Final Report

RESTORATION OF RIPARIAN HABITAT AND ASSESSMENT OF RIPARIAN CORRIDOR FENCING AND OTHER WATERSHED BEST MANAGEMENT PRACTICES ON NUTRIENT LOADING AND EUTROPHICATION OF CROWLEY LAKE, CALIFORNIA

(SWRCB # 9-175-256-0)

Robert Jellison and Daniel R. Dawson

Sierra Nevada Aquatic Research Laboratory

Marine Science Institute

University of California, Santa Barbara

HCR 79, Box 198

Mammoth Lakes, CA 93546

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EXECUTIVE SUMMARY

Crowley Lake (Long Valley Reservoir), Mono County is a valuable aquatic resource. The lake and its tributaries are the premier trout fishery in the Eastern Sierra and the reservoir constitutes 60% of the storage capacity of the Los Angeles Aqueduct system. The watershed is approximately 380 sq. miles and is predominately public lands administered by Inyo National Forest (INF), Bureau of Land Management (BLM), and the City of Los Angeles. Crowley Lake was first classified as eutrophic by EPA's National Eutrophication Survey (1975), is 'listed' for nutrients per Section 303(d) of the federal Clean Water Act, and is a TMDL priority for the Lahontan Regional Water Quality Control Board.

The purpose of the work covered by this contract was to restore a substantial length of the main tributary (Owens River) immediately upstream of Crowley Lake by implementing grazing BMPs including riparian fencing (Chapter 2), to develop an annual nutrient loading budget for Crowley Lake (Chapter 3), to determine the major sources of nutrients (Chapter 4), and monitor continuing eutrophication via transparency, nutrient concentrations, and characterization of the plankton communities (Chapter 5).

In 2000, as part of this contract, the Owens River, from Benton Crossing to a point near Crowley Lake was corridor fenced and livestock excluded for at least five years. Physical data on the river characteristics was collected before and after fencing in an attempt to determine the effectiveness of the project, however the treatment interval was too short to reveal any changes. Photo-monitoring of the other tributaries in the watershed, including the Owens River above Benton Crossing show considerable change since the application of the various BMPs previously implemented and monitoring conducted in this project will provide a baseline for assessing future changes.

Nitrogen and phosphorous loading to Crowley Lake is high and dominated by the Owens River. The average annual loading during the two runoff years, April 2000 to March 2001, and April 2001 to March 2002 was 1.2 g P m^{-2} yr^{-1} and 2.1 g N m^{-2} yr^{-1}. Although the actual levels of nutrient loading which can be sustained without causing eutrophication depend on a wide array of environmental factors, the P loading rates estimated in this study exceed what are generally considered acceptable.

Ninety-six percent of the measured phosphorus loading to Crowley Lake enters through the Owens River whose flows account for only half the overall water budget. Large natural springs along the upper Owens River above East Portal and along Mammoth/Hot Creek from below US highway 395 to the lower end of the Hot Creek thermal area account for nearly all of the phosphorous loading. While the Owens River also accounts for most (79%) of the total nitrogen inputs, McGee Creek also contributes significantly (13%) to overall N loading. The nutrient loading has low N:P ratios, thus favoring the growth and development of cyanophyte (blue-greens) blooms. The estimates of annual P loading are approximately equal to measured outflows. However, the export of N in the reservoir outflows is 3 to 4 times the measured inflows. The difference is presumably due to unmeasured inputs via nitrogen fixation by cyanobacteria (see Contract SWRCB #00-196-160-0).

Natural springs, originating from the Big Springs complex (which includes Alpers spring) and the Hot Creek Hatchery spring complex, are the dominant sources of nutrients in the watershed. With their high flow volume and relatively high concentrations of P and N, these natural sources dominate nutrient loading to Crowley Lake. Both SRP and TP concentrations are low in all tributaries except the Owens River and Mammoth/Hot Creek. Similarly, NH_4, NO_3, and TN concentrations are relatively low in all other tributaries except that modest (0-20 µM) increases in TN are observed across irrigated pastures on McGee and Convict Creeks. While the Hot Creek Hatchery springs are high in both NO_3 and TN, hatchery operations apparently contribute significant amounts of NH_4 and TN.

The communities of Mammoth Lakes, McGee Creek, and Hilton Creek show surprising little effect on in-stream nutrient concentrations.

There is a small but consistent increase of TN and TP in McGee and Convict Creeks as they flow through irrigated pasturelands. The mean increase in TN and TP for all 23 dates (6 longitudinal and 17 paired samplings) was 8.1 and 0.6 µM, respectively. However, these increases constitute only 6.1% of total measured N loading and measured N loading is only 30% of measured export of N from the lake.

The concept of lake trophic status is multidimensional and includes measures of nutrient concentration and loading, transparency, chlorophyll, and floral and faunal composition. Crowley Lake would be classified as eutrophic by all of these indicators, except that transparency is often quite high when episodic cyanophyte blooms are absent. Thus mean summer transparencies might suggest mesotrophic conditions.

Given the low N:P ratios of inputs and the high overall rates of phosphorus loading to Crowley Lake, the sestonic (particulates lake) molar ratio of TN:TP was surprisingly high through much of the summer (range 9 – 36, mean 22.4) suggesting that nitrogen fixation or release of previously sequestered nitrogen from the sediments is making up the nitrogen deficit. In fact, N:P ratios greater than 23 are generally considered an indication of P-limited phytoplankton growth (Healy and Hendzel 1980). Molar carbon to nitrogen ratios of summer seston (planktonic particulates) in the upper 5 m ranged from 5.0 to 8.4 with a mean of 6.3, very close to the Redfield molar ration of 6.6 for balanced growth providing further evidence of nitrogen sufficiency.

Freshwater lakes are generally limited by phosphorus, in part, because nitrogen fixation by cyanobacteria (blue-green algae) is often able to make up nitrogen deficits. In Crowley Lake, sestonic C:N and N:P ratios provide little evidence of nitrogen-limited growth and even suggest phosphorus-limited growth. The presence of heterocystic cyanobacteria, the recurring cyanophyte blooms, and the low molar N:P ratios of nutrient loading (~4.5) all suggest nitrogen fixation to be an important part of the overall nitrogen budget.

Riparian conditions along Crowley Lake tributaries are expected to continue to improve following BMPs implemented as part of this project. The current high P loading rates of Crowley Lake are almost entirely due to natural sources. While land-management activities account for a portion of the N inputs observed in McGee Creek, the eutrophic state of Crowley Lake is unlikely to be significantly altered without reducing the inputs of P derived from natural sources along Hot Creek and the Owens River, or by taking in-lake restoration measures.

Acknowledgments:

We gratefully acknowledge the support of the California State Water Resources Control Board and the cooperation of project manager Cindy Wise of the Lahontan Regional Water Quality Control Board. This work was based at the University of California's Sierra Nevada Aquatic Research Laboratory, part of Valentine Eastern Sierra Reserve. We would like to thank the Los Angeles Department of Water and Power who provided matching funds, data, and unfettered access to their lands and facilities, specifically Glen Singley, Clarence Martin, Brian Tillemans, Dale Schmidt, Wayne Hopper, and the poor fellows who had to meet us at the dam for outlet sampling.

Ms. Kimberly Rose performed much of the sampling and virtually all of the laboratory analyses on the project. We appreciate her hard work, good attitude, and attention to detail. Without her the project would not have been done. We also thank Erika Zavala for field work in the early part of the project. Dr. John Melack provided valuable scientific input, comment, and editing.

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CHAPTER 1: INTRODUCTION

Crowley Lake (Long Valley Reservoir), Mono County is a valuable aquatic resource whose management requires the balancing of competing economic, recreational, and ecological values. The lake and its tributaries are the premier trout fishery in the Eastern Sierra providing excellent angling opportunities for fishermen and an important economic resource to local communities. Approximately 300,000 angler-hours are observed at Crowley Lake during a typical season (Milliron 1997) and as much as 80,000 pounds of fish are caught by an estimated 19,000 anglers on opening weekend (Pister 1965). The lake also constitutes 60% of the storage capacity of the Los Angeles Aqueduct system and is thus integral to managing the water supply for the state's largest metropolitan area. Crowley Lake is situated on the eastern slope of the Sierra Nevada in southern Mono County at an elevation of 6781 feet. It was created by the impoundment of the Upper Owens River in 1941 by the City of Los Angeles. With a surface area of ca. 5300 acres, it is the largest reservoir in the Los Angeles Aqueduct system. The mean depth is 35 ft and maximum depth 126 ft. The Department of Fish and Game maintains an annual stocking program consisting of 350,000 rainbow trout and 15,000-50,000 brown trout.

The watershed is approximately 380 sq. miles and is predominately public lands administered by Inyo National Forest (INF) and the Bureau of Land Management (BLM). The City of Los Angeles own lands immediately adjacent to the lake. The only significant private ownership occurs on the Upper Owens River ca. 9.6 km north of the lake, in the town of Mammoth Lakes, and in several smaller communities west and south of the lake. Extensive grazing occurs on INF, BLM, and Los Angeles' lands within the basin. In addition to the Upper Owens River, four smaller tributaries flow directly into the lake from the west (McGee, Hilton, Whiskey, and Crooked Creeks), and Leighton Springs flow into the lake from the east.

As part of the EPA's National Eutrophication Survey, Crowley Lake was surveyed in 1975 and classified as eutrophic based on nutrients, dissolved oxygen, chlorophyll a, the phytoplankton community, and Secchi disk transparency (Corvallis Environmental Research Lab 1975). In subsequent decades, many of the management issues and concerns have centered on mitigating the impacts of eutrophication of the lake. Management actions have included the use of copper sulfate to control blue-green algae populations which result in taste and odor problems and occasional fish kills, and aeration of dam outflows to mitigate the impact of low oxygen on downstream fisheries. In August and September of 1996 significant fish kills occurred in Pleasant Valley Reservoir, immediately downstream of Crowley Lake. This kill resulted when deoxygenated water was delivered through the Crowley Lake penstock to Pleasant Valley. Declining angler success beginning in 1987 raised concern over the perceived increasing eutrophication of the lake with undesirable impacts (Milliron 1997). In the last two decades recreational boating and water skiing have increased significantly in Crowley and these users have become a vocal lobby for improved water quality. As increased eutrophication could seriously impact both water quality and recreational uses, it is important to establish the extent and causes so that appropriate mitigation measures may be incorporated into the RWQCB's watershed management plan. Crowley Lake is 'listed' for nutrients per Section 303(d) of the federal Clean Water Act, and is a TMDL priority for the Regional Water Quality Control Board. Although a TMDL is not yet in place, the preliminary TMDL strategy for the waterbodies listed in this watershed includes implementation of BMPs geared toward reducing nutrients from non-point sources. The restoration strategy in this project serves this purpose, and thus implements the preliminary TMDL strategy. Another aspect of TMDL implementation included in this project is the step of monitoring and re-evaluation. Because the preliminary TMDL strategy for the CWA 303(d)-listed waterbodies in this watershed is based on implementing more of the same types of BMPs that are already in place and that are included as part of this project, an evaluation of the effectiveness of the various treatments is essential. There is evidence that some of these BMPs (e.g., fencing, revised grazing strategies) have made improvements in riparian habitat, but it is unknown if there have been similar improvements in water quality.

Eutrophication caused by excessive inputs of phosphorus (P) and nitrogen (N) is the most common impairment of surface waters in the United States (U.S. EPA 1990). While point sources of nutrient inputs have in many cases been reduced, non-point sources remain a major problem. Gakstatter et al. (1978) estimate that 80% of eutrophic lakes would require control of non-point phosphorus input to meet water quality standards. Urbanization and agricultural practices are the major contributors to non-point nutrient inputs in rural watersheds. Watershed management of non-point nutrient sources requires an assessment of the relative contribution of all the various land-use practices and natural sources. The direct impacts of cattle use on riparian systems in the arid West are widely documented. However, the contribution of arid-land grazing to non-point pollution is poorly documented. While numerous studies (e.g. Haygarth and Jarvis 1997, Flaig and Havens 1995, Carpenter et al. 1998) show heavily managed pastures result in significant non-point sources of nutrients, these pastures usually involve high densities of animals and external nutrient sources via the application of fertilizers and manure. Given the absence of fertilizer and manure applications, the relative contribution of grazing to non-point nutrient sources may be small relative to natural sources and those associated with residential development. Furthermore, studies indicate riparian corridors are effective in reducing non-point nutrient loading from adjacent pastures (Lowrance 1997).

