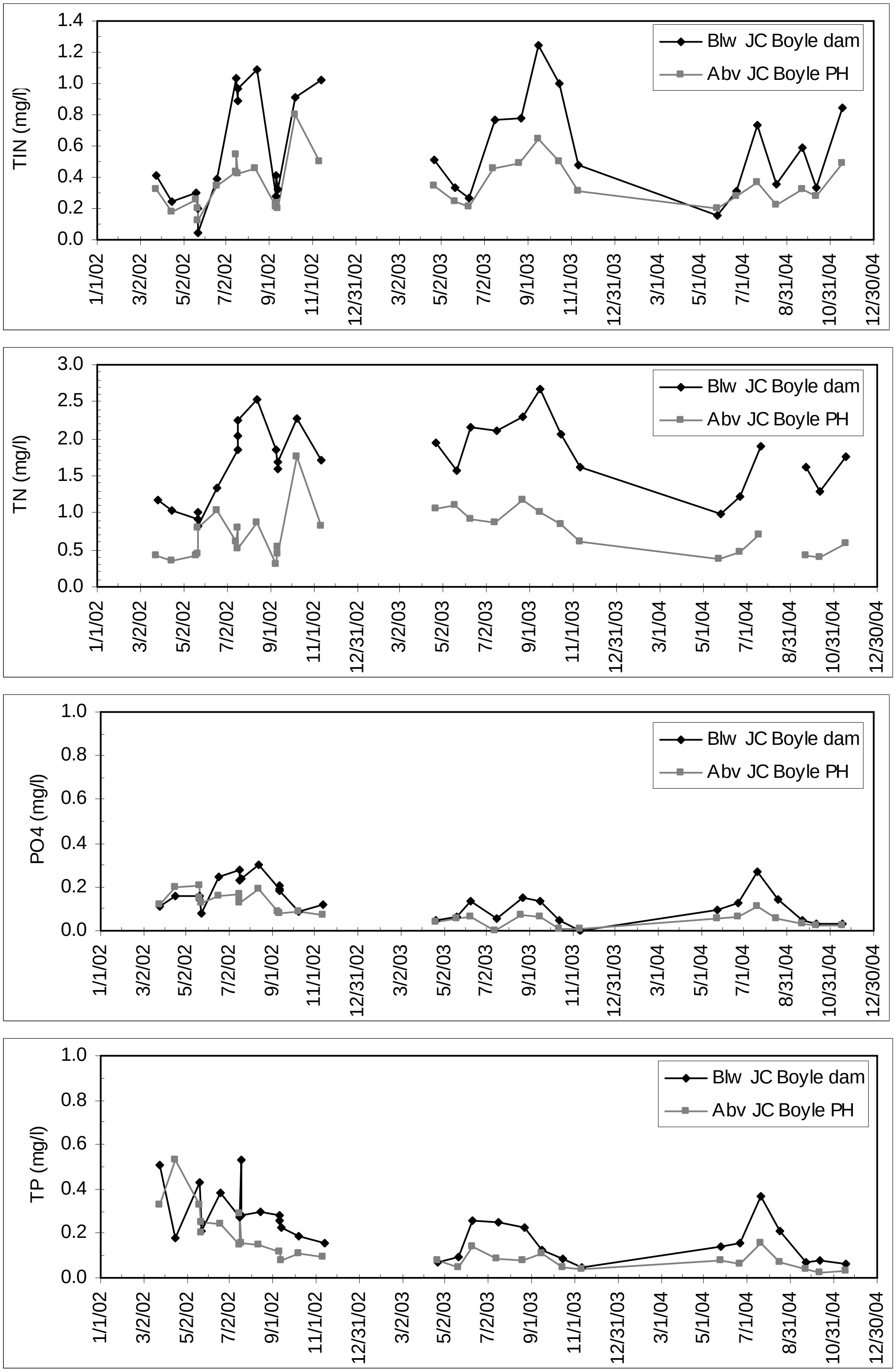


Figure 4-9. Observed total inorganic nitrogen (TIN), total nitrogen (TN), orthophosphate (PO4), and total phosphorus (TP) in the upper and lower end of the J.C. Boyle bypass reach, 2002-2004.

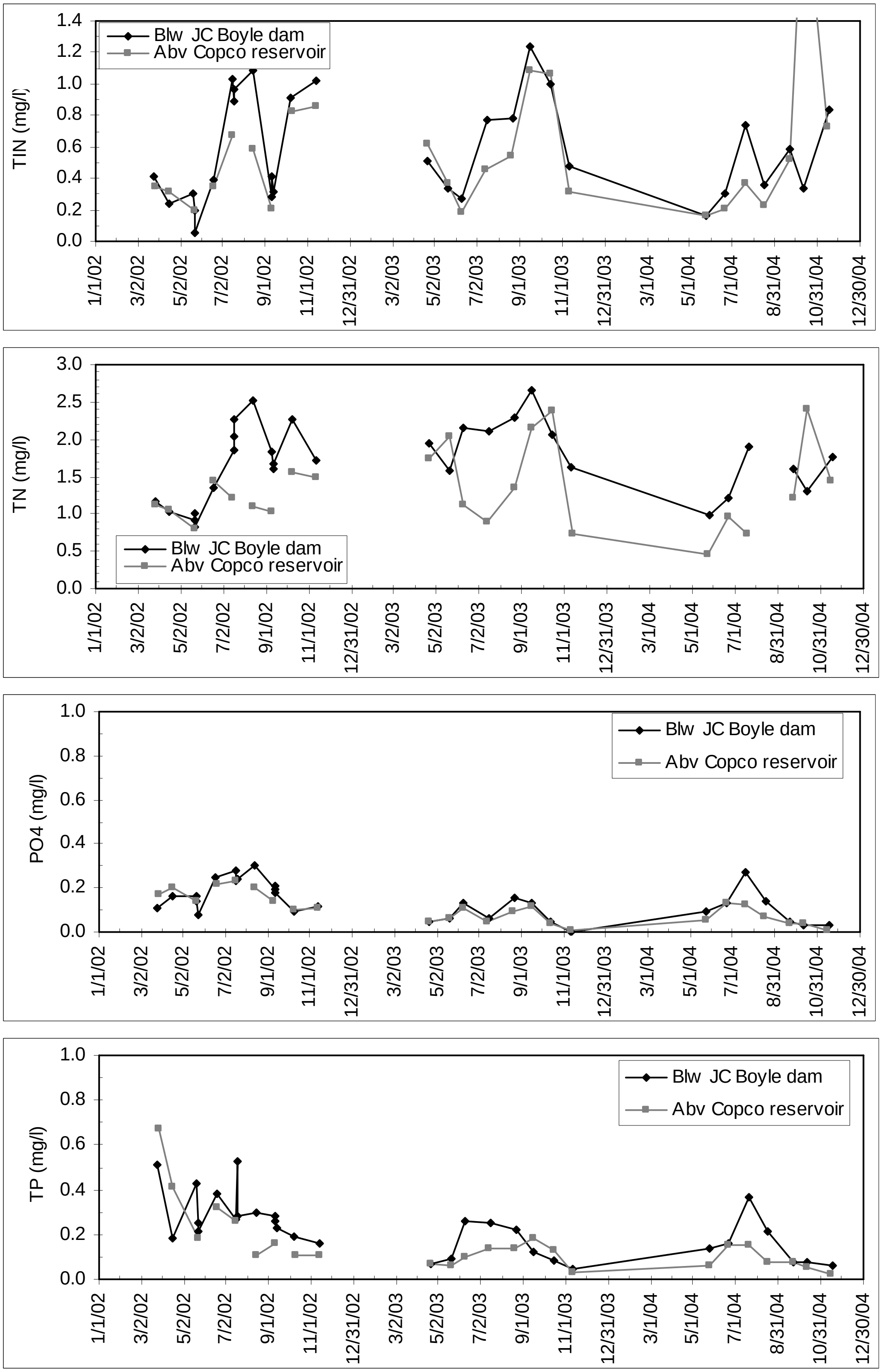


Figure 4-10. Observed total inorganic nitrogen (TIN), total nitrogen (TN), orthophosphate (PO4), and total phosphorus (TP) in the upper end of the J.C. Boyle bypass reach and lower end of the J.C. Boyle peaking reach, 2002-2004.

4.2.2.3 Klamath River from Iron Gate Dam to the Shasta River

The Iron Gate dam to Shasta River reach extends from Iron Gate dam (RM 190.1) to the river near the mouth of the Shasta River (RM 177.3). Travel time through the reach under typical summer flows is on the order of about 12 hours.

The Klamath River downstream of Iron Gate dam is a eutrophic stream, largely due to upstream sources of nutrients, particularly Upper Klamath Lake. Presumably due to the short residence time of river flows between Iron Gate dam and the mouth of the Shasta River, the observed concentrations of nutrients in waters released to the reach from Iron Gate dam are similar to those at the end of the reach (Figure 4-11). (Note: data for 2003 for the site near the mouth of the Shasta River is incomplete).

Although PacifiCorp has not collected data on attached benthic algae (periphyton) in the Iron Gate dam to Shasta River reach, our visual observations during trips for relicensing studies indicated that periphyton growth can be extensive in the reach during the late spring-summer period when flows are relatively low and water temperatures are relatively warm. The river's high nutrient content and the relatively broad shallow nature (and relatively stable bed) of the reach from Iron Gate dam to the Shasta River provide a favorable environment for such extensive periphyton growth.

Other field observations suggest dynamic changes in attached benthic algae (periphyton) can occur in the Klamath River from Iron Gate dam to the mouth of the Shasta River. In September 2004, Eilers (2005) sampled periphyton at ten locations in the Klamath River from immediately below Iron Gate dam (RM 189.7) to just above the Trinity River (RM 43.5). He observed consistently high periphyton coverage (near 80 percent) on stream rocks immediately below Iron Gate dam (RM 189.7), but consistently low periphyton coverage (near 10 percent) on stream rocks just several miles downstream near the Collier Rest Area at the I-5 bridge (RM 178). Eilers (2005) also observed high periphyton chlorophyll content (near 50 ug/cm^2) in samples immediately below Iron Gate dam, but very low periphyton chlorophyll content (less than 5 ug/cm^2) in samples just several miles downstream near the Collier Rest Area at the I-5 bridge. Interestingly, downstream of the Collier Rest Area, both periphyton coverage and chlorophyll content increased gradually and consistently to peak levels in the Klamath River near the mouth of the Salmon River (RM 67). Eilers (2005) indicates that the trends observed were not conclusive, particularly since significant changes in the river's flow regime occurred just before the September survey that may have altered the density of periphyton in the river.

These field observations suggest that periphyton growth can be extensive in the reach, particularly during the late spring and summer period. However, given that the observed concentrations of nutrients do not change appreciably in the reach from Iron Gate dam to the Shasta River (Figure 4-11), it appears that significant retention of nutrients does not occur in the reach even with this substantial periphyton growth. This suggests that the large loads of nutrients in the river from upstream sources, particularly Upper Klamath Lake, are far in excess of what are required to supply periphyton growth, and river reaches such as this do not provide nutrient "recovery zones" as Asarian and Kann (2006) contend, particularly in the face of such large nutrient loads.