In addition to extensive areas of cattle grazing, the Crowley Lake watershed includes increasing residential and commercial development, and recreational use. Also, natural springs on the headwaters of the Owens River have elevated concentrations of phosphate and constitute a significant source of nutrient inputs (Melack and Lesack 1982). Therefore, restoration of riparian corridors in the upper Owens watershed through the corridor fencing and the adoption of a riparian grazing management program on Los Angeles lands will likely reduce any non-point nutrient loading associated with livestock grazing. But without adequate monitoring, the relative nutrient contributions of various land uses in the watershed will remain unknown.

The purpose of the work covered by this contract was to restore a substantial length of the main tributary (Owens River) immediately upstream of Crowley Lake by 1) implementing BMPs to reduce or prevent pollution from discharges associated with livestock grazing, irrigation, recreation, and physical habitat alteration; 2) determining the effectiveness of the restoration and BMPs by measuring a variety of recovery parameters both upstream and downstream of the restoration site; 3) developing an annual nutrient budget for the lake; 4) determining the sources of those nutrients; and 5) monitoring the lake by measuring nutrient concentrations, characterizing phyto- and zooplankton blooms, and measuring basic limnological parameters.

This project specifically addressed six priority activities identified by the Lahontan Regional Water Quality Control Board in its Watershed Management Initiative (WMI) Planning

Chapter. It will provide critical information useful to the landowner and operator in evaluating their BMPs, and to the Lahonton Board in implementing its WMI.

CHAPTER 2: IMPLEMENTATION AND EFFECTIVENESS OF BEST MANAGEMENT PRACTICES ON THE OWENS RIVER AND MAMMOTH CREEK

Introduction:

Management practices are implemented on agricultural lands for a variety of purposes, including protecting water resources, protecting terrestrial or aquatic wildlife habitat, and protecting the land resource from degradation by wind, salt, and toxic levels of metals. Best Management Practices (BMPs) are defined as "a practice or combination of practices that is determined by a state to be the most effective means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals" (Federal Clean Water Act, 1977). These may include, but are not limited to:

1. Structural and nonstructural controls (eg. fencing)
2. Operation and maintenance procedures (eg. rest/rotation of grazing)
3. Other requirements and scheduling and distribution of activities.

Usually BMPs are applied as a system of practices rather than a single practice. BMPs are selected on the basis of site-specific conditions that reflect natural background conditions and political, social, economic, and technical feasibility.

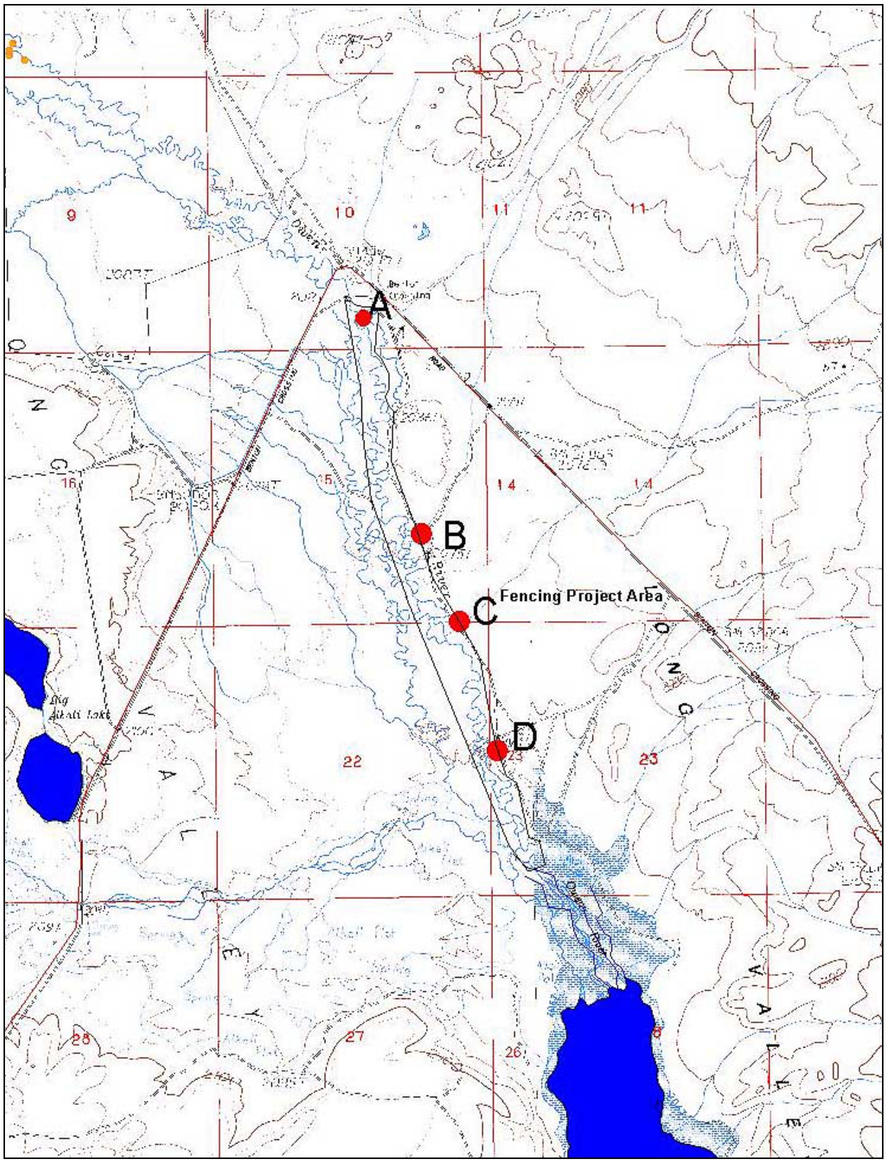
In 1995 the California State Water Resources Control Board (SWRCB) adopted Resolution 95-43 which set forth the California Rangeland Water Quality Management Plan (RWQMP). The plan limits its scope to water quality impacts on all non-federal rangelands, pasture and other grazed lands of California, including private lands and public lands not owned by the federal government. Included in the plan are example BMPs suitable for California rangeland including those of the Upper Owens River Watershed.

As part of this project, certain BMPs were implemented and an attempt was made to evaluate their effectiveness.

Owens River Riparian Corridor Fencing:

Fencing is a commonly practiced structural range improvement. In the summer of 2000 approximately 4.4 km of riparian corridor fencing was constructed along both sides of the Owens River from Benton Crossing downstream to a point near Crowley Lake (Fig. 2.1). The point where the river becomes the lake is difficult to determine because of the broad river channel and the large fluctuations in lake surface elevation. The fence was constructed by the landowner, the Los Angeles Department of Water and Power (LADWP), as part of this project. This section of river was the last remaining major tributary to Crowley Lake on LADWP land that was unfenced. Photographs showing representative sites before and after fencing were taken (Appendix A).

Fig. 2.1 Owens River Corridor Fencing



Public access is allowed to the river through a variety of convenient access points constructed in the same location as historical access points. Roads were closed within the project area and parking was relocated to outside to reduce human and vehicle impacts on the floodplain and riverbanks. LADWP makes a distinction between corridor fencing and riparian pasture in its livestock management. Corridor fencing is constructed very close to the river or creek, keeping the animals off the banks and out of the water but not excluding much pasture. Riparian pastures are much wider and contain significant amounts of storage that are grazed on a rest-rotation basis. Other private landowners in the watershed have also implemented BMPs (Table 2.1).

Table 2.1 Upper Owens River Grazing Management Changes

Stream	Reach	Treatment	Year
Convict Creek	US 395 – McGee Creek	riparian pasture, 3 yr rest/rot.	1994
McGee Creek	US 395 to Crowley Lake	riparian pasture, 3 yr rest/rot.	1994
Mammoth Creek	Chance Ranch	corridor fencing, riparian pasture, different rest/rots.	1994
Mammoth Creek	Chance Ranch	irrigation improvements	2001
Owens River	Arcularius Ranch	livestock reduced by 75%	1998
Owens River	Inaja Land Co.	livestock removed	1999
Owens River	Howard Arcularius	corridor fencing	2000, 2001
Owens River	Benton Crossing – private land	corridor fencing, 5 yr rest	1996
Owens River	Benton Crossing – lake	corridor fencing, 5 yr rest	2000

Other BMPs implemented for the same reach of the Owens Rivers are use exclusion and prescribed grazing. Originally, livestock were to be excluded for the term of the contract. After the exclusion period livestock were to be allowed within the corridor in early summer, with use of 40% of the herbaceous vegetation. However, at this time LADWP has indicated that livestock will be excluded for at least the first five years following the fencing at which time the excluded area will be evaluated and a decision made whether to reintroduce livestock on a limited utilization basis.

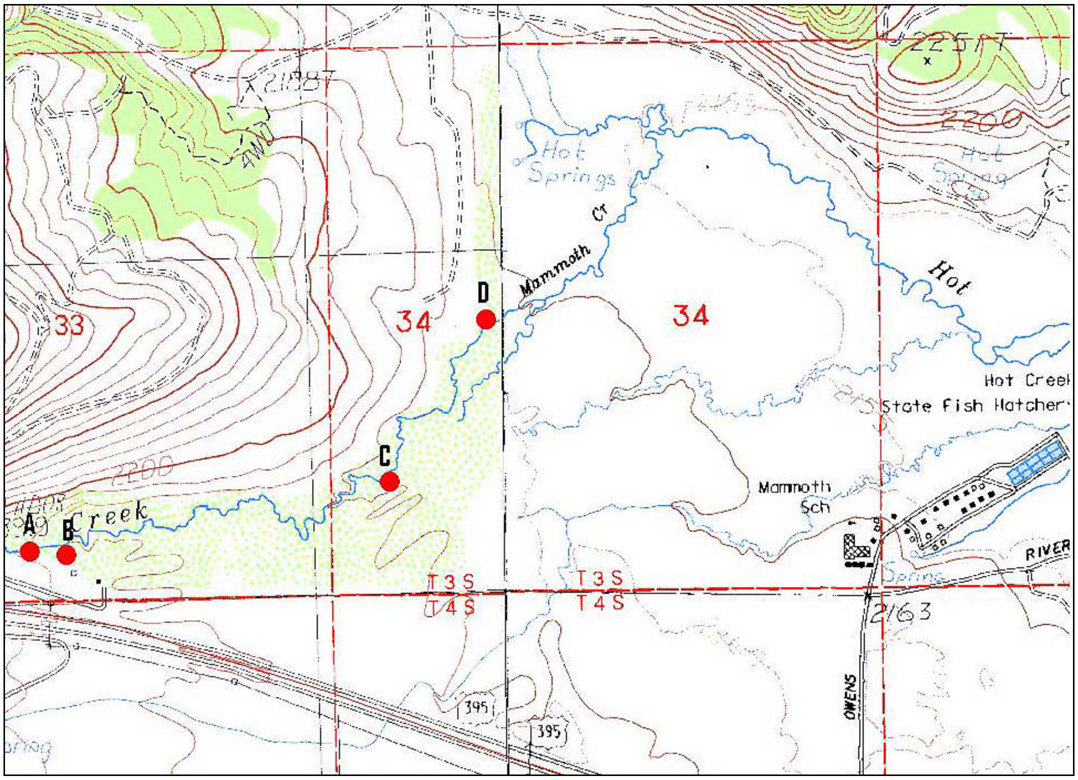
In summer 2001 adjustments were made to the fencing project (Appendix B). Location A (Fig. 2.1) is a simple improvement to a pedestrian walk-through on the Owens River fence directly below Benton Crossing. The wooden fence rails were extended over the bank to prevent cattle from moving downstream into the fenced area. At location B the fence was rerouted to protect a population of *Astragalus johannis-howellii*, the Long Valley milkvetch. The fence was moved further from the river to move the plants inside. This required the relocation of a section of road and the ripping of the old road. Location C is the location of a walk-over ladder constructed over the fence. This was at a location where people were parking and climbing over or through the fence to gain access to the river. It was far from any constructed corner or pull point so it was not practical to install a gate. Location D is an example a typical improvement that was made throughout the newly fenced area. As fishermen were not properly closing gates a modification was made to all the gates to make them self closing.

Mammoth Creek Irrigation Improvements:

Many pastures in the Upper Owens River watershed are irrigated by flooding using water turned out from the tributaries through a series of ditches. Return flows, that is water that comes off an irrigated pasture and returns to the stream channel, may pick up nutrients from the pasture and associated cow manure, and return to the tributary nutrient rich. Ideally just enough water is turned out to balance the evapotranspiration demand of the pasture and result in no return flow. However, this requires careful attention and ability to precisely meter the volume of water turned out.

On Mammoth Creek through Chance Ranch (Fig. 2.2) the irrigation structures were constructed of wood and probably dated back to the early 1900s. These structures were capable of only the grossest adjustment and diversions could never be turned off completely. During the summer 2001 the three primary irrigation structures were replaced with new concrete structures as part of this project. The details of those replacements are described in Appendix B.

Fig. 2.2 Irrigation Improvements



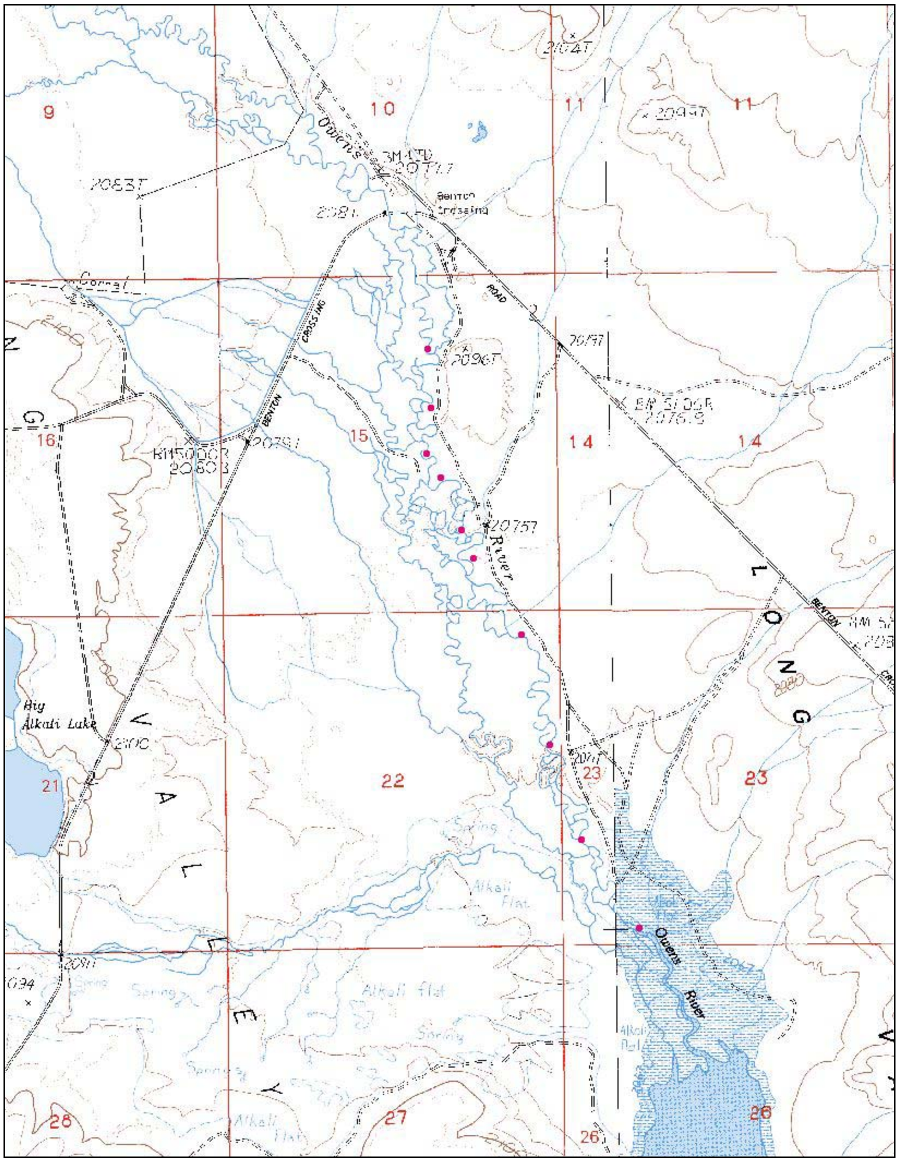
Effectiveness of Corridor Fencing:

In order to determine the effectiveness of the corridor fencing a time series of riparian monitoring measurements were conducted before and after the project. Baseline measurements were collected in 1994, 1996, and 1999 by Ecosystems Sciences (http://www.ecosystemsciences.com/) of Boise, Idaho under contract from LADWP. Measurements were taken at thirty transect locations between Benton Crossing and Crowley Lake (Fig. 2.3). One transect is taken at each indicated point, as well as one each, 100 m upstream and 100 m downstream Transects extend from both sides of the wetted channel laterally at least 50 m or to the edge of the riparian vegetation, whichever distance was greater. Measurements consisted of

- channel cross section
- landform
- dominant vegetation type
- woody species cover
- bank angles
- percentage bank alteration
- bank undercut

Plant community types were classified according to Manning and Padgett (1995). Elevations of each landform above the channel bed were measured using a tripod, transit, and stadia rod. These measurements were repeated in 2001, one year after construction of the corridor fencing. In addition, in 2001 so-called Greenline transects were sampled. These consist of detailed point intercept measurement of vegetative cover and type.

Fig. 2.3 Riparian Monitoring Transects



The post-fencing monitoring was conducted in 2001 as part of this contract but took place too soon after fencing to expect measurable changes. The data will be valuable for comparison with future monitoring and will be included in the database supplied with this report. Ecosystem Sciences and LADWP supplied the following statement as their analysis.

"Monitoring of selected sites south of Benton crossing road took place in 2001 to

obtain vegetation and channel morphology baseline data in order to track future progress of our Riparian livestock fencing program. This project was implemented in fall of 2000 and has been in place for one growing season.

Due to the fact the program has only been in place for one field season, monitoring data results do not exhibit any significant responses that can be reported at this time. In 2000 (sic) baseline/pre-project data was obtained and in 2001 the first year of actual monitoring took place. Vegetation is usually the first parameter to respond with channel morphology lagging behind the vegetation response. This has occurred on our previous projects on Convict, Mcgee (sic), and Mammoth creeks, as well as the Upper Owens River above Benton Xing Bridge (sic). It takes time for the vegetation to become sufficiently established and interact with stream hydraulics in order to influence channel morphology characteristics.

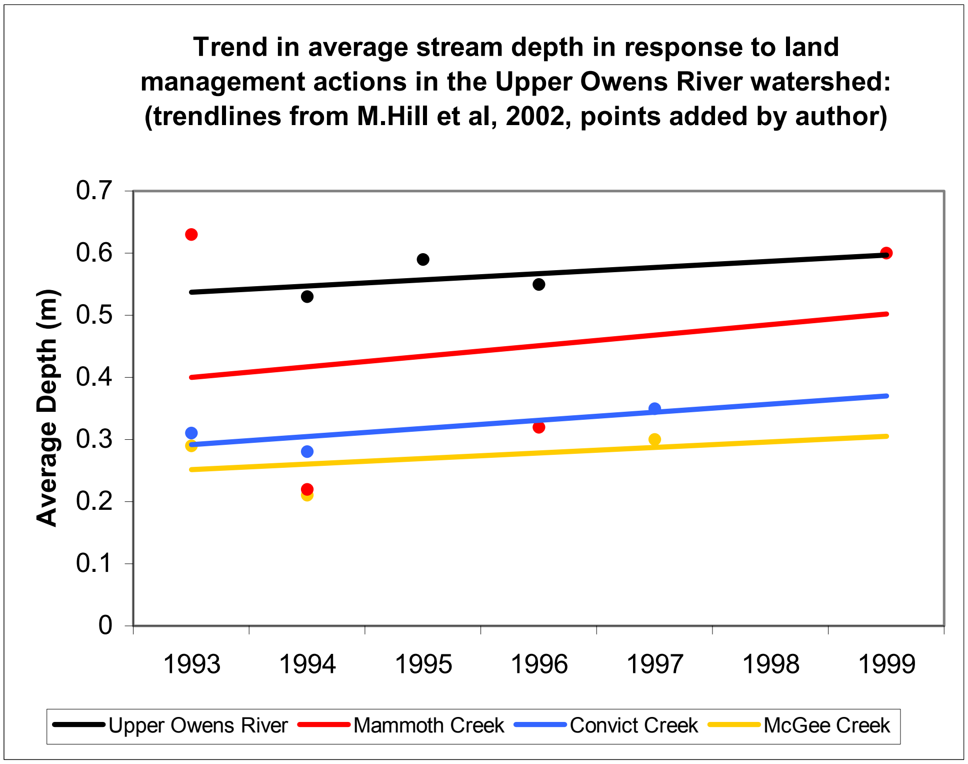
There were no signs of woody species recruitment as peak flows in this low elevation watershed occur in late winter and much prior to peak seeding. Therefore establishment of woody species is expected to be a slow process in comparison to the other Crowley Lake tributaries with high elevation watersheds having peak flows close to seeding periods in late spring/early summer.

The data exhibits many species that prefer drier floodplain habitats such as rabbit brush (CHNA) and wiregrass (JUBA). In the future it is anticipated that species such as Carex spp. and willow (Salix spp.) will takeover and become the dominant vegetation types as water tables rise within the floodplain and riparian wetlands reestablish. As deep-rooted, hydric species become established, fine sediments, which have a higher water holding capacity, are retained within the system. This results in an increase in forage biomass and a rising water table." (Tillemans, 2002)

Typically, LADWP monitors its stream/range projects on a 1-3-5-10 year schedule. They are scheduled to monitor the Owens River reach below Benton Crossing again in 2004, 2006, and 2011 (Tillemans, 2003).

To anticipate the changes we might see below Benton Crossing in future years we can look upstream at the reach that has been fenced since 1966. M. Hill et al (2002) report that the channel for the Owens River (as well as the other tributaries) has both narrowed and deepened as a result of the fencing and livestock management treatment (Fig. 2.4).

Fig. 2.4



However, simple linear regression statistics of the summary data they provided (Z. Hill, 2002) to us do not show slopes significantly different from zero (Fig. 2.4). For each tributary the standard error associated with the trend is larger than the trend (Table 2.2).