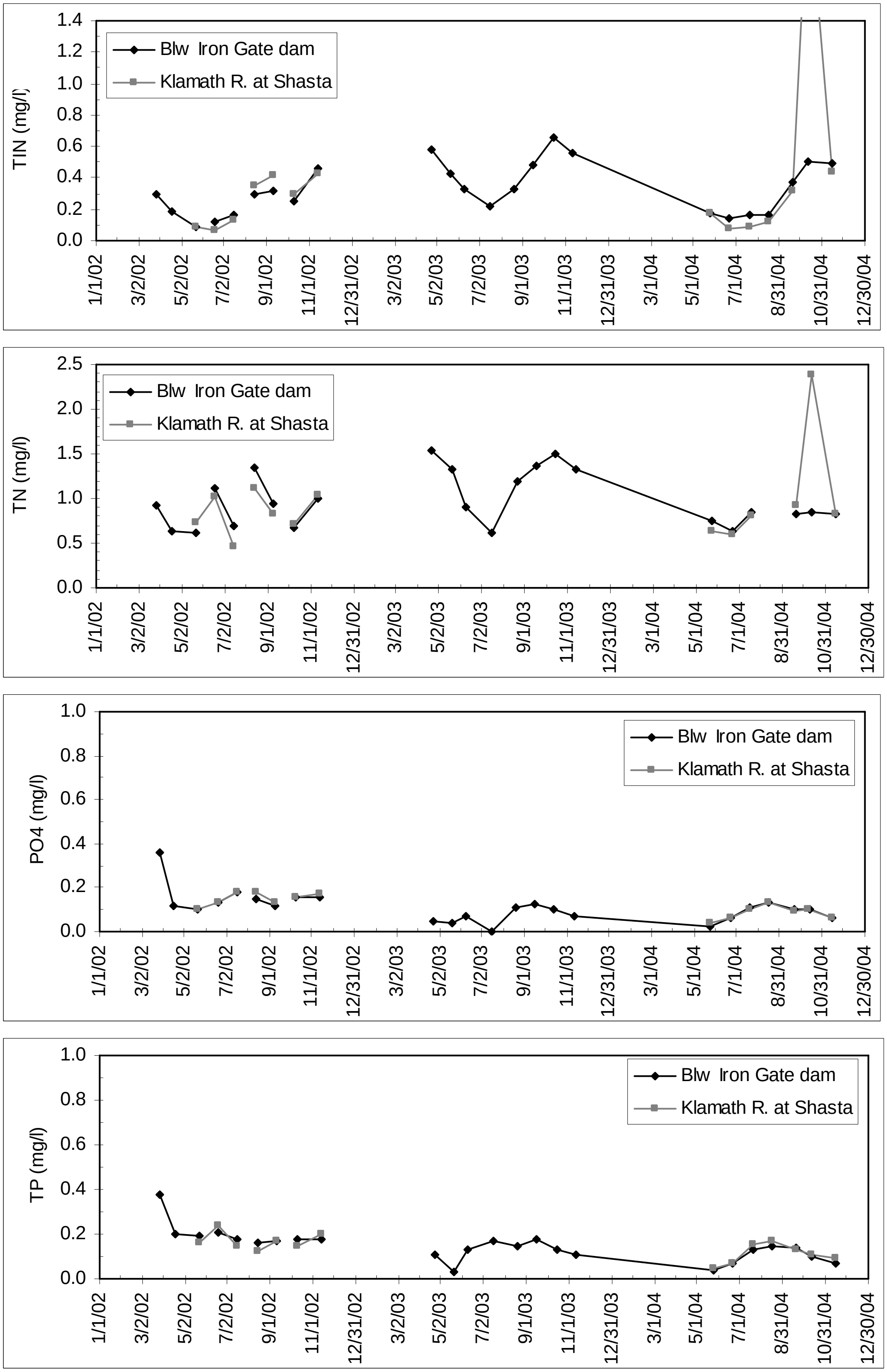


Figure 4-11. Observed total inorganic nitrogen (TIN), total nitrogen (TN), orthophosphate (PO4), and total phosphorus (TP) in the upper and lower end of the Iron Gate to Shasta River reach, 2002-2004.

4.3 PROCESSING OF ORGANIC MATTER IN THE KLAMATH RIVER WITH AND WITHOUT PROJECT RESERVOIRS

A straight-forward conceptual means of illustrating the effects of the Project reservoirs on the processing and retention of nitrogen in organic matter in the upper Klamath River is by estimating theoretical rates of organic matter decay with and without the reservoirs. As described in section 4.1, very large loads of algae biomass are discharged to the upper Klamath River from Upper Klamath Lake, particularly during summer, and these loads diminish in consistent fashion with distance from Keno reservoir through the Project area reservoirs and river reaches downstream to near the mouth of the Shasta River (Figures 4-1 and 4-2).

The decomposition of these very large algae loads during downriver transit is not only a large potential source of nitrogen (via mineralization) but also of biochemical oxygen demand (BOD) imposed on the water's dissolved oxygen (DO) content. Gunnison and Alexander (1975) compared various algae for susceptibility to decomposition and showed that blue-green algae, like *Aphanizomenon* and *Anabaena*, lost cell structure rapidly during the decomposition process. Fallon and Brock (1979) found that mineralization of inorganic nitrogen and short-term oxygen demand correlated well with algae biomass (as measured based on chlorophyll *a* content of samples). Fallon and Brock (1979) also derived kinetic data that suggested that mineralization of inorganic nitrogen and short-term oxygen demand from blue-green algae decay approximately follows a first-order decay rate. As such, decay is quite rapid during the initial stages of the decomposition process (e.g., about ¾ of the oxygen demand present would on average be expended within about 10 days).

As a first step in assessing organic matter decay with and without the reservoirs, the travel times of flows for the Klamath River from Link Dam to Turwar were calculated for existing conditions and hypothetical without-Project conditions. The information for river reaches was calculated using simulated velocities from the RMA-2 model and known river distances (river miles) along the Klamath River. The travel time in reservoirs was determined using CE-QUAL-W2 "age of water." Table 4-1 lists reach travel time with and without dams (based on summer flows) in number of days.

Table 4-1. Reach Travel Time With and Without Project Reservoirs for Typical Summer Flows

	No. of Cumulative Days/(Reach Travel Time - days)		
	Existing Conditions	**Without All Reservoirs**	**Without Copco and Iron Gate Reservoirs**
Keno Dam	0	0	0
J.C. Boyle Dam	1.5 (1.5)	0.3 (0.3)	1.5 (1.5)
Copco Dam	20 (18)	1.2 (0.9)	2.4 (0.9)
Iron Gate Dam	42 (22)	1.5 (0.3)	2.7 (0.3)
Pacific Ocean	46 (4)	6 (4)	7 (4)

These estimates indicate that travel times are much shorter under hypothetical without-Project conditions (Table 4-1). The estimated travel time under existing conditions from Link dam to the Klamath River estuary is about 46 days. From Link dam to Iron Gate dam the under existing conditions is about 42 days. By comparison, the estimated travel time under hypothetical without-Project conditions from Link dam to the Klamath River estuary is about 7 days, and from Link dam to Iron Gate dam is about 2 to 3 days.

As a second step in assessing organic matter decay with and without the reservoirs, the processing/decay of upstream organic matter was estimated based on first-order decay rate at an assumed first-order decay coefficient (k) of 0.15 day^{-1} (based on information in Corbitt 1990). The k value yields an estimate of the rate of loss per day of oxygen demand, and this is an indication of the rate of organic matter decomposition.

The first-order reduction in organic matter from decay at an assumed first-order decay coefficient (k) of 0.15 day^{-1} is illustrated in Figure 4-12. This relationship indicates that about 80 percent of the organic matter present would decay within about 10 days. This is similar to the rate of mineralization of inorganic nitrogen and short-term oxygen demand from blue-green algae decay reported by Fallon and Brock (1979) as described above.

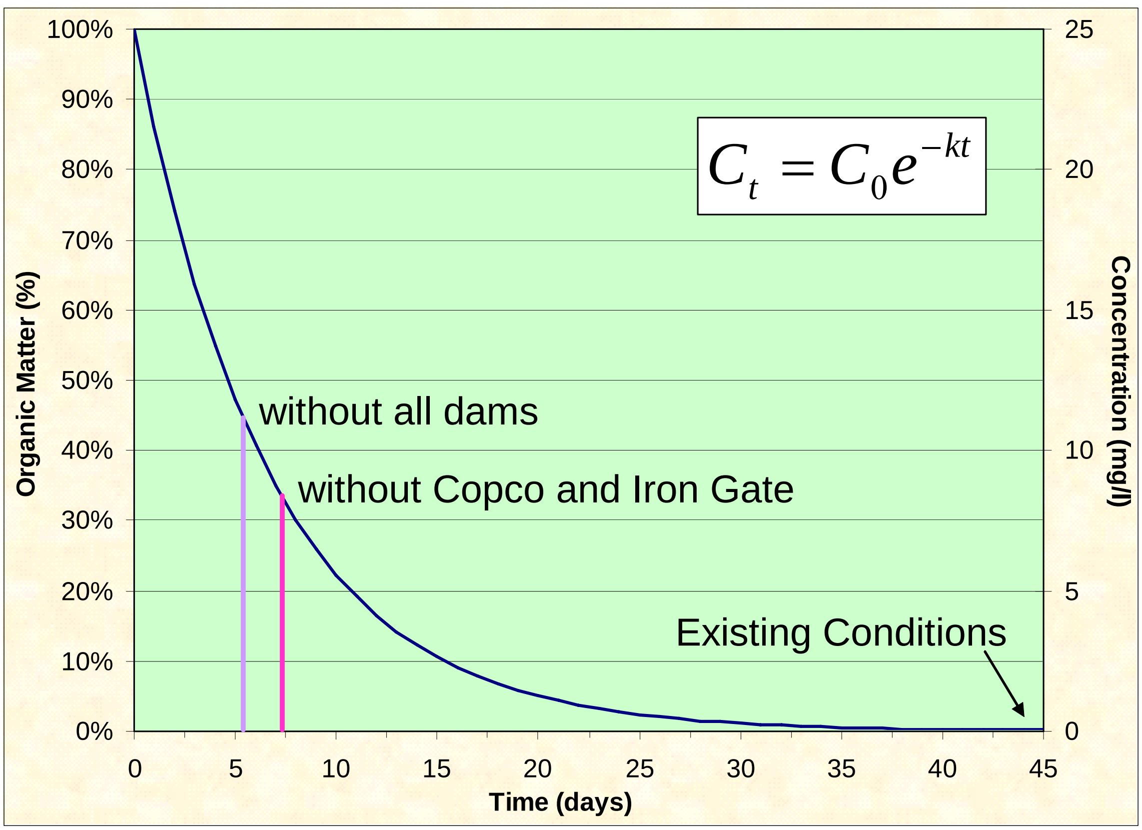


Figure 4-12. The first-order reduction in organic matter from decay at an assumed first-order decay coefficient (k) of 0.15 day^{-1}. The vertical lines on the graph indicate the amount of organic matter that would be processed in the river upon reaching the estuary under existing conditions, a hypothetical scenario without Copco and Iron Gate dams or reservoirs, and a hypothetical scenario without all Project dams or reservoirs.