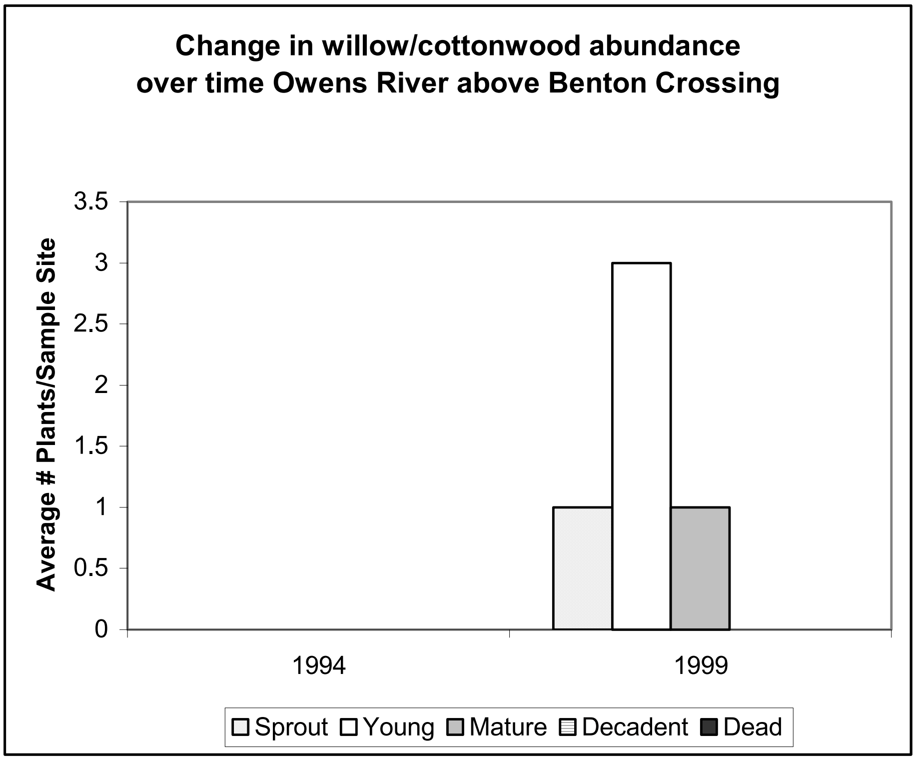
Table 2.2 Linear Regression Statistics

	Convict	McGee	Mammoth	Owens
r squared	0.60	0.14	0.05	0.11
slope	0.01	0.01	0.02	0.01
std error of slope	0.01	0.02	0.05	0.03

Although channel morphology may be changing on these tributaries as a result of BMPs, the data provided to us are not adequate to assess change, and more detailed analysis is outside the scope of this contract.

As indicated in the statement from LADWP, changes in vegetation immediately adjacent to the channel should be the first changes to appear. The Owens River above Benton Crossing had no measurable riparian vegetation in 1994. By 1999 some willow (*Salix spp.*) and cottonwood (*Populus spp.*) plants were recruited (Fig. 2-5). We anticipate this will take longer below Benton Crossing due to the considerable distance from any seed source.

Fig. 2.5 (from M. Hill et al, 2002)



Photomonitoring offers another method to document changes in the riparian condition. Photos taken by LADWP staff at the same location on the Upper Owens River in 1995 and 1998 (Fig. 2.6) demonstrate considerable recovery.

Fig. 2.6 Photomonitoring over time on the Owens River above Benton Crossing

September 1995

September 1998

September 1995 September 1998

Discussion:

Since 1994 a number of Best Management Practices have been implemented in the Upper Owens River Watershed. In 2000, as part of this contract, the Owens River, from Benton Crossing to a point near Crowley Lake was corridor fenced and livestock excluded for at least five years. Physical data on the river characteristics was collected before and after fencing in an attempt to determine the effectiveness of the project however the treatment interval was too short to reveal any changes. Photomonitoring of the other tributaries in the watershed, including the Owens River above Benton Crossing show considerable change since the application of the various BMPs.

In the second year of the contract adjustments were made to the fencing, roads, and access points for the fencing below Benton Crossing. Three new large irrigation structures were constructed on Mammoth Creek to better regulate irrigation flows and prevent return irrigation flows from re-entering Mammoth Creek. No attempt has been made to determine the effectiveness of these changes.

CHAPTER 3: NUTRIENT LOADING TO CROWLEY LAKE

Introduction

Crowley Lake is eutrophic (see Chapter 5) and CWA 303(d) listed for impairment due to nutrients. Crowley Lake receives tributary inflows from five major streams (Upper Owens River and McGee, Hilton, Whiskey, and Crooked Creeks) draining a 380 sq. mi. watershed. Two other large creeks, Mammoth/Hot Creek and Convict Creek are tributary to the Upper Owens River and McGee Creek, respectively. Also, water imported from Mono Basin enters the Owens River and minor diversions from the Rock Creek drainage enter Crooked Creek near the southern end of the lake. Here, we assess nutrient loading to the lake based on year round sampling of the five major tributaries during two consecutive runoff years, April 2000 to March 2001 and April 2001 to March 2002.

Methods

LADWP Long Valley Hydrology & Gauging

The water budget for Crowley Lake is fairly well-characterized by a suite of permanent gauging stations which continuously record stream flow in tributaries to Crowley Lake, evaporation and rainfall estimates from a meteorological station adjacent to the dam, and gauged reservoir outflows (Fig 3.1, Table 3.1).

Fig. 3.1 Gauging stations for Crowley Lake Water Budget

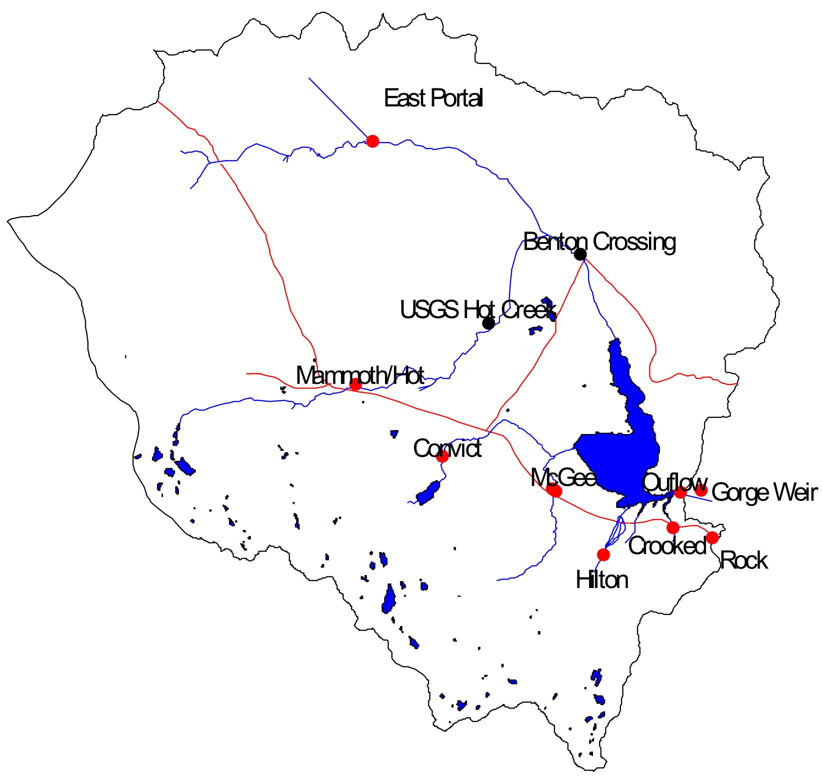


Table 3.1 Crowley Lake Water Budget: Terms and Gauging stations

Inputs	LADWP Station ID	Type	Distance from Lake (km)
Owens River below East Portal	5052	20' Flume and Recorder	19.2
McGee Creek Lower Station #2	4013		2.54
Mammoth/Hot at 395	4026	7' Parshall Flume and Register Station	22.4
Convict Creek above 395	4014	Meter and Register Station	8.83
Hilton Creek at base of mountains		Register and Meter Station	3.12
Crooked Creek at Little Round Valley	4021	3' Parshall Flume and Register Station	0.65
Rock Creek Diversion below intake	4024	4' Flume and Register Station	3.21
Long Valley precipitation	4080		0.15
Outputs			
Long Valley Reservoir Outflow	4018		0
Owens River Gorge at main weir	4015	10' CIPP Weir - Register & Meter Station	1.05
Evaporation	4066	Floating evaporation pan	0
Measured irrigation diversions			
McGee Creek Diversion #31	4005		2.47
McGee Creek Diversion #29	4007		2.55
Lake storage	4070		0

*Based on LADWP Long Valley Runoff Summary

However, despite this array of gauging stations, significant uncertainties in the water budget arise due to sources and land management activities between the gauging points and the lake. The overall LADWP hydrological budget for Long Valley (Crowley Lake) is calculated as:

$$LVAI - LVEIP - \Delta Storage - LVAO = LVUL$$

where Long Valley Actual Inflow (LVAI) is the sum of the Owens River below East Portal (5052), Mammoth/Hot (4026), Convict (4014), Hilton (4019), Crooked (4021), the three McGee stations (4013, 4005, and 4007) and Rock Creek diversions (4024); Long Valley Evaporation Including Precipitation (LVEIP) is evaporation minus precipitation onto the lakes surface; Long Valley Actual Outflow (LVAO) is the sum of reservoir outflow (4018) plus flows in the upper stretch of the Owens River gorge (4015); and LVUL is the uses and losses or gains determined as the remainder. The 50-yr mean (1945-1995) of this gain and loss term was -43,253 ac-ft or 23% of the measured inflow (LVAI, mean 186,985 ac-ft) and indicates substantial unmeasured inputs.

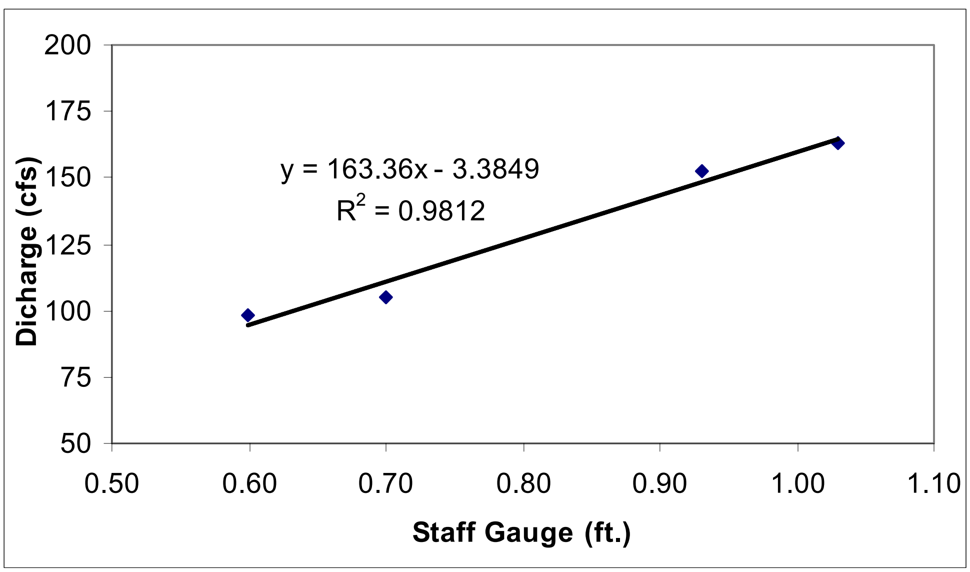
A large portion of these unmeasured inputs derives from the large spring inputs at Hot Creek Hatchery and Hot Creek Gorge downstream of the Mammoth/Hot Creek gauge at 395.

The USGS conducts continuous stream flow measurements at the lower end of Hot Creek Gorge. The estimated flow at this station exceeds the LADWP flows measured at US395 by an average of 39.2 cfs (or 28,400 ac-ft per year) for the 1996-2001 runoff years. During the runoff years of this study (2000-01 and 2001-02) flows gauged by USGS downstream of the LADWP measuring station at US395 totaled 26,705 ac-ft and 25,150 ac-ft more for the two years, respectively. This exceeds the unmeasured gains in LADWP's water budget during both years. Including these in the budget would suggest Uses and Losses of ~7,000 and 16,000 ac-ft for 2000-01 and 2001-02, respectively.

Owens River stream flow at Benton Crossing

The location of gauging stations well upstream from Crowley Lake and the absence of accurate measurements of the amount of water spread for irrigation will increase the uncertainty in the nutrient loading estimates based solely on these flows. As the largest errors would derive from uncertain stream flow estimates of the Owens River, we installed a staff gauge at the Benton Crossing Bridge (4.75 km from the lake) and developed a rating curve through detailed stream velocity measurements employing a Marsh McBurney velocity meter and discharge estimates based on the velocity-area method (Nolan and Shields 2000) on four dates; 19 July 2000, and 3, 15, 21 May 2001. The rating curve was nearly linear over the range of stage heights (0.60 to 1.03 m) observed on these dates (Fig. 3.2).

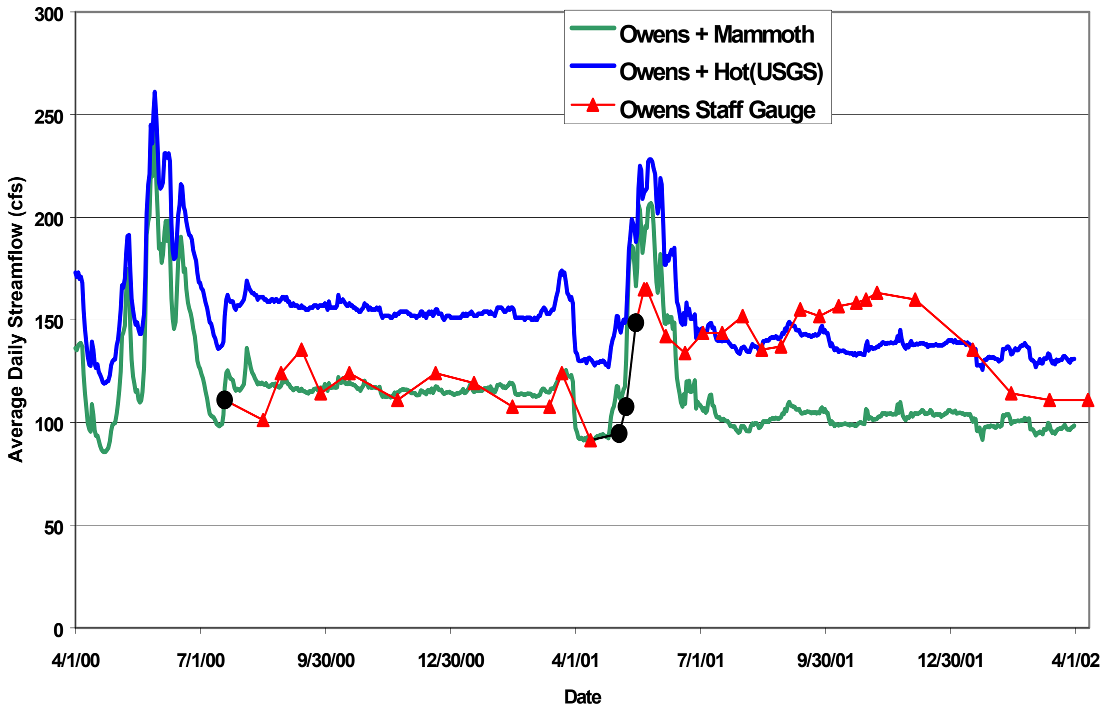
Fig. 3.2 Rating curve for staff gauge installed on Owens River at Benton Crossing



The sum of LADWP gauged flows at Owens River below East Portal and Mammoth Creek at US395 was nearly equal to those estimated by the installed staff gauge at Benton Crossing during the first year of our study (Fig. 3.3). However, following peak spring runoff in 2001, large discrepancies occur. Because the estimated higher flows by this staff gauge during 2001-02 are inconsistent with the rest of the water budget and no significant changes in water management were implemented during 2001-02, we are forced to assume the channel morphology was altered by peak flows subsequent to development of the rating curve. Thus, staff gauge readings during 2001-02 are not usable.

During both runoff years the USGS measured flows at the lower end of Hot Creek Gorge were ~36 cfs higher than flows measured above the gorge at US395. The 2000 staff gauge estimates at Benton Crossing suggest losses due to spreading for irrigation on the upper Owens or below Hot Creek Gorge use much of this gain.

Fig. 3.3 Comparison of flow estimates at Benton Crossing between those based on a staff gauge readings and the sum of measured flows on Mammoth/Hot Creek and Owens River at East Portal.



Field Sampling

Tributary inflows to Crowley Lake were sampled biweekly during the spring-summer period (May-September) and monthly the rest of the year. Tributaries include the Owens River, McGee, Convict, Hilton, Whiskey, and Crooked Creeks. In addition, Mammoth Creek and the dam outflow were also sampled. Mammoth, McGee, Whisky, and Crooked Creeks were sampled just below highway US395. Hilton Creek was sampled adjacent to the lake. Convict Creek was sampled just below SNARL (~1 km above US395). On most dates, additional samples were collected on the Owens River and McGee Creek where they enter the lake to better assess nutrient loading to the lake and determine changes occurring across heavily grazed pastures.

For the purposes of this project, DIW is used to refer to filtered, de-ionized, reverse osmosis treated water. This is our primary washing and rinse water with a specific conductance of approximately 5 μS cm^{-1}. For reagent and standard preparation this water is further polished by ion exchange to a specific conductance of approximately 0.5 μS cm^{-1}.

All apparatus and bottles used in surface water sampling were soaked in de-ionized water (DIW) and then rinsed 3 times with DIW. Sample collection bottles were rinsed with 10% HCl before DIW soaking and rinsing. Filtered samples were filtered in the field with plastic syringes fitted with Gelman A/E filters (1 micron) which were rinsed with at least 150 ml of DIW or sample water. All stream samples with the exception of Benton Crossing were "grab" samples taken at a well-mixed location in the stream such as the outlet of a culvert. Samples at Benton Crossing were integrated across the river with a DH-48 sampler. Samples were kept cool and in the dark during transport. For medium-term storage, samples were frozen.

Dissolved oxygen (DO) and temperature were measured at each sampling location using a YSI Model 57 meter with combination DO and temperature probe

Precipitation was measured at SNARL using a tipping-bucket rain gauge (Qualimetrics model 6011-B) connected to a solid-state data logger. Precipitation samples were collected in polyethylene buckets using an Aerochemetrics wet/dry collector for nitrogen and phosphorus analysis. The Los Angeles Department of Water and Power also measured precipitation at the Crowley Lake Dam.

Laboratory Methods

Immediately following sample collection, samples were transported cold and in the dark to the Sierra Nevada Aquatic Research Laboratory (SNARL) for processing and analysis. pH measurements were done on unfiltered subsamples immediately upon return to the laboratory using a Fisher Acumet digital pH meter and Ross (Orion) combination electrode. The meter was calibrated in a two-point calibration with NRS-traceable buffers near room temperature. After calibration the accuracy of the calibration was checked using dilute solutions of HCl (10^{-4} and 10^{-5} N). The electrode was then rinsed with stirred DIW for several minutes before the pH of the quiescent sample was measured. Specific conductance of unfiltered subsamples was measured on a YSI Model 32 digital conductance meter (cell constant=1.0) corrected to 25°C. A 10^{-4} M KCl conductivity standard, which has a theoretical specific conductance of 14.7 μS cm^{-1} at 25°C was measured at the beginning of each laboratory session.

NH_4 and SRP were analyzed on each field sample on the same day as collection. Remaining filtered field samples were frozen and analyzed for NO_3 within two months of collection. Unfiltered samples for TN and TP were frozen upon return to the laboratory and kept frozen until analysis within two months of collection. TN, TP, and NO_3 were analyzed at the SNARL. Table 3.2 indicates the method and detection limit for each method employed. Detection limits are reported as two times the standard deviation of replicate analyses. Detection limits for total fractions were more variable because of the digestion step.

Table 3.2 Methods for Nutrient Analysis

Species	Method	Reference:	Detection Limit (μM)
NH_3 + NH_4^+	phenol-hypochlorite colorimetric	Strickland and Parsons, 1972 Wetzel and Likens, 1991	0.30
SRP	phospho-molybdate colorimetric	Strickland and Parsons, 1972 Wetzel and Likens, 1991	0.06
NO_3	Cd reduction followed by azo dye colorimetric	Strickland and Parsons, 1972 Wetzel and Likens, 1991	0.20
TP	Valderrama (oxidation/phospho-molybdate)	Valderrama, 1981	0.4
TN	Valderrama (oxidation/Cd reduction/azo dye)	Valderrama, 1981	0.4
TDN	Valderrama (oxidation/Cd reduction/azo dye)	Valderrama, 1981	0.4
TDP	Valderrama (oxidation/phospho-molybdate)	Valderrama, 1981	0.4
As	As(V)$\rightarrow$As(III) reduction/phospho-molybdate	Johnson, 1971	0.02
MTBE	EPA Method 8260A	EPA Manual SW846	1 ppb

Annual Nutrient Loading

The annual nutrient loading from streams was calculated using the period-weighted sample method (PWS) (Dann et al. 1986). Coats et al (2002) did a detailed comparison of four different load calculation methods for Lake Tahoe and concluded the PWS method was generally superior to the other estimators. In the PWS method, each two successive concentrations are averaged, multiplied by the cumulative discharge between sampling times, and the resulting load increments summed over the water year.

Owens River flows at Benton Crossing were estimated as the sum of the LADWP Mammoth Creek gauge and Owens River below East Portal. Although significant unmeasured spring inflows occur downstream of the Mammoth station, flows estimated from the staff gauge at Benton Crossing during 2000 were almost identical to the sum on the Owens River at East Portal and Mammoth Creek at US395. This implies losses on the upper Owens and on Hot Creek below the gorge approximate the spring inflows (see earlier section on Benton Crossing staff gauge).

Two large diversions (#29 and #31) on McGee Creek are used for irrigation and we assume the return flows from these diversions were negligible for this analysis.

A portion of Convict Creek is also diverted to irrigated pastures below the measuring station but we cannot assess these losses and assume they are small relative to the entire water budget.

Whiskey Creek is not gauged. The long-term (1945-1995) average annual runoff in Crooked Creek immediately adjacent to Whiskey Creek was 3206 ac-ft or less than 2% of the measured inflows. The Whiskey Creek watershed is approximately one third as large as Crooked Creek's watershed and thus likely to contribute less than 1% to overall Long Valley. For the purposes of this analysis, we will assume Whiskey Creek runoff is one third the runoff measured at Crooked Creek.

Results

Hydrology

Long Valley (Crowley basin) runoff was below normal during both runoff years of this project (2000/01 and 2001/01) (Table 3.3, Fig. 3.4A). Gauged inflows during the two project years were 135,281 and 115,869 ac-ft or only 72 and 62% of the 50-yr (1945-95) average for 2000-01 and 2001-02, respectively.

Table 3.3 Long Valley (Crowley basin) Runoff (ac-ft) during 2000-01 and 2001-02 Runoff (Apr-March) years

Runoff Term	Station ID	50-yr Average (1945-1995)	Recent 5-yr Average (1995-2000)	April 2001 - March 2002	April 2000 - March 2001
Long Valley Actual Inflow	LVAI	186,985	180,970	135,281	115,869
Owens River below East Portal	5052	118,196	79,148	75,473	68,897
Mammoth/Hot Creek at US395	4026	15,698	24,920	13,481	10,227
Convict Creek just above SNARL	4014	18,514	25,891	14,944	12,643
McGee Creek just below US395	MGCRLV	21,374	30,628	19,178	15,438
Hilton, Crooked, and Rock Creek	4019,4021,4024	13,203	20,383	12,205	8,664
Unmeasured losses and gains	LVUL	43,253	36,458	19,808	8,896

The Owens River supplemented by diversions from the Mono Basin and Mono Craters tunnel make-water constitutes about half of the Long Valley runoff (Fig. 3.4B). Hot (measured above the gorge), Convict, and McGee Creeks contribute 7-10% each, with smaller contributions from Whiskey, Hilton, and Rock Creek. Precipitation onto the lake surface is a minor (<2%) part of Crowley's water budget. However, unmeasured inputs ranged from 7 to 19 % of the sum of gauged inflows and estimated unmeasured gains. A major portion of these un-gauged inputs is presumably spring inputs in Hot Creek Gorge as the annual mean difference between the USGS gauge at the lower end of the gorge and LADWP's gauging station above the gorge is 26,000 ac-ft or 11% of the sum of gauged runoff and estimated unmeasured gains.