The first-order reduction in organic matter from decay as illustrated in Figure 4-12 indicates that, under existing conditions, the processing of the loads to the upper Klamath River of upstream organic matter is largely completed by the time water travels past Iron Gate dam. By contrast, under hypothetical without-Project conditions, about 50 percent or more of the load of upstream organic matter would still be present as water travels past Iron Gate dam. This indicates that, in the absence of Project reservoirs, a substantial amount of organic matter would remain available throughout the lower Klamath River downstream of Iron Gate dam (Figure 4-13), acting as a source of inorganic nitrogen, phosphorus, and BOD from ongoing decay. This substantial remaining organic matter would exacerbate water quality impairment in the river downstream of Iron Gate dam to the estuary by increasing BOD, potentially reducing DO, and further promoting growth of benthic algae (periphyton).

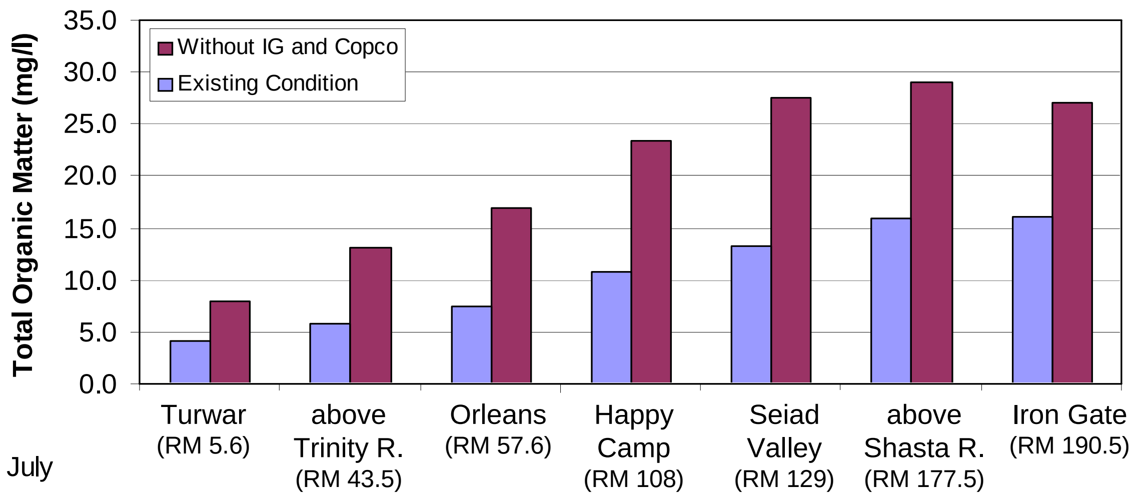


Figure 4-13. Assumed concentrations of organic matter in the Klamath River below Iron Gate (under existing conditions and a hypothetical condition with Copco and Iron Gate reservoirs) based on calculations using the first-order decay of organic matter.

4.4 NITROGEN RETENTION IN RESERVOIR AND RIVER REACHES IN THE UPPER KLAMATH RIVER

The Project itself is not a source of nitrogen that could contribute to excess production in the Klamath River below the Project area. For example, as discussed in section 4.2, data collected during 2002-2004 show that total nitrogen and inorganic nitrogen are substantially lower below Iron Gate dam than below Keno dam (e.g., compare TIN and TN plots in Figures 4-8 and 4-11), and are consistently lower below Iron Gate reservoir than above Copco reservoir (Figure 4-7).

As discussed in section 3.3, Kann and Asarian (2005) calculated nutrient retention in Copco and Iron Gate reservoirs based on nutrient data collected by PacifiCorp during March to November 2002, with some supplemental data from USFWS for June through mid-September 2002. As mentioned in section C3.5, Kann and Asarian (2005) developed inappropriate daily time-series of "nutrient loadings" from this monthly data to assess nutrient retention in the reservoirs. Interestingly, there are more appropriate monthly nutrient retention values listed in Kann and Asarian's (2005) Tables 5 and 6 that are not discussed by the report's authors. The TN and TIN values from Kann and Asarian's (2005) Tables 5 and 6 are summarized in Table 4-2. These monthly results indicate that Copco and Iron Gate reservoirs act to retain nutrients in most months.

Overall, the monthly nitrogen retention values summarized in Table 4-2 indicate that the reservoirs acted to retain a significant percentage of inflowing TN (21 percent) and TIN (42 percent) over the entire evaluation period of March-November 2002. This generally corresponds to previous conclusions from PacifiCorp's FLA analysis. Given the large inflowing nitrogen load of nearly 600 metric tons to Copco reservoir over the entire evaluation period of March-November 2002, the substantial net retention provided by Copco and Iron Gate reservoirs is an important process for reducing downstream loads to the Klamath River below Iron Gate dam.

In their subsequent report, Asarian and Kann (2006) again developed inappropriate *daily* time-series of "nutrient loadings" from monthly data to estimate nutrient retention in various reaches of the Klamath River below Iron Gate dam. On the basis of their analysis, Asarian and Kann (2006) concluded that "the river consistently provides moderate positive retention, while the combined retention of Iron Gate and Copco reservoirs alternates between positive and negative values". However, examination of more appropriate total nutrient retention values listed in Asarian and Kann's (2006) Table 8 suggests an opposite conclusion – that is, the reservoirs consistently provide nitrogen retention, while the retention of river reaches varies widely between positive and negative values. The total TN retention values from Asarian and Kann's (2006) Table 8 are summarized in Table 4-3. These results indicate that, based on 2001-2002 nutrient data, the river reaches of the Klamath River below Iron Gate dam (as defined by Asarian and Kann 2006) varied between as much as a positive net retention of 115 metric tons over the 42-mile reach from Happy Camp to Orleans to a negative net retention of 92 metric tons over the 34-mile reach from Martins Ferry to Klamath Glen.

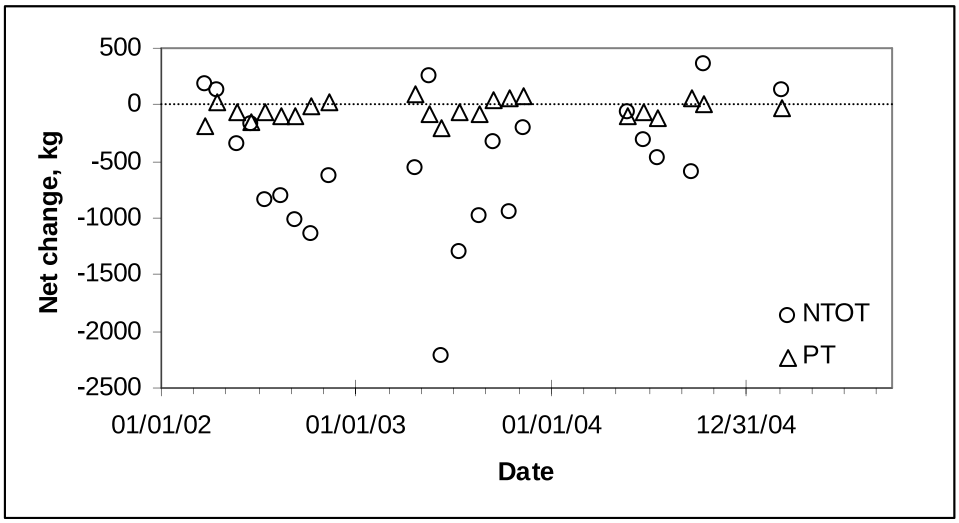
Table 4-2. Summary of total nitrogen (TN) and total inorganic nitrogen (TIN) retention in Copco and Iron Gate reservoir (in metric tons) as reported by Kann and Asarian (2005) based on 2002 nutrient data.

	Klamath above Copco Reservoir	**Klamath below Copco Reservoir**	**Klamath below Iron Gate Reservoir**	**Total Net Retention**
TN				
April	114	100	89	25
May	85	71	65	20
June	71	69	48	23
July	75	67	59	16
August	48	40	58	-10
September	58	77	56	2
October	104	78	67	37
November	41	31	27	14
Total	*597*	*531*	*470*	*127*
TIN				
April	34	25	24	9
May	21	13	25	-4
June	19	10	7	12
July	31	13	12	19
August	22	15	13	9
September	20	11	17	3
October	55	30	21	34
November	24	17	12	12
Total	*226*	*134*	*132*	*94*

Table 4-3. Summary of net total nitrogen (TN) retention in reaches of the Klamath River below Iron Gate dam (in metric tons) as reported by Asarian and Kann (2006) based on 2001-2002 nutrient data.

	Iron Gate to Seiad Valley	**Seiad Valley to Happy Camp**	**Happy Camp to Orleans**	**Orleans to Martins Ferry**	**Martins Ferry to Klamath Glen**
Length (RM)	RM 190 to 129	RM 129 to 101	RM 101 to 59	RM 59 to 40	RM 40 to 5.8
Length (miles)	61	28	42	19	34
TN Retention					
2001	104	28	115	-38	-92
2002	80	-37	87	-76	62

The more consistent long-term nitrogen retention provided by the reservoirs, and more variable retention in the river reaches is also borne out by PacifiCorp's own computations of nitrogen flux. Figure 4-14 shows the difference in total N flux (in kg per sampling day) between the Klamath River above Copco reservoir and the Klamath River below Iron Gate reservoir using the empirical data for 2002 through 2005 from PacifiCorp and other sources as reported by Asarian and Kann (2006). As can be seen, the difference is nearly always negative, i.e., the nutrient quantity below Iron Gate reservoir is less than above Copco reservoir. The few instances when the quantity was higher below Iron Gate reservoir occurred outside the primary growing season of June to through September.



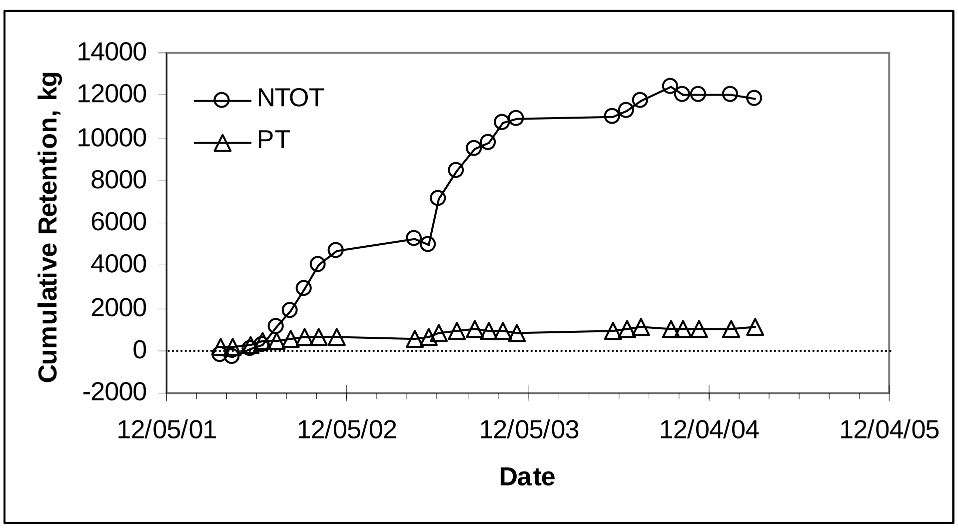


Figure 4-14. Net change and cumulative retention of total nitrogen (NTOT) and total phosphorus (PT) in Copco and Iron Gate reservoirs in 2002 through 2005, based on grab samples collected on the same or sequential days at both sites. Negative values in the upper plot indicate that the TN quantity at the downstream station (above J. C. Boyle) is less than at the upstream station.