The seasonal variation in Owens River flows differs markedly from that of the other major tributaries due to management of flows from the Mono Basin and the sizeable contribution of springs on the upper Owens River (Fig. 3.5). During both years, daily stream flows in the Owens River below East Portal were maintained between 80 and 120 cfs and were nearly constant from August through March during both years at an average of 109 and 95 cfs for 2000-01 and 2001-02, respectively. In contrast, the other tributaries exhibit a 10-fold seasonal variation in flow. Half (mean, 49%; range 43-55%) of the annual flow of Convict, McGee and Hot (measured above the gorge) Creeks occurs during May and June during snowmelt runoff.

Fig. 3.4 Long-term (1945-95), Recent (1995-00), Project Years (2000-01, 2001-02) Annual Runoff Summaries; A) average acre-ft yr-1 B) % contribution

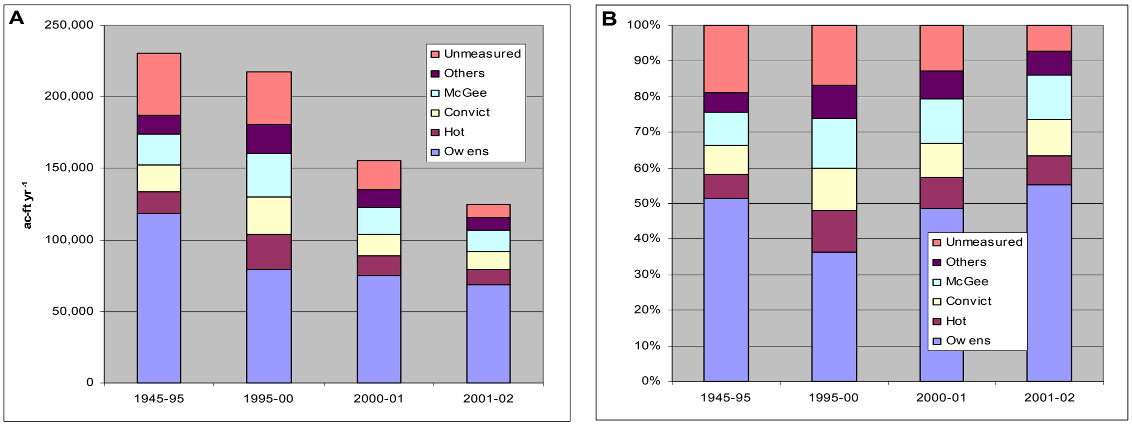
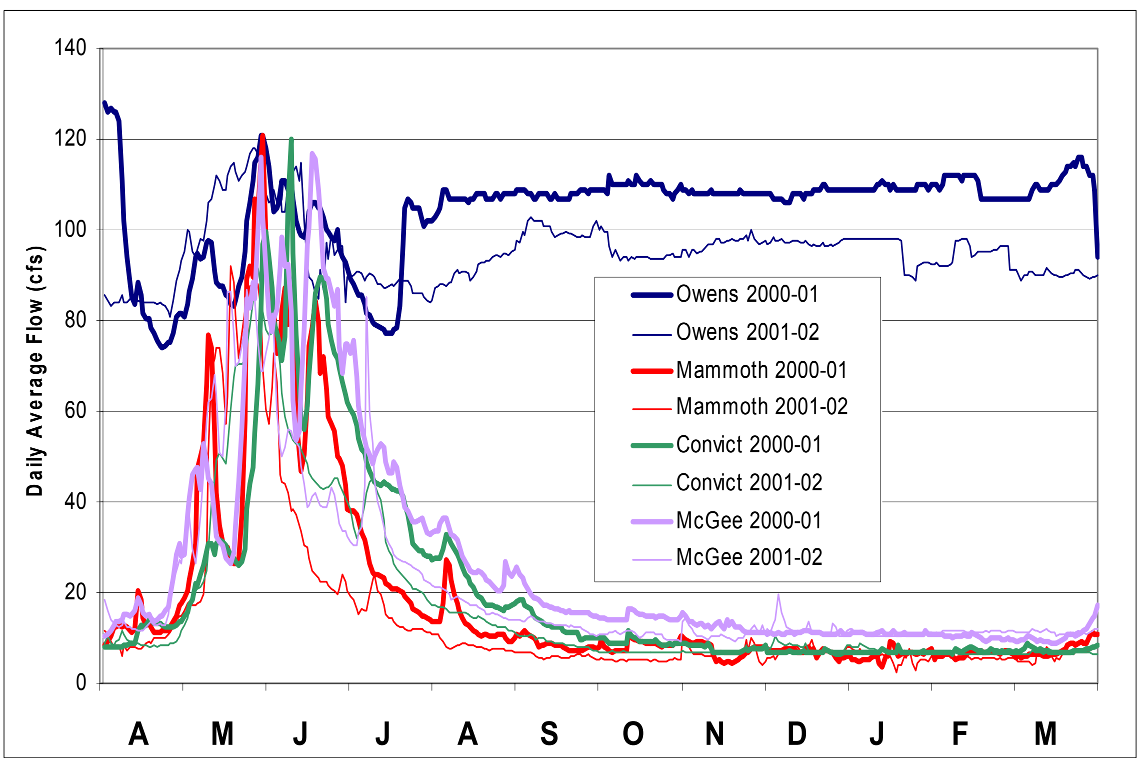


Fig. 3.5 Average Daily Streamflows in Major Tributaries during 2000-01 and 2001-02 Runoff years

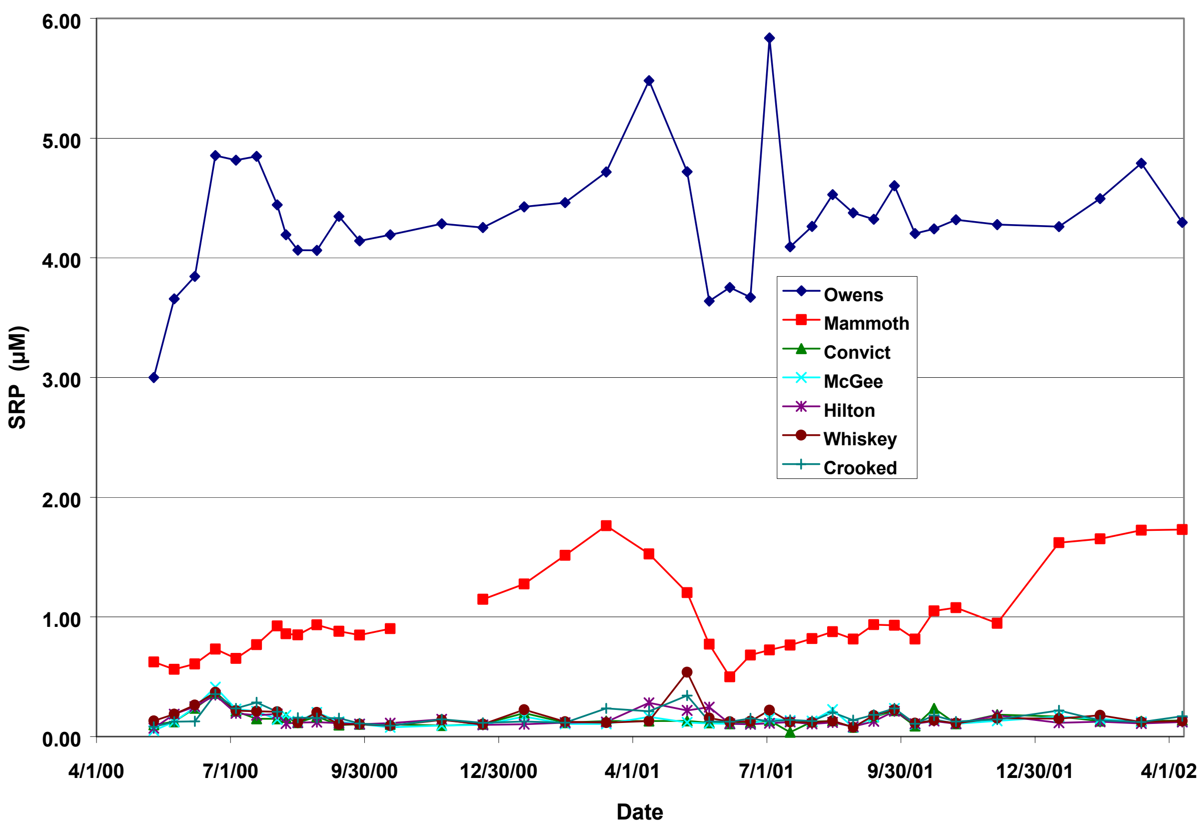


Stream Chemistry

Tributary inflows to Crowley Lake were sampled biweekly during the spring-summer period (May-September) and monthly the rest of the year. Water samples were analyzed for soluble reactive phosphorus (SRP), and total phosphorus (TP), ammonia-ammonium (NH_3), nitrate (NO_3), and total nitrogen (TN). Each of the nutrient constituents exhibited marked seasonality and varied among tributaries.

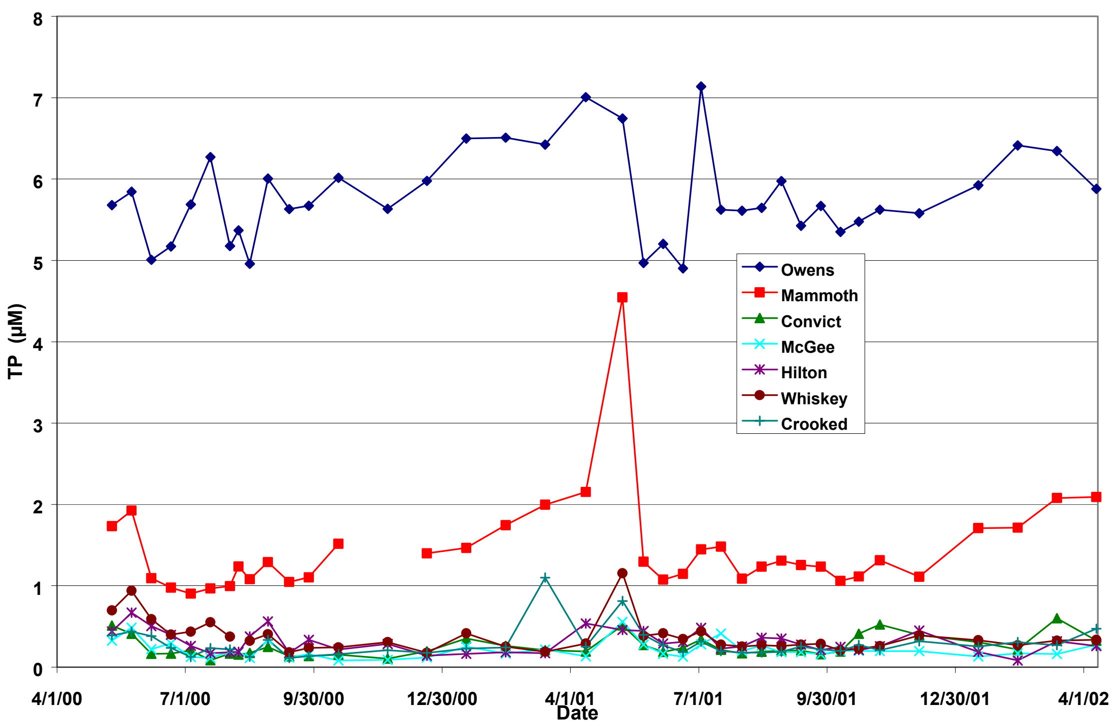
Soluble reactive phosphorus (SRP) concentrations were low (<0.5 µM) throughout the year in Convict and McGee Creeks and the three small tributaries, Hilton, Whiskey, and Crooked Creeks (Fig. 3.6). SRP concentrations in Mammoth/Hot Creek above Hot Creek Gorge and the hatchery were intermediate ranging from 0.3 to 2.4 µM with an overall mean of 1.0 µM. SRP concentrations in the Owens River at Benton Crossing Bridge were much higher throughout the year ranging from 3.0 to 5.8 µM with an overall mean of 4.3 µM. There was a consistent and almost linear increase in concentrations over the course of the runoff year (April-March) during both years 2000/01 and 2001/02 on Mammoth Creek. While less pronounced, the trend was also apparent at the Owens River monitoring site to which Mammoth Creek is tributary.

Fig. 3.6 Soluble Reactive Phosphorus in Major Tributaries to Crowley Lake During 2000-01 and 2001-02 Runoff Years.



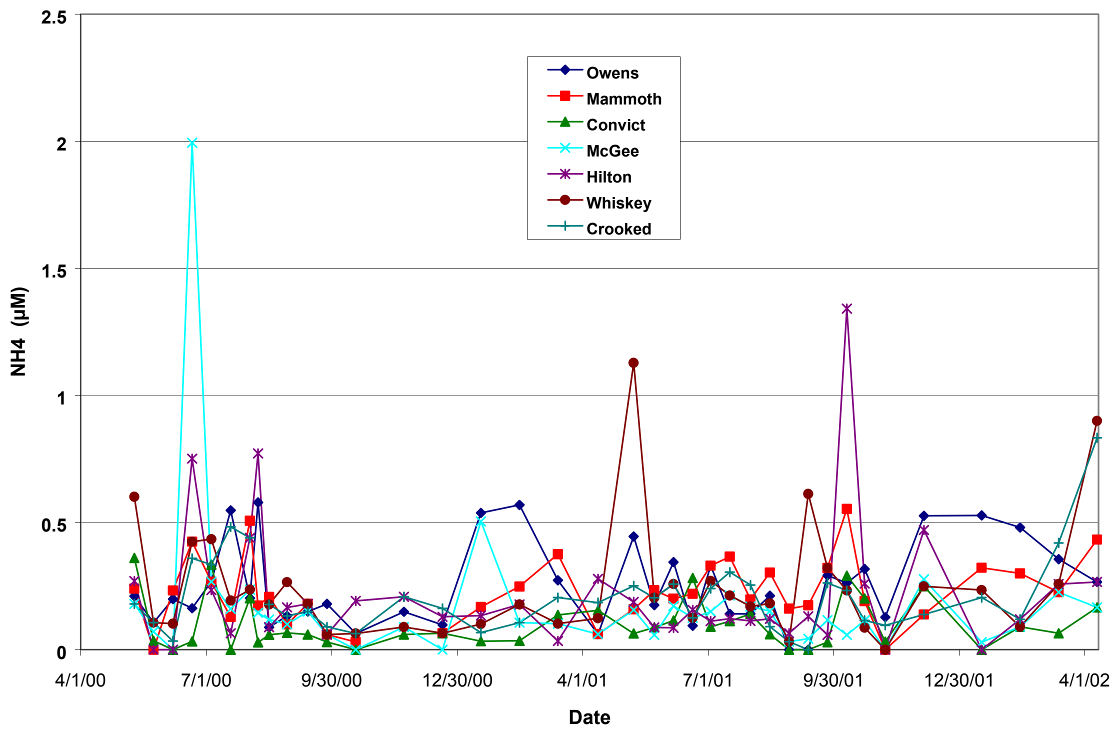
Total phosphorus (TP) includes SRP, particulate P, and dissolved organic P. As with SRP, stream concentrations of TP were low in Convict and McGee Creeks and the smaller tributaries (Fig. 3.7). Concentrations ranged from 0 to 1.2 µM with overall average concentrations of 0.3, 0.2, 0.3, 0.4, and 0.3 µM in Convict, McGee, Hilton, Whiskey, and Crooked Creeks, respectively. TP concentrations were higher in Mammoth Creek ranging from 0.9 to 4.5 µM with an overall mean of 1.5 µM. Owens River TP was high throughout the year ranging from 4.9 to 7.1 µM with an overall mean of 5.8 µM or nearly 4 times that of Mammoth Creek (at highway US 395). At both the Mammoth and Owens River stations SRP constituted the majority of the TP, averaging 75 and 71% of TP for Owens River and Mammoth Creek, respectively.

Fig. 3.7 Total Phosphorus in Major Tributaries to Crowley Lake during 2000-01 and 2001-02 Runoff Years.



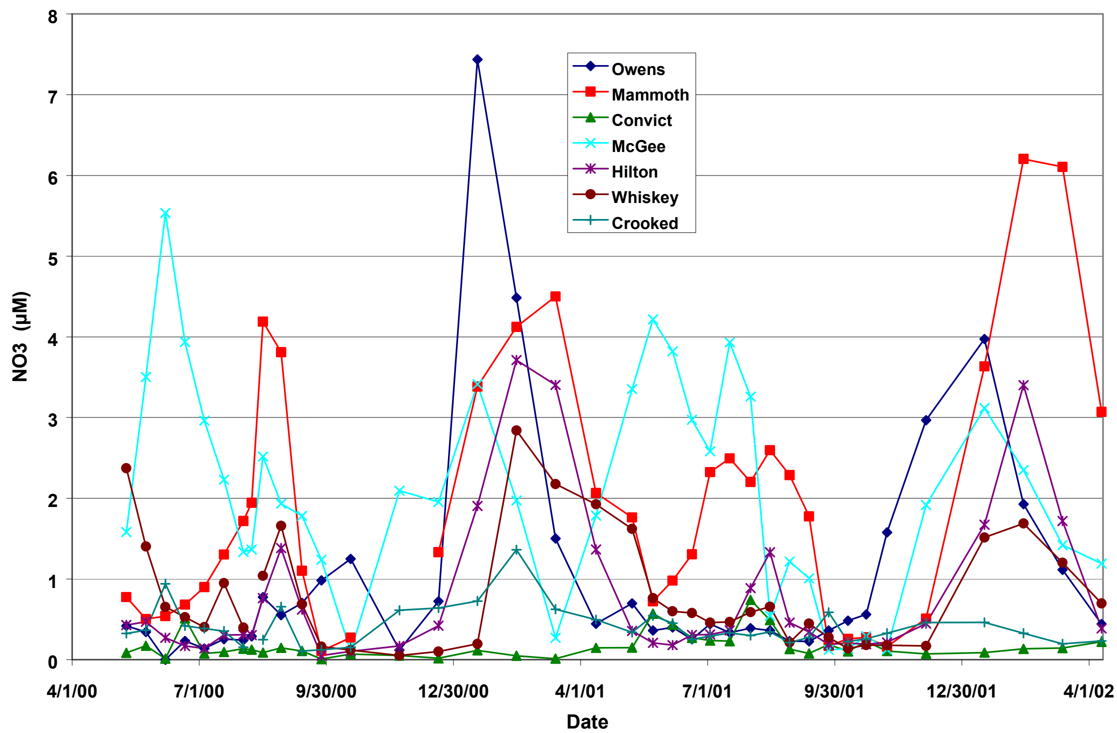
Ammonium concentrations were generally low on all tributaries (Fig. 3.8) with an overall mean concentration of 0.2 µM. However, prominent peaks up to 2 µM were observed on McGee and Convict Creeks on a single date and somewhat lesser peaks (1.1-1.4 µM) occurred on Whiskey and Hilton Creeks. Concentration in the Owens River exhibited seasonal midwinter increases to 0.5 µM and in 2000 slightly elevated concentrations (0.5-0.6 µM) on single dates in July and August.

Fig. 3.8 Ammonia-ammonium in Major Tributaries to Crowley Lake During 2000-01 and 2001-02 Runoff Years



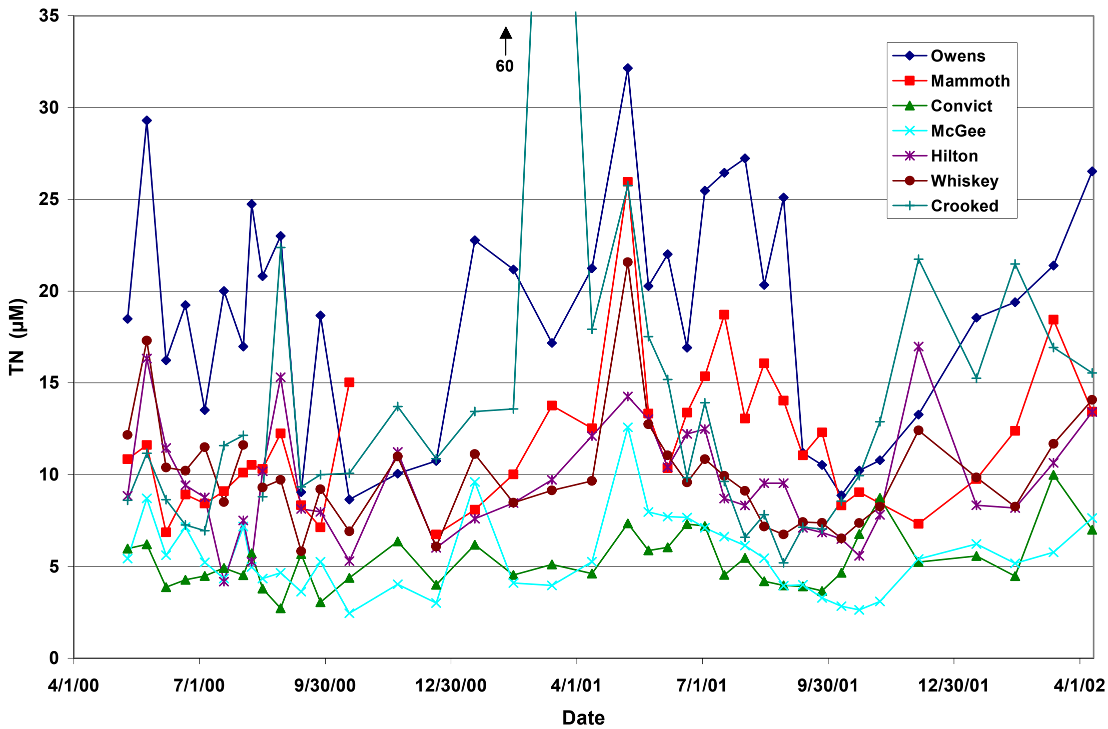
Stream nitrate concentrations ranged from 0 to 7.4 µM and showed marked seasonal variation (Fig. 3.9). Overall mean concentrations for individual tributaries were 1.0, 2.0, 0.2, 2.0, 0.8, 0.8, and 0.4 µM for the Owens River and Mammoth, Convict, McGee, Hilton, Whiskey, and Crooked Creeks, respectively. The Owens River show prominent increases during winter (4-7.5 µM) and a small peak (1.5 µM) in October 2000. Mammoth, McGee, and Whiskey Creeks all exhibited midsummer peaks in addition to midwinter peaks. Winter peaks varied from 3 to 6 µM in these three streams. The summer peaks were most pronounced in McGee and Mammoth Creeks ranging from 2 to 6 µM. During both years, the summer peak occurred earlier on McGee Creek than on Mammoth Creek. Although the summer peak was present on Hilton Creek during both years, it was much smaller (~1.4 µM). Convict Creek nitrate concentrations were low throughout the year never exceeding 0.7 µM.

Fig. 3.9 Nitrate in Major Tributaries to Crowley Lake during 2000-01 and 2001-02 Runoff Years



Total nitrogen (TN) includes the digestible particulate and organic pools and nitrate and ammonia pools. Total nitrogen was generally more variable and exhibited seasonal minima during autumn. Except for a single outlier on Crooked Creek, concentrations ranged from 2 to 32 µM (Fig. 3.10). Overall mean concentrations were 19.1, 11.9, 5.4, 5.5, 9.6, 10.0, and 13.6 µM for the Owens River and Mammoth, Convict, McGee, Hilton, Whiskey, and Crooked Creeks, respectively. The ammonia pool constituted 1-2% of TN in Owens River, Mammoth and Crooked Creek samples and 2.7-3.4% of TN in samples from Convict, McGee, Hilton, and Whiskey Creeks. Nitrate constituted a much larger fraction of TN; 6, 16, 3, 3, 9, 8, and 4%, for the Owens River and Mammoth, Convict, McGee, Hilton, Whiskey, and Crooked Creeks, respectively.