Figure 4-15 shows the change in total N flux (in kg per sampling day) in the Klamath River between Keno Dam and J.C. Boyle reservoir using the actual empirical data for 2002 through 2005 (the same as that used by Asarian and Kann 2006). These values indicate wide variability in flux (or retention) of TN. About half of the flux values show a net negative retention in TN through this reach, and about half indicate a net positive retention in TN. This shows that N uptake and retention in this reach is variable and inconsistent, in contrast to the conclusion of Asarian and Kann (2006), who erroneously claim that the river reaches show consistent positive retention.

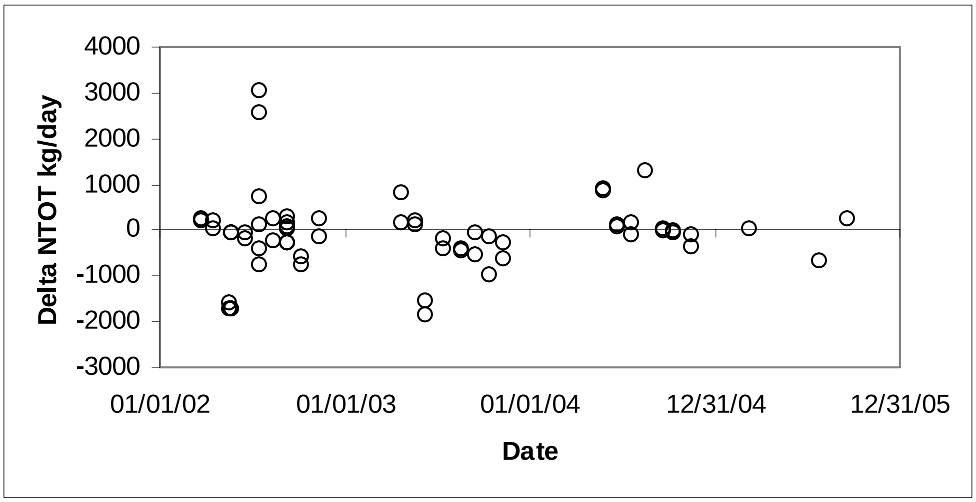


Figure 4-15. The change in total nitrogen flux between the Klamath River at Keno dam and the Klamath River above J. C. Boyle reservoir. Negative values indicate that the TN quantity at the downstream station (above J. C. Boyle) is less than at the upstream station.

Figure 4-16 shows calculated TN flux values (in kg per sampling day) for the Klamath River reach from Iron Gate dam (RM 189.7) to the I-5 bridge (RM 178) based on 1995-2004 nitrogen data. These values also indicate variable and inconsistent flux (or retention) of TN. About 1/3 of the flux values show a net negative retention in TN through this reach, and about 2/3 indicate a net positive retention in TN. In addition, there is no obvious seasonal trend; e.g., net negative retention (N export) occurs at least occasionally in all seasons.

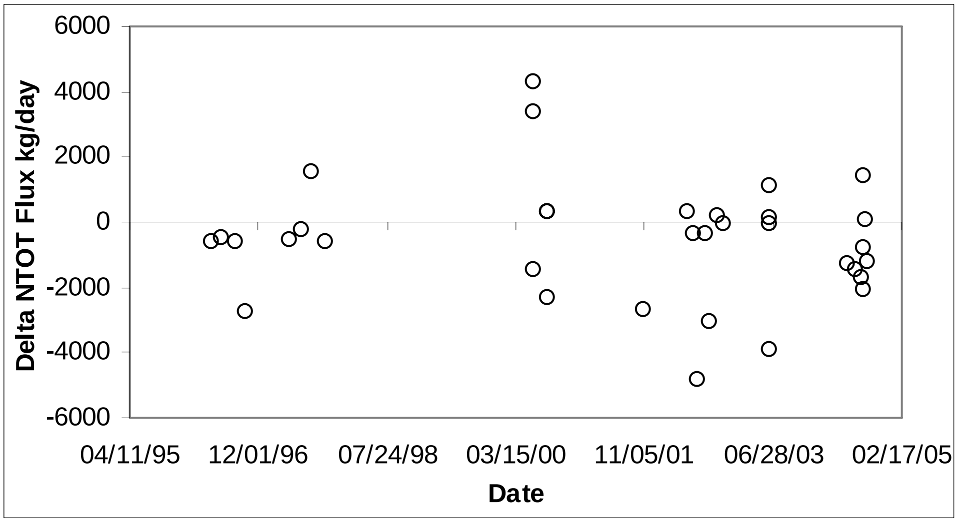


Figure 4-16. The change in total nitrogen flux between the Klamath River below Iron Gate dam and the Klamath River at the I-5 freeway bridge. Negative values indicate that the TN quantity at the downstream station (I-5) is less than at the upstream station.

4.5 ACCOUNTING FOR TRAVEL TIME "LAG" IN NUTRIENT TRENDS

As discussed in section C4.3 with respect to processing of organic matter, the travel times of flows in the river are important to understanding and explaining nutrient dynamics in the Klamath River. It is apparent that the very large loads of nutrients and organic matter in the Klamath River from Upper Klamath Lake and other upstream sources are often "event-driven" – that is, characterized by large "spikes" of organic matter delivered to the river following the collapse of large algae blooms that are typical in Upper Klamath Lake during the algae growing season (Figure 4-17). Therefore, it follows that such substantial nutrient "events" would have a downstream influence on nutrient concentrations at a particular point in space and time along the river. This influence would manifest itself in the form of a downriver "lag" in the event, the extent to which would depend on river travel times.

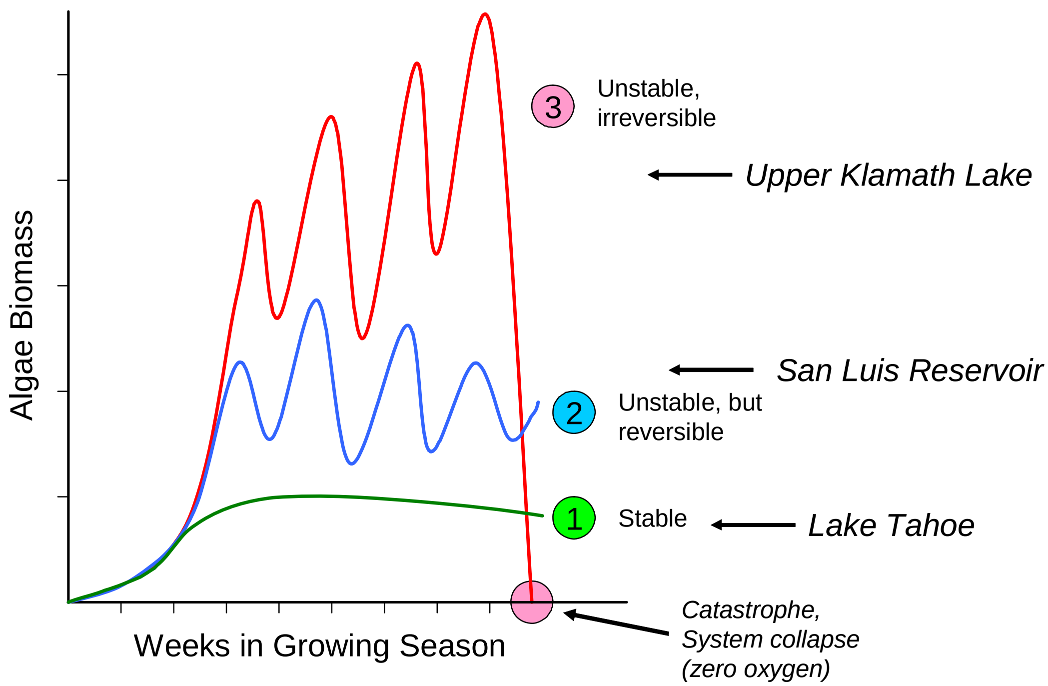


Figure 4-17. Conceptual diagram of algae bloom dynamics under differing trophic status from hypereutrophic (Upper Klamath Lake), to mesotrophic (San Luis Reservoir), to oligotrophic (Lake Tahoe).

To assess potential "lag", the downstream movement of a hypothetical nutrient event was simulated using PacifiCorp's water quality model (consisting of the RMA-2 dynamic hydraulic model and the RMA-11 water quality model as described in PacifiCorp 2004). PacifiCorp notes that Kann and Asarian (2006) prepared a critique of the PacifiCorp model in which they raise concerns regarding the PacifiCorp model's performance in simulating nutrients[2]. PacifiCorp recognizes that nutrient dynamics in the Klamath River system are complex, and that there is uncertainty in the ability of this, or any, numerical model to accurately predict changes in nutrient concentrations. However, the model reasonably simulates temporal and spatial trends in nutrient conditions that are instructive of potential Project effects when applied using a comparative analysis[3].

The output of model simulations of total nitrogen in the downstream direction for the Klamath River from Link dam to Iron Gate dam are shown in Figure 4-18 for existing condition and Figure 4-19 for hypothetical conditions without Copco and Iron Gate reservoirs (graphic labels correspond to the head of each reach). These simulations clearly illustrate the occurrence of a lag associated with travel time through the river and reservoir reaches, and also support the

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[2] It is important to point out that the model was developed within a comprehensive stakeholder process in which Kann and Asarian did not participate. Throughout the stakeholder process, the model's strengths and limitations were thoroughly documented, including a detailed expert review by Dr. Scott Wells of Portland State University. Kann and Asarian's (2006) critique does not acknowledge or account for the model's original purpose – that is, to identify trends and potential Project effects through a comparative analysis of different scenarios of Project operations and facilities. The model provided a basis for simulating scenarios and assessing potential Project effects that were not otherwise possible using only existing monitoring data. Notwithstanding the Kann and Asarian (2006) critique, PacifiCorp's model has provided valuable insights into system processes with regard to the impact of free flowing river reaches and Project dams and reservoirs on water quality.

[3] A comparative analysis compares one model simulation to another model simulation with the assumption that uncertainty in each run is approximately similar. In this fashion, the impact of a change in system response can be assessed by comparing a base condition with an alternative condition.

results as described in section 4.2 that total nitrogen decreases in the downstream direction, with substantial reductions in reservoirs and mostly modest reductions in river reaches. The empirical monitoring data (presented in section 4.2), although more variable, show similar trends that support this modeling result (Figure 4-20).

The large influx of nutrients from Link dam assumed in the simulated event shows no decrease through the short Link River reach. Subsequently, the event's "peak" works its way downstream showing a modest loss by the time it reaches Keno dam about a week later. In traversing the Keno dam to J.C. Boyle reservoir reach of the Klamath River, little change occurs. A reduction in the peak is shown during transit through J.C. Boyle reservoir, with the peak occurring later than at Link dam, accounting for the travel time through the reservoir. Subsequently, the concentration drops enroute to Copco reservoir through the J.C. Boyle peaking reach, which is almost entirely accounted for by the dilution from the 220-250 cfs of spring flow that enters the river in the J.C. Boyle bypass reach. Although the concentration drops, note that there is very little lag in the timing of peak concentration because of the short transit time through this riverine reach. These results indicate that river reaches are traversed relatively rapidly, which minimizes the potential for uptake and other loss mechanisms.

Further notable decreases in the simulated event are evident in Copco reservoir, as is the lag due to travel time through Copco reservoir. Similar decreases and lag times occur through Iron Gate reservoir. The reservoir lag times are considerable, allowing for processes such as decay and settling to occur – two processes well supported by literature and empirical data observations as described in sections 4.1 and 4.2. These lag times are important to recognize and consider when assessing the roles of nutrient retention in the system. If the reservoirs are assumed as static, isolated systems, and inflow and outflow nutrient conditions are compared on a given day, as done by Kann and Asarian (2005) and Asarian and Kann (2006), it is easy to mistakenly identify that the reservoirs are sources of nutrients. For example, as identified in Figure 4-18 in late October, Copco reservoir inflows may indicate higher levels of total nitrogen than Iron Gate reservoir outflows. However, Iron Gate is actually further reducing the input from Copco reservoir because of the considerable lag; that is, TN in Copco reservoir inflows has been reduced as the "peak" passes through the reservoirs.

Another process identified in the simulation results is that the lag displaces the peak influx of TN further into the future. In this case, the peak TN leaves Link dam in late July in the middle of the algae growth season. This peak does not manifest itself at Copco dam until some weeks later, and does not appear at Iron Gate dam until well into October, and then is considerably attenuated. This displacement of TN influx further into the future suggests the reservoirs have a beneficial effect on reducing downstream attached benthic algae (periphyton) in the river during the peak algae growing season. Without the reservoirs, the simulations indicate that peak TN conditions would occur coincident with maximum standing crop of benthic algae in late July or early August. With the reservoirs, the simulations indicate that peak TN conditions are lagged by several weeks into late summer and early fall when the benthic algae community is in overall senescence due to lower solar altitude and decreased day length. Conversely, in the absence of the Copco and Iron Gate reservoirs, it is likely that attached benthic algae (periphyton) would increase in the river downstream of Iron Gate during the peak algae growing season. Nutrients released to the river system below Iron Gate dam in mid-summer rather than in late summer and early fall would have a considerably greater potential for being sequestered in algal biomass.

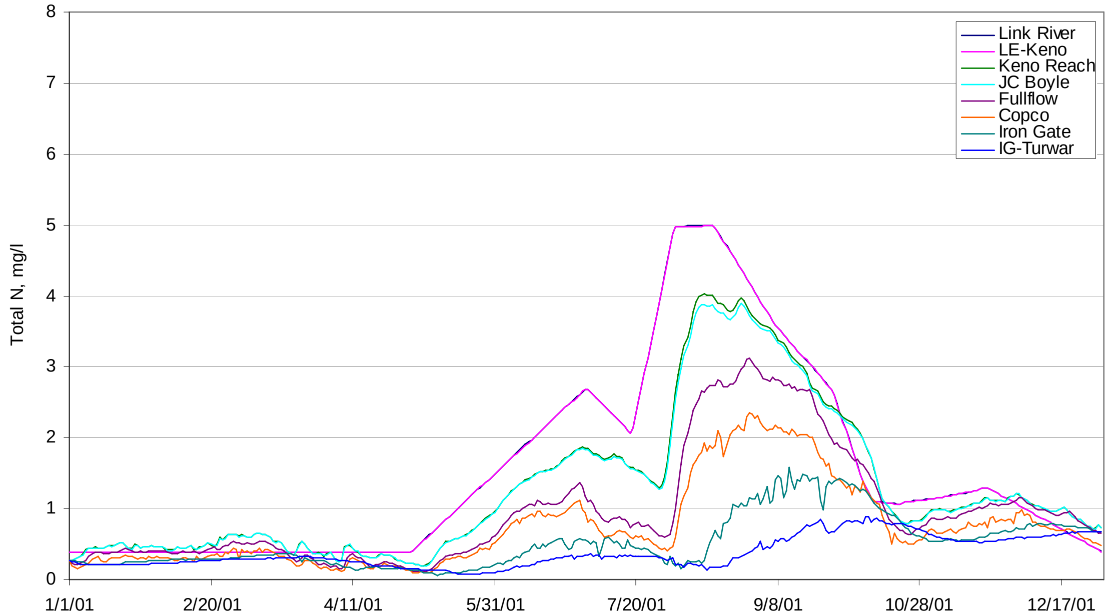

Figure 4-18. Model simulations of total nitrogen in the downstream direction for the Klamath River from Link dam to Iron Gate dam for existing condition (graphic labels correspond to the head of each reach).

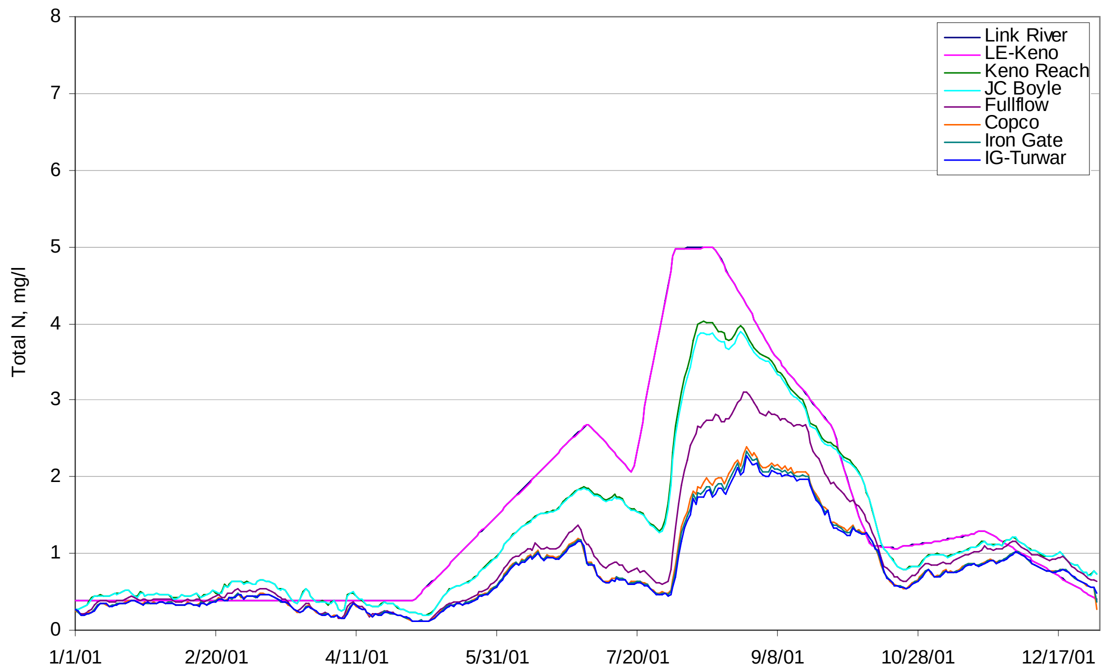

Figure 4-19. Model simulations of total nitrogen in the downstream direction for the Klamath River from Link dam to Iron Gate dam for hypothetical conditions without Copco and Iron Gate reservoirs (graphic labels correspond to the head of each reach).

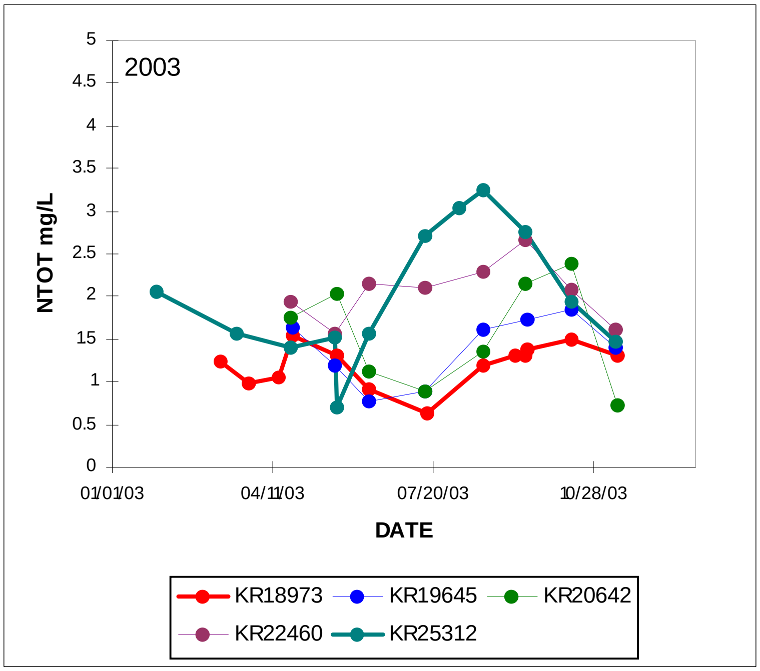

Figure 4-20. Observed total nitrogen values (NTOT; in mg/L) during 2003 in the Klamath River below Iron Gate dam (KR18973), above Iron Gate reservoir (KR19645), above Copco reservoir (KR20642), below J.C. Boyle dam (KR22460), and below Link dam (KR25312).

5.0 CONCLUSIONS

The key conclusions from information presented in this document include:

- There is no specific process or discharge associated with the Klamath Hydroelectric Project that contributes nutrients to the Klamath River. The nutrient concentrations observed in the Project area are the result of input from upstream sources, particularly Upper Klamath Lake, and as modified by physical and biological processes in the river and reservoirs during transit.
- Upper Klamath Lake is hypereutrophic – that is, it is highly-enriched with nutrients. Upper Klamath Lake has been recognized as the cause of poor water quality in the Klamath River, all the way to the mouth, since at least the 1950s. Upper Klamath Lake has had abundant blue-green algae blooms since at least the 1930s. Blue-green algae blooms have extended the entire length of the river even before the construction of Iron Gate dam.
- Nutrient concentrations and loads in the Upper Klamath Basin (upstream of the Project) have been and remain very large. These large nutrient concentrations and loads are unusual for a river headwaters and cause significant water quality impairments in the system.
- Nutrients traveling through the Project area undergo an overall annual net reduction compared to inflowing conditions. This annual net reduction is much greater than would occur in the absence of the Project reservoirs.
- In contrast to the conclusions of Asarian and Kann (2006), the actual data suggests that the reservoirs are retaining and reducing total nitrogen during most months.
- In contrast to the conclusions of Asarian and Kann (2006), the actual data suggest that the Klamath River reaches in the Project area have a small and inconsistent effect on the retention of total nitrogen.
- Periphyton in the Project area and in the Klamath River downstream of Iron Gate dam would be substantially increased in the absence of the Project reservoirs. This increase in periphyton could increase the habitat for the polychaete host of *C. shasta*.

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Attachment A

History of Investigation of Upper Klamath Lake Water Quality Impairment

UPPER KLAMATH LAKE AND ITS INPUT TO THE UPPER KLAMATH BASIN – A LONG HISTORY OF NUTRIENT ENRICHMENT AND WATER QUALITY IMPAIRMENT

Water quality in the upper Klamath River in the vicinity of the Klamath Hydroelectric Project is strongly influenced by the abundant amount of nutrients (particularly the various forms of nitrogen and phosphorous), organic matter, and algae entering the river from Upper Klamath Lake. Upper Klamath Lake is a large (121 mi2), shallow (mean depth about 7.8 feet) lake that is geologically old and classified as hypereutrophic (highly enriched with nutrients and supporting high abundance of suspended algae) (Johnson et al. 1985).

Concerns about the quality of water in the Upper Klamath Lake date back to the earliest recorded contacts with that body of water. Bortleson and Fretwell (1993) suggest that the lake has probably been naturally enriched with nutrients (eutrophic) since before settlement of the basin by non-Native Americans. A paleolimnological study by Eilers et al. (2001) revealed that Upper Klamath Lake has been a very productive lake, with high nutrient concentrations and blue-green algae, for at least the period of record represented by the study (about 1,000 years). However, recent lake sediments showed that the water quality of Upper Klamath Lake has apparently changed substantially over the past several decades. The most dramatic changes in the basin during the 20th century were the result of agricultural modifications. Since the 1930's, large areas of marsh surrounding the lake have been diked, ditched, and drained for agricultural use, leading to the decomposition of organic soils. Riparian vegetation has been degraded or completely eliminated.

Owing to its hypereutrophic state, Upper Klamath Lake has been the subject of scientific investigation dating back to the 1950s. A detailed history of scientific investigations of water quality in Upper Klamath Lake is provided by Wee and Herrick (2005). Wee and Herrick (2005) report that despite these investigations, no viable solutions to remedy the lake's hypereutrophic condition have been identified by these studies.

EARLY OBSERVATIONS AND STUDIES

The earliest recorded statement regarding Upper Klamath Lake's water quality was made on August 14, 1855 by Lieutenant Henry L. Abbot, who led an exploration party that surveyed a line for a proposed railroad running north from the Sacramento River to the Columbia River. Lt. Abbot commented upon the "dark color" and "disagreeable taste" of the waters of Klamath Lake, attributing these characteristics to decaying tule growth. Abbott's party spent a few days at the lake and camped in the vicinity of Cove Point. He reported that his party had difficulty drinking water from the lake: "The taste of the water was so disagreeable that several vain attempts were made to discover a spring in the vicinity."

Several other statements regarding the lake appear in the historical record throughout the next 50 years. In September 1879, Edward Drinker Cope, a prominent naturalist and one of the founders of American paleontology, visited the Upper Klamath Basin. He later remarked that Upper Klamath Lake's waters "are full of vegetable impurities living and dead and mollusca and crustacean abound everywhere." In 1894, Charles H. Gilbert, a professor of zoology at Leland Stanford Junior University, observed "many dead and dying fish" in both Upper Klamath Lake and the Klamath River. Barton Evermann and Seth Meek, investigators of fish populations for the U. S. Fish Commission, noted in 1896 that Upper Klamath Lake "contains considerable water vegetation." Everman and Meek observed that the lake became "more shallow year by year," because of the surrounding, "ever-increasing area of tule lands" and influx of "decaying vegetation."

The "impurities" of Upper Klamath Lake's water became the focus of a 1905 controversy in Klamath Falls regarding possible "disease laden ice." One Klamath Falls citizen commented "there is no pure ice in Klamath county … the waters of the lake are not fit to drink …" while another held that "the ice on the Upper [Klamath] Lake runs a chance of being infected with the flotsam and jetsam of that great body of water. A great many fish of the sucker species die and float into the waters of the lake, which give a chance for impurity…"

The first report of *Aphanizomenon* in Upper Klamath Lake was made by Ethel Ida Sanborn of Oregon State College in the summer of 1933. Sanborn found other algal varieties as well, including the additional blue-green forms *Anabaena* and *Microcystis*; diatoms *Melosira* and *Navicula*; and the green algae *Pediastrum*. In the late 1930s, researchers from the Department of Entomology at Oregon State College, D. E. Bonnell and D. C. Mote, found *Aphanizomenon flos-aquae* to be "abundant," but not always the predominant form of algae. They reported that the vast masses of suspended blue-green algae were "filamentous in form (*Aphanizomenon*) and during the summer so dense as to give the water only a quasi-liquid appearance." In 1938, Stanley Jewett, Jr. reported that *Aphanizomenon flos-aquae* was "taking over" Upper Klamath Lake, and becoming a "serious problem." Jewett observed: "During the summer months, the growth is so dense that foam turned up behind a power boat was green instead of white." Algae had formed a thick covering over the water of Howard Bay at the time of Jewett's study, creating a "strong pig-pen stench" in the vicinity. By 1957, *Aphanizomenon* populations had reached levels ten times those recorded by Bonnell and Mote less than two decades earlier.

THE 1950S: BEGINNING OF SCIENTIFIC STUDIES

By the 1950s, recurring blooms of algae in the Upper Klamath Basin had become a matter of greater concern for Klamath County residents, particularly to the increasing number of residents with property riparian to the waterways of the Basin. Fish and wildlife kills within the basin had increased in frequency. Dead waterfowl were found in the Link River during several successive springs. Fish kills reported in the Klamath River near Keno in 1928, 1938, 1944, 1950, and 1951 also caused apprehension regarding the state of the watershed. The Oregon State Game Commission's Fishery Division attributed the 1950 and 1951 fish kills on the Klamath River to a lack of dissolved oxygen.

In 1953, the Oregon State Game Commission undertook a study to learn about the causes and development of the lake's algal blooms, and their effects upon water quality in the upper Klamath River. The 1953 study found that the algal bloom for that year, composed almost entirely of *Aphanizomenon flos-aquae*, began to appear "in appreciable concentrations in late May and started to decline in October." The investigators observed *Aphanizomenon* as far downriver as Hamburg, California (below the confluence with the Scott River), and reported that later information gathered by the cooperating agencies indicated that the algae bloom extended the entire length of the river to the ocean. By August and September of that year, the algal blooms along the river had started to die. The decomposition of this mass of organic material reduced the dissolved oxygen content of the Klamath River at Keno to a minimum of 0.4 parts per million (ppm), far below the minimum to sustain fish life. In order for dissolved oxygen to be depleted to such low levels, the researchers estimated that the Klamath River would have to contain a level of pollution equal to the raw sewage produced by a population of more than 240,000 persons. Since an inventory of the sewage and industrial wastes of the area indicated a total population equivalent to only 14,200 persons, researchers concluded that about 94 per cent of the biochemical oxygen demand is derived from "natural causes". The researchers observed:

> "The plankton and the elements of fertility responsible for production of plankton blooms are important contributing factors in the overall pollution problem…The total organic matter plus the bloom which flows from the [Upper Klamath] lake places a tremendous burden of natural purification on downstream waters."

Starting in 1955, Dr. Harry Phinney of Oregon State College conducted a three-year study of algae in Upper Klamath Lake. In a summary of his findings submitted to the supporting agencies in about 1959, Phinney stated that the "organisms responsible for the nuisance condition in Klamath Lake are all members of the blue-green algal group (Cyanophyta)," although other species of algae were found in the lake. Phinney attempted to explain the presence of high levels of algae blooms in the lake. He observed that the shallow configuration of Upper Klamath Lake provides not only for rapid decomposition of dead organic material, but also puts the lake into almost constant circulation. Therefore, recirculation of the nutrients released through decomposition "is essentially immediate," making the nutrients quickly available to organisms at the surface as well as the bottom of the lake.

Phinney also noted the problems caused when water flow from Upper Klamath Lake into the Link River and subsequently the Klamath River caused algae to drift into the Klamath River system. He suggested that the algae floating into the river from Upper Klamath Lake eventually resulted in a relatively uniform, although "considerably reduced," algae population density between Copco Reservoir and Klamath River's outlet at the sea. Phinney noted that the suspended algal matter in the Klamath River limited the river's utility as an effective means to dispose of domestic and industrial waste, as the total organic load able to be carried by the river "is not much greater than the natural load." Phinney also reported that this algae load "very definitely" affected the "biology and chemistry" of the Klamath River, but did not provide any details on specific changes caused by the quality of the water flowing out of Upper Klamath Lake.

THE 1960S THROUGH 1980S: FEDERAL AND STATE GOVERNMENT INVESTIGATIONS

Fish kills continued during the 1960s, most notably in the Klamath River Straits and in Lake Ewauna during 1966 and 1968, respectively. Oregon State Game Commission fish biologists attributed both of these fish kills to a lack of dissolved oxygen. These fish kills helped keep Klamath Basin water quality issues at the forefront of the minds of residents and government officials alike. Several studies were conducted in the 1960s regarding Klamath Basin water quality in general and algae in particular. Despite these efforts, however, researchers appeared no closer to a solution to the algae problem than when Phinney conducted his investigations in the 1950s.

The Oregon State Sanitary Authority (OSSA) continued sampling that had started in the 1950s, though not as frequently, until 1963. The OSSA summarized their findings in a report released in 1964. Much of this report focused on domestic and industrial waste producers in the Klamath Basin, but the OSSA did refer to Upper Klamath Lake algae levels. They found that "all of the man-made BOD [biochemical oxygen demand] loadings in the [Klamath] Basin are quite insignificant when compared to the BOD of naturally occurring organic materials emitting from Upper Klamath Lake." The study also acknowledged that "chemical, physical and biological activities in Upper Klamath Lake dominate the water quality of the Klamath River in Oregon."

Scientists of the U. S. Public Health Service began studying Upper Klamath Lake in 1964. The principal early objectives of the study, known as the Klamath Lake Project, "were to determine the role of the watershed as a source of algal nutrients and to learn if one or more nutrients could be diverted and, thereby, limit the growth of algae." William Miller, project leader and chemist, and Jerry C. Tash produced an interim report regarding these Upper Klamath Lake studies in 1967. Miller and Tash found that the lake's major tributaries as well as agricultural drainage and various "pristine streams" (small mountain creeks within the watershed) contributed to levels of inorganic nutrients such as phosphorus, nitrogen, and iron in Upper Klamath Lake. No one source of inflow was found to be the sole contributor of any particular nutrient, but the drainage systems of the Wood and Williamson rivers contributed the majority, between 43 and 79 percent, of the "inflowing nutrients" to the lake. Agricultural drainage accounted only for approximately 20 percent of the nitrogen, ten percent of the iron, and 26 percent of the phosphorus flowing into Upper Klamath Lake.

Miller and Tash also discussed findings regarding analysis of Upper Klamath Lake's bottom sediment. Although they reported that a "tremendous potential source of algal nutrients" existed in the bottom of the lake, the researchers admitted that "the total impact of the bottom sediments in a dynamic eutrophic lake system is not understood." They recommended further study into the extent to which nutrients from the lake's bottom sediment interchange with overlying waters and thereby become available for use by floating organisms such as algae. Nutrients from bottom sediment may, they stated, contribute to large algal populations, and were made up almost entirely in 1965 and 1966 of the blue-green algae *Aphanezomenon flos-aquae* (representing 90 to 99 percent of the algal population during the summer).

Between July 1967 and March 1969, A. R. Gahler of the Federal Water Pollution Control Administration conducted studies regarding the interchange of inorganic nutrients between Upper Klamath Lake's bottom sediment and the overlying waters. Gahler found that an interchange of nutrients between bottom sediment and water occurred in the lake during June and September of 1968, when the organism *Oscillatoria* (a cyanobacteria, or an aquatic, photosynthetic bacteria), with attached sediment, floated to the surface. This resulted in a mixing of sediment with surrounding water, thereby increasing levels of phosphorus, ammonia, and nitrogen. This nutrient interchange, felt Gahler, dictated that any proposed algal control method on Upper Klamath Lake should include a program by which the upper layer of sediment was immobilized, and thereby unable to mix with the overlying water:

Gahler reiterated his conclusions in 1974, when he, William D. Sanville, and Charles F. Powers produced yet another report regarding sediment-water nutrient interchange in Upper Klamath Lake. In this report, Gahler and the other authors stated that seasonal variations in nutrient concentrations were reflected in the population densities of *Aphanizomenon flos-aquae*. They also found "unconsolidated sediments" in the Upper Klamath Lake bottom reaching depths of up to 107 feet below the lake bottom. The researchers reported that sedimentation rates (the rate at which sediment is deposited in the bottom of a body of water) "have increased greatly in recent time," as shown by radiocarbon dating of sediment samples. The researchers suggested that this increase in sedimentation rate could have been caused by "changes in the watershed and in the trophic status of the lake." The interchange of nutrients between this bottom sediment layer and the overlying water, as well as the thickness of that sediment layer, appeared to preclude the "restoration of Upper Klamath Lake to a less eutrophic condition…by dredging." Therefore, Gahler, Sanville, and Powers concluded:

> "There is at the present time no obvious practical means for eliminating the regularly-occurring nuisance blue-green algae blooms in the Upper Klamath Lake system. … A program of restoration for the lake would have to include both control of nutrient flux from the watershed and exchange of nutrients between sediments and lake water. Neither of these appears possible at present."

Oregon's State Water Resources Board (OSWRB) produced a report in 1971 regarding an inventory of Klamath Basin water resources conditions. The report addressed algal blooms in Upper Klamath Lake and their impact upon Link River, Lake Ewauna, and Klamath River, calling such algal growth "seriously detrimental to the quality of water". The OSWRB reiterated the conclusion reached by studies in the 1960s: that natural sources supplied most of the lake's dissolved nutrients, while "man's contaminating contributions, although accelerating the eutrophication process, are minor in comparison." Masses of algae passing from Upper Klamath Lake downstream caused a "severe dissolved oxygen deficiency during summer months" in Link River, Lake Ewauna, and the upper portions of the Klamath River.

By the mid-1970s, frustration on the part of Klamath County citizens became more evident as scientific study after scientific study was completed but none had found a viable solution to the algae problems of Upper Klamath Lake. For instance, in 1973, a local newspaper ran a brief article regarding the lake, questioning whether the state of Oregon, which claimed title to the lake's bottom, would also assume the responsibility for "taking any and all reasonable steps to protect the environment from adverse effects caused in part by the lake bottom." At the end of this article, the author remarked "Why not another study. A fresh look might turn up some feasible answers." Headlines in Klamath Falls newspapers from the 1970s read "Klamath Lake 'Stinking Mess,' Lots of Promises, No Action," and "Action Needed on Klamath Lake."

In 1977, the U. S. Congress authorized that the Army Corps of Engineers (Corps) undertake a study to "review the existing situation in the Klamath River Basin, Oregon, with the purpose of determining whether modifications to existing policies regarding the development, management, conservation, and environmental enhancement of water, land, and related reservoirs are presently advisable". The Corps released a preliminary "Reconnaissance Report" regarding the Klamath River Basin in Oregon in September 1979. This "Reconnaissance Report" reviewed and briefly related the findings of previous studies; identified the problems to be addressed by further study; provided potential solutions and alternative plans in response to the problems; and established planning objectives and a course of action for the remainder of the study. The Corps stated that review of previous studies and visual observations of the lake "has shown the problems to be obvious" and "the lake is hyper-eutrophic with extremely dense blue-green algal blooms, abundant midge flies and encroaching macrophytes". Additionally, the Corps found "the causes of the problems" to be "equally obvious":

> "High nutrient loadings and associated sedimentation of organic matter have produced an ideal habitat for the abundant growth of algae, benthic animals, and macrophytes. If no restorative action is taken, it is reasonable to expect continued sedimentation, high algal densities and encroachment of macrophytes."

In 1982, the Corps produced a second report that described research methods and data collection in Upper Klamath Lake, including water quality monitoring of major tributaries to Upper Klamath Lake; the collection of benthic invertebrates and adult midges; examination of the composition, nutrient, and metal profiles of lake sediment cores; and analysis of nutrients released from "surficial" bottom sediments. After examination of this data in light of the potential restoration methods suggested in the "Reconnaissance Report," the Corps concluded that "… the feasibility of full-scale phosphorus limitation in the lake is highly questionable":

> "The lake receives high external loading as well as internal cycling from shallow nutrient-rich bottom sediments due to frequent wind-generated resuspension. From loading models, it is estimated that an 88 percent reduction of the present annual phosphorus loading of 505 tons would be necessary to avert eutrophic lake conditions. Such a reduction on a lake-scale basis is not deemed possible given technical unfeasibility and excessive sustained costs."

The Corps continued:

> "Limnological implications for full-scale restoration or management of water quality in Upper Klamath Lake are not promising. The presence of high ambient phosphorus concentrations in area groundwaters and major tributaries, in combination with shallow, organically rich and biologically active bottom sediments, virtually excludes a full-scale phosphorus limitation program."
>
> "Furthermore, the size of the lake poses substantial technical, financial, and political constraints to full-scale implementation of restoration or management techniques."
>
> "These and other considerations are persuasive in concluding that a full-scale reversal of the lake's long-term, natural, and ultimately irresistible eutrophication is simply not feasible given the present limits of applied limnology, economic means, and project priority."

A few other reports were produced in the 1980s, but intensive study of the lake appeared to be winding down as authorities accepted the aging process of the lake as inevitable. For instance, in 1980 the Klamath County Commission and the Environmental Protection Agency allocated $100,000 in order to fund a study of Upper Klamath Lake designed to "draft a plan to make the lake more usable," rather than a study to determine methods of reversing the eutrophication process. The commission contracted with Klamath Consulting Service, Inc. to undertake this proposed study, in the hope that "steps can be taken to retard the lake's continued degradation". This report, released in 1983, recommended off-stream storage in order to provide water for flushing and dilution; dredging from the marinas at the south end of the lake to deeper water, which would allow boats access to a larger percentage of the lake; and mechanical weed control in localized areas. However, the Environmental Protection Agency did not allocate additional funds to follow-up this work.

RECENT RENEWAL OF SCIENTIFIC INVESTIGATION

Less than a decade later, problems in Upper Klamath Lake once again received increased scrutiny, and investigations have continued until the present time. The U. S. Geological Survey (USGS), in cooperation with the several local, state and federal agencies including the U. S. Bureau of Reclamation and the Klamath Tribes, initiated a phased program of research regarding eutrophication in Upper Klamath Lake, focusing on possible causes of the excessive nutrient enrichment of its waters as well as the reasons for sucker population decline. These studies, undertaken throughout the 1990s, resulted in several publications, including further reports regarding bottom sediments and their relation to nutrients in the lake, as well as nitrogen and phosphorus loading of the lake from inflowing waters.

In 1993, USGS scientists Gilbert C. Bortleson and Marvin O. Fretwell proposed several hypothetical explanations for the causes of nutrient enrichment and sucker decline in Upper Klamath Lake. The three hypothetical causes considered the most significant by Bortleson and Fretwell, and recommended as having the most priority in terms of future testing, included:

- Soil character changes caused by the conversion of marshland to agricultural land could accelerate release of nutrients via surface and ground water flows into the lake. Decomposition of organic matter is slower when said matter is under water than when exposed to atmospheric conditions. Draining marshland therefore results in a layer of upper soil having large accumulations of organic nitrogen from increased decomposition rates. This nitrogen can subsequently be carried to adjacent waters through surface and ground water flows. Additionally, phosphorus compounds and particles unable to be carried through marsh soils could also be exported to the lake through increased erosion rates stemming from ditching and draining.
- Agricultural activities in the Klamath Basin could have caused greater nutrient loads in streams that flow to the lake. Livestock grazing, with its subsequent production of waste material and loss of riparian vegetation, as well as application of fertilizers, were cited as potential means by which the nutrient levels in Upper Klamath Lake could be increased.
- The regulation of water surface levels via the operation of Link River Dam could have an impact upon water quality in Upper Klamath Lake through two factors: (a) when water levels are kept higher than natural conditions, more of the winter and spring run-off is held in the lake, thereby potentially allowing more nutrients to settle out of these inflowing waters than would normally have occurred; and (b) periodic lowering of the lake below natural levels, made possible by the notch cut in the reef separating Upper Klamath Lake and Link River, could render the lake more susceptible to wind-induced resuspension of sediment and therefore further interchange of nutrients.

The potential relationship between fluctuation of lake levels and nutrient loading in Upper Klamath Lake was addressed by Antonius Laenen and A. P. LeTourneau in another USGS study published in 1995. Laenen and LeTourneau held that in a shallow lake such as Upper Klamath Lake, "wind-induced resuspension of bed sediment into the lake water increases dramatically as the lake elevations become lower." They found that at lake elevations lower than 4,140 feet (generally held to be the "natural" low water level of the lake prior to the construction of Link River Dam and outlet structures) approximately 75 percent of the lake's surface could be affected by resuspension of bottom sediment. Winds of ten miles per hour or greater in velocity during the summer months could create four times as much bottom shear stress (one of the factors that helps determine the amount of sediment disturbed) at a water surface elevation of 4,137 feet (the minimum lake level as provided for by the contract between the United States and Copco) than at lake surface elevation 4,140 feet. As resuspension of bottom sediment "may be a major source of the internal [in-lake] phosphorus loading," Laenen and LeTourneau recommended further study into phosphorus loading mechanisms in the lake.

Based on water quality observations made over the course of several years, the Klamath Tribes recommended in 1995 that the USBR modify its operating plan for Link River Dam in order that minimum lake levels during the summer months of June, July, and August (the months during which the algae problem typically reached its height) would more closely resemble those of pre-Link River Dam conditions. Subsequently, USGS was asked to analyze available data and to assess whether year-to-year differences in lake water quality variables were related to year-to-year differences in lake level. In a 1996 report, USGS researchers described that during the month of June lake levels were related to both the appearance of the first algae bloom (the higher the lake level, the later the bloom appeared) and pH levels (higher lake levels resulted in lower pH values). However, USGS concluded that there was no evidence for a relation between any of the water-quality variables considered (chlorophyll-a, dissolved oxygen, pH, and total phosphorus) and lake level on the basis of the seasonal distribution of the data or summary seasonal statistics.

USGS and USBR researchers also examined the level of nutrient loading from drained marshland adjacent to Upper Klamath Lake, in a study by Daniel T. Snyder and Jennifer L. Morace published in 1997. Drainage of marshlands surrounding the lake began prior to 1900 and continued throughout much of the 20th century. These drainage systems concentrated around the north and west edges of Upper Klamath Lake, and on the lower reaches of the Williamson River, near its mouth in the lake. Excess water was often pumped or diverted off of these lands into Upper Klamath Lake or its tributaries. The researchers estimated that approximately 34,140 acres of wetlands in this area have been drained for agricultural production.

The USGS and USBR researchers attempted to ascertain the level of this leaching of nutrients from drained marshland into Upper Klamath Lake. They found that the total phosphorus and nitrogen lost by drained marshlands around the lake represented about 22 and 30 percent, respectively, of the mass of these nutrients that initially existed in the soil. This equated to approximately 250,000 tons of nitrogen and 4,300 tons of phosphorus. Not all of these nutrients, however, necessarily ended up in Upper Klamath Lake.

Eric Henry of Oregon Sate University's Department of Botany and Plant Pathology undertook a study in the early 2000s regarding the role of wetlands in the regulation of Upper Klamath Lake's water quality, particularly nutrient uptake and plant decomposition within wetlands areas.

Henry suggested that prior to Euro-American settlement of the region, wetlands "could well have created conditions … that prevented *Aphanizomenon* from establishing significant populations." This possible regulatory function was lost when extensive stretches of wetlands adjacent to the lake were diked and subsequently drained. Henry also hypothesized that conversion of wetlands for agriculture "has degraded the water quality of this lake [Upper Klamath Lake] primarily by the resultant deprivation of wetland functions and not by subsequent agricultural drainage discharges."

In 2001, yet another study regarding the lake's bottom sediment was released, this one concentrating upon the changes in sediment composition that may have occurred in the past 100 to 150 years. Conducted by J. Eilers, J. Kann, J. Cornett, K. Moser, A. St. Amand, and C. Gubala and submitted to the USBR in 2001, this "paleolimnology" study of Upper Klamath Lake concluded that sediment accumulation rates in the lake increased substantially during the 20th century, corresponding to increased cultural development in the region.

Although the mixing in the upper sediments prevents high-resolution temporal analysis of the recent history (e.g. last 30 years) of Upper Klamath Lake, the results demonstrate that major changes in water quality likely have occurred leading to a major modification of the phytoplankton assemblage [i.e., the dominance of the blue-green algae *Aphanizomenon flos-aquae* in the lake's algae population over the last 50 years]. The changes in sediment composition are consistent with land use activities during this period that include substantial deforestation, drainage of wetlands, and agricultural activities associated with livestock and irrigated cropland.

The researchers stated that even given the high level of wind-induced sediment mixing in Upper Klamath Lake, the "most conservative of interpretations" indicate that the lake's bottom sediment appeared to be divided into different zones. The top 20 to 25 centimeters of sediment was determined to represent the most recent 150 years, while sediment below that level had been deposited in the pre-development period. The top, most recent, layer of sediment is highly enriched with nutrients such as nitrogen and phosphorus as compared with the lower levels. The researchers also found evidence of increased erosion and higher rates of sediment accumulation in this top layer of sediment. They noted that *Aphanizomenon flos-aquae* did not appear below the top 20 centimeters of the sediment cores that were examined, and labeled this blue-green algae's rise to dominance as evidence in the sediments to support the view that the nutrient productivity and resulting water quality impairment in Upper Klamath Lake took a more serious turn in the early part of the 20th century.

UPPER KLAMATH LAKE TMDL

High algal productivity in Upper Klamath Lake has been accompanied by violations of Oregon's water quality standards for dissolved oxygen, pH, and free ammonia. Such water quality violations led to 303(d) listing of UKL in 1998 by ODEQ. In May of 2002, ODEQ established a total maximum daily load (TMDL) for the Upper Klamath Lake drainage to define "the maximum amount of pollution [from all sources] that a water body can receive without violating water quality standards". The Upper Klamath Lake TMDL for nutrient-related pollution identified controlling total phosphorous loading as the "primary and most practical mechanism to reduce algal biomass and attain water quality standards for pH and dissolved oxygen." The

TMDL stated that "mobilization of phosphorus from agriculture and other nonpoint sources … appears to have pushed the lake into an exaggerated state of eutrophication".

The TMDL estimated that of the total phosphorus loading in the lake, only 39 percent could be attributed to external loading, while approximately 61 percent was generated by internal loading mechanisms such as sediment-water nutrient exchange. Further, the release of phosphorus from sediment into lake waters is facilitated by increased pH levels. Evidence gathered by previous studies suggested that as the *Aphanizomenon flos-aquae* population increases, pH levels increase. The increased pH levels then help release more phosphorus into the water, further elevating the blue-green algae population and pH levels, and thereby "setting up a positive feedback loop." To address the phosphorus issue, the TMDL called for a 40 percent reduction of total phosphorous loading to Upper Klamath Lake.

This 40 percent reduction in total phosphorus loading could be achieved, stated the TMDL, through wetlands restoration, changes in hydrology along the watercourses flowing into the lake as discussed above, and reducing phosphorus discharge levels from two point sources, Chiloquin Sewage Treatment Plant and Crooked Creek Hatchery (although these two point sources combined supplied only an estimated 2.5 metric tons of phosphorus to the lake per year, a relatively minor phosphorus source when compared to the 179.2 metric tons estimated to be supplied by non-point external sources). The TMDL estimated that up to 29 percent of the external phosphorus load could possibly be attributed to the drainage of wetlands adjacent to the lake, and that restoration of the wetlands could reduce the external phosphorus loading of Upper Klamath Lake by that 29 percent. An additional 18 percent reduction in external phosphorus loading could be achieved, according to the TMDL, through restoring land cover to areas cleared by timber harvesting or livestock grazing, and also changing the hydrology of upland agricultural and drainage systems along the Williamson, Sprague, and Wood rivers.

In order to implement the load allocations stipulated by the TMDL, and achieve the targeted 40 percent reduction in total phosphorus loading, the "first iteration" of a water quality management plan was included in the TMDL document. This water quality management plan "is the overall framework describing the management efforts to implement TMDLs in the UKLDB [Upper Klamath Lake Drainage Basin]." The proposed water quality management plan did not specify specific remedial measures that would attain the necessary load reductions (internal and external) to resolve water quality problems in Upper Klamath Lake, rather the intent was to provide a foundation for more specific implementation plans. The water quality management plan listed various management measures ranging from public outreach and education to erosion control, wetlands restoration to enforcement of trash dumping and pollution discharge, and riparian forest management to proper road construction and repair. Recent TMDL efforts for downstream Klamath River reaches have identified additional questions for the existing Upper Klamath Lake TMDL, including the fact that the Upper Klamath Lake TMDL only addresses phosphorous and not nitrogen.

THE 2004 REPORT OF THE NATIONAL RESEARCH COUNCIL

In 2004, the National Research Council's Committee on Endangered and Threatened Fishes in the Klamath River Basin issued a report regarding endangered and threatened fishes in the Klamath Basin, including sucker and salmonid species to "evaluate the strength of scientific support for the biological assessments and biological opinions on the three listed species, and to identify requirements for recovery of the species." The committee had a primary interest in regard to Upper Klamath Lake as a factor influencing the health and survival of endangered sucker species. In this regard, the committee studied the various proposed causes of Upper Klamath Lake's hypereutrophic status, which have the potential to cause direct or indirect harm to sucker populations. These factors, now familiar to the reader, include the various roles played by the nutrients nitrogen and phosphorus, pH levels, dissolved oxygen levels, and the predominance of *Aphanizomenon flos-aquae* in the lake's algal populations.

In evaluating the scientific research conducted regarding Upper Klamath Lake, the National Research Council committee found four hypotheses regarding the lake's water quality to be "well supported" by the available evidence:

- That "algal abundance as measured by chlorophyll is positively related to total phosphorus in the water column."
- That algal population levels are "positively related to daytime pH."
- That the rate of development of the algal population in early spring is "positively related to the rate of warming in the water column."
- That large amounts of the phosphorus present in the lake's waters during the algal growing season (spring, summer, and early fall) originate in the lake's bottom sediments, being transferred to the overlying water through internal loading mechanisms.

The committee concluded that various other hypotheses, however, did not seem to be supported by the evidence so far collected. For instance, the committee found the various hypotheses linking lake levels to water quality issues like early spring algal growth, algal biomass, and algal abundance to be "weak" or "inconsistent with field data." The committee found that lake levels did not appear to have a significant impact upon either fish mortality or poor water quality within the lake:

> "There is no evidence of a causal connection between water level and water quality or fish mortality over the broad operating range in the 1990s, the period for which the most complete data are available for Upper Klamath Lake. Neither mass mortality of fish nor extremes of poor water quality show any detectable relationship to water level."

Additionally, while the committee acknowledged that typically the most effective way to limit algal growth is to restrict phosphorus loading, Upper Klamath Lake did not seem to lend itself to this technique, contrary to the conclusions of ODEQ's Upper Klamath Lake TMDL. Internal loading mechanisms exist in the lake whereby nutrients are exchanged between bottom sediment and the overlying waters. External loading mechanisms are also present, although they provide only about one half of the phosphorus load that internal mechanisms introduce to the lake's waters. These external phosphorus loading factors include some level of artificial phosphorus introduction from agricultural, municipal, and industrial sources. The committee noted, however, that approximately 60 percent of the external phosphorus load derived from natural sources rather than artificial ones. In addition, most of that portion of the phosphorus load stemming from artificial sources originates from non-point sources such as agricultural and other land use practices rather than point sources, which are easier to control and regulate. The implementation of regulations regarding non-point sources, stated the committee, would involve major changes in land use upon privately-held land, a difficult proposition at best and one that seemed to make “even a reduction of 20%” in external phosphorus loading,” half of what the TMDL recommended, “ambitious and potentially infeasible…”

Even if the TMDL’s targeted 40 percent reduction in external phosphorus loading could be achieved, the committee held that it would “probably be ineffectual without suppression of internal phosphorus loadings, given that internal phosphorus loading is very large for Upper Klamath Lake” and that “available evidence indicated that … internal loading appeared sufficient to maintain algal populations”.

The committee perceived another deficiency in ODEQ’s Upper Klamath Lake TMDL document as well: the TMDL document failed to satisfactorily explain why *Aphanizomenon* had become the dominant algae species during the latter portion of the 20th century. The committee stated that available evidence (including the paleolimnological study discussed above) seemed to indicate that the recent rise to dominance of *Aphanizomenon flos-aquae* in Upper Klamath Lake could be attributed to “human influences.” The specific causative factors of this shift in algal population, however, “remain unclear.” The committee’s report noted that studies had shown nutritional conditions in the pre-development era of the Klamath Basin to be favorable to algae such as *Aphanizomenon flos-aquae*, even before human alteration of the basin. Therefore, the committee reasoned, conditions in Upper Klamath Lake prior to human alteration “could have involved some factor that prevented the population growth of blue-green algae…”

The committee postulated that organic acids (called “limnohumic” acids) present in wetland sediments could have played a part in inhibiting the growth of blue-green algae species before diking and subsequent drainage of wetlands adjacent to the lake. The influx of these limnohumic acids into the lake’s waters was probably high, and could have inhibited algal growth through either preventing light penetration of the lake waters, or even having a toxicity to certain types of algae. When the levels of these acids dropped after development of the wetlands for agricultural purposes, according to this hypothesis, *Aphanizomenon* would have been “released from suppression by weak light availability or chemical inhibition,” and thereby begun its ascension to its current dominant role.

This hypothesis was more attractive to the committee than the phosphorus-loading hypothesis for its ability to explain both the change in the composition of algal population (to a population dominated by *Aphanizomenon*), and also the increase in the amount of algae in the water.