Fig. 3.10 Total Nitrogen in Major Tributaries to Crowley Lake During 2000-01 and 2001-02 Runoff Years

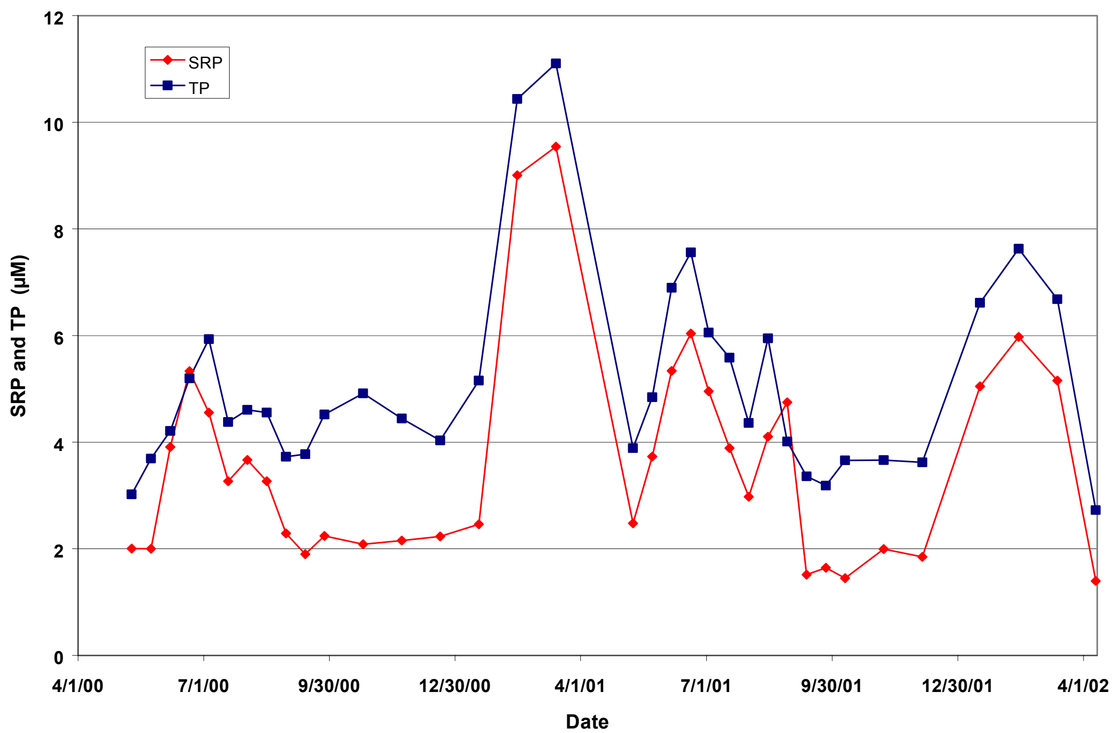


Crowley Lake outflow chemistry

Water samples were collected directly from the Crowley outflow pipe from within the base of the dam on the same schedule as the major tributaries and analyzed for SRP, TP, NH4, NO3, and TN. SRP outflow concentrations ranged from 1.4 to 9.5 µM with an overall mean of 3.6 µM. Both years exhibited summer and winter peaks corresponding to stratified periods in this dimictic lake. SRP constituted most (68%) of the TP in the samples. Only during the well-mixed periods during September-November and at ice-off (mid-April) did the SRP fraction decline to approximately half of TP.

Nitrogen outflows exhibited the same pattern of seasonal peaks corresponding with the stratified periods (Fig. 3.12). However, nitrogen outflows were dominated by organic and particulate fractions as the relative proportions of NH4 and NO3 to TN averaged only 29 and 1.5%, respectively. Outflow TN ranged from 25 to 120 µM (mean, 57 µM), while NH3 ranged from near zero to 50 µM (mean, 18 µM). Nitrate concentrations were low throughout the year in the outflow.

Fig. 3.11 Soluble reactive (SRP) and total (TP) phosphorus concentrations in outflows from Crowley Lake



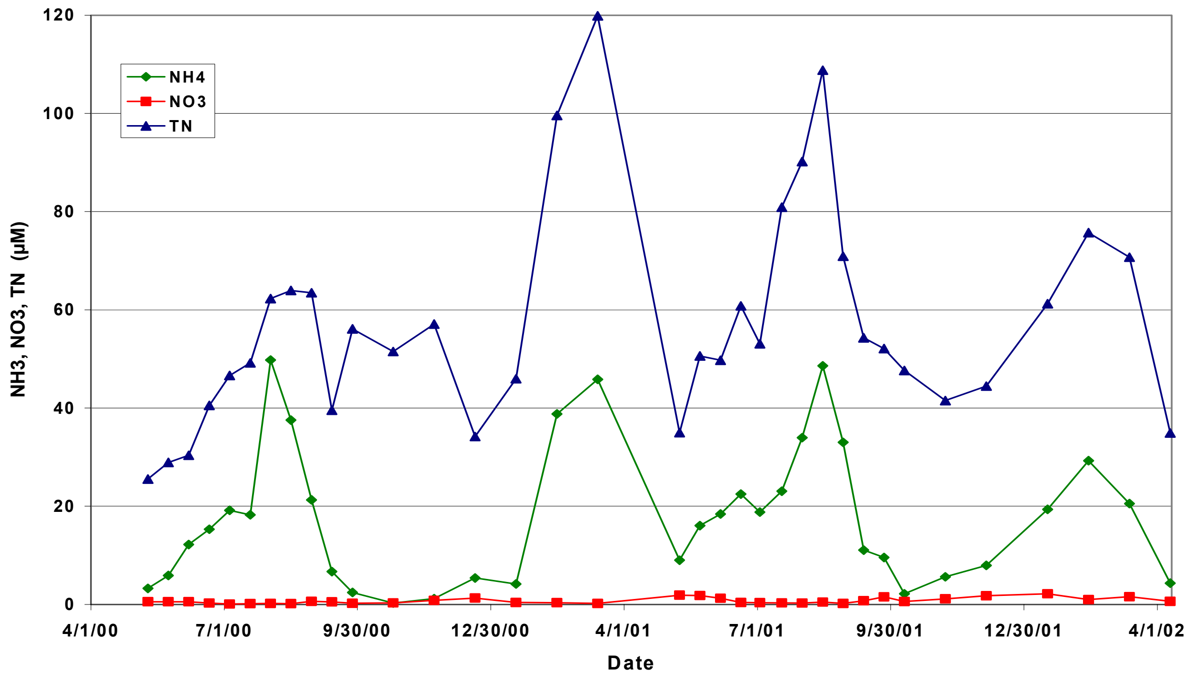
Precipitation chemistry

Analyses of nutrient concentrations of precipitation were performed on samples collected at the Sierra Nevada Aquatic Research Laboratory. Nitrogenous fractions were variable and at times high (Table 3.4). The volume-weighted mean for each year was calculated and applied to the precipitation data from Crowley Lake (provided by LADWP) to estimate the contribution of atmospheric deposition to nutrient loading. The estimated nutrient loading due to atmospheric deposition was similar between the two years.

Table 3.4 SNARL Precipitation Chemistry, April 2000 – March 2002

Concentrations (µM)	**NH_4**	**NO_3**	**TN**	**SRP**	**TP**
Minimum	<0.01	3.7	7.8	<0.01	0.09
Maximum	88.3	85.5	112.0	1.7	3.8
Volume Weighted Mean	7.3	9.0	18.7	0.2	0.3
Annual lakewide loading (moles yr^{-1})					
2000-01	21158	26065	50292	430	666
2001-02	15622	19019	43126	425	684
Mean	18390	22542	46709	428	675

Fig. 3.12 Ammonium (NH_4), nitrate (NO_3), and total nitrogen total (TN) concentration in outflows from Crowley Lake



Nutrient Loading

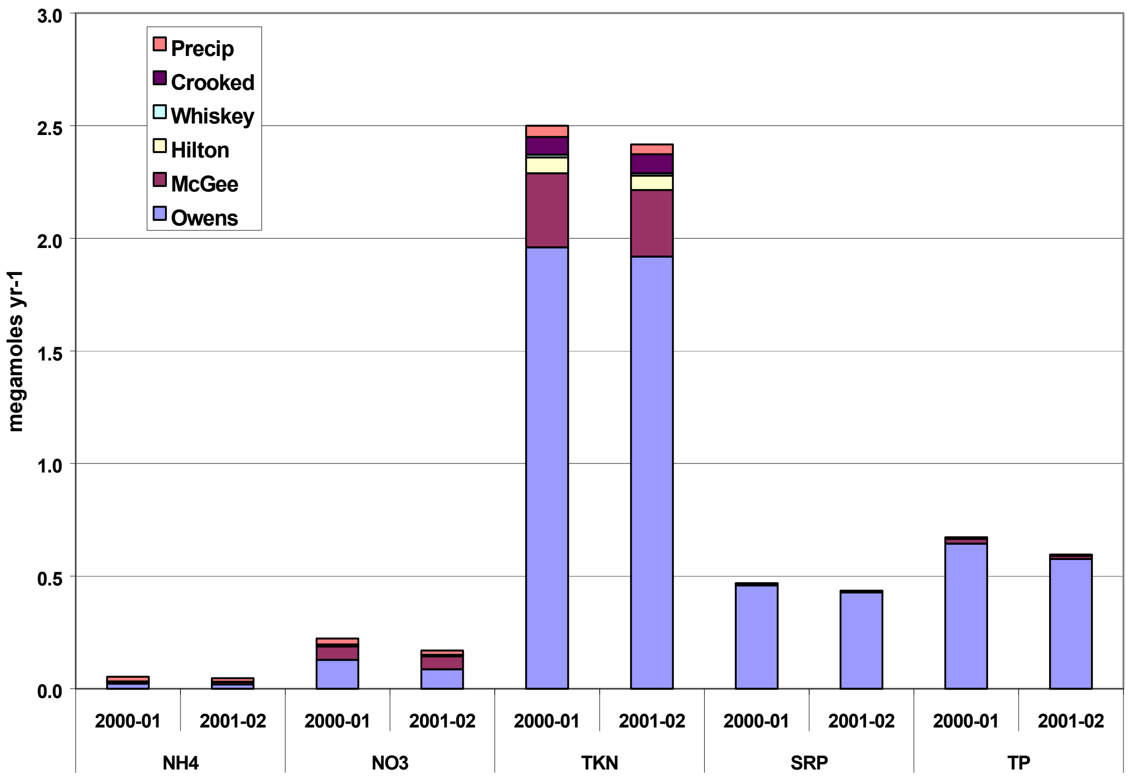
Nutrient inputs from the Owens River dominated both nitrogen and phosphorus loading to Crowley Lake (Fig. 3.13). While the overall nutrient loading was slightly higher in 2000-01 compared to 2001-02, the relative inputs were very similar between the two years.

Total phosphorus (TP) loading during the two years was 0.67 and 0.60 megamoles, respectively, which given an approximate surface area of 16.7 km^2 yields an average of ~1.1 g m^{-2} yr^{-1}. Inputs from the Owens River constituted 96% of the total SRP and TP load. Soluble reactive phosphorus was ~71 % of total P.

Estimates of total nitrogen (TN) loading for the two years were similar at 2.50 and 2.42 megamoles yr^{-1} or an average annual loading rate of 1.9 g m^{-2}. While the Owens River dominated nitrogen inputs (79%), McGee accounted for 13% of the total loading, and Hilton and Crooked Creeks an additional 3% each. Whiskey Creek contributed less than 0.5% of the total and precipitation accounted for the remaining ~2% of measured TN loading.

Dissolved inorganic fractions of nitrogen (NO_3 and NH_4) constituted 10% of the TN loading. While the Owens River dominated the NO_3 loading (42%), McGee Creek and precipitation accounted for 29 and 12 %, respectively. In contrast to McGee Creek, Convict Creek accounted for only 2% of the NO_3 loading. While the Owens River supplied 42% of the measured NH_4 inputs, precipitation and McGee Creek accounted for 37 and 16%, respectively. Although, precipitation contributes a major portion of the ammonia loading, NH_4 is a small portion (<2%) of total nitrogen loading.

Fig. 3.13 Annual Nutrient Loading to Crowley Lake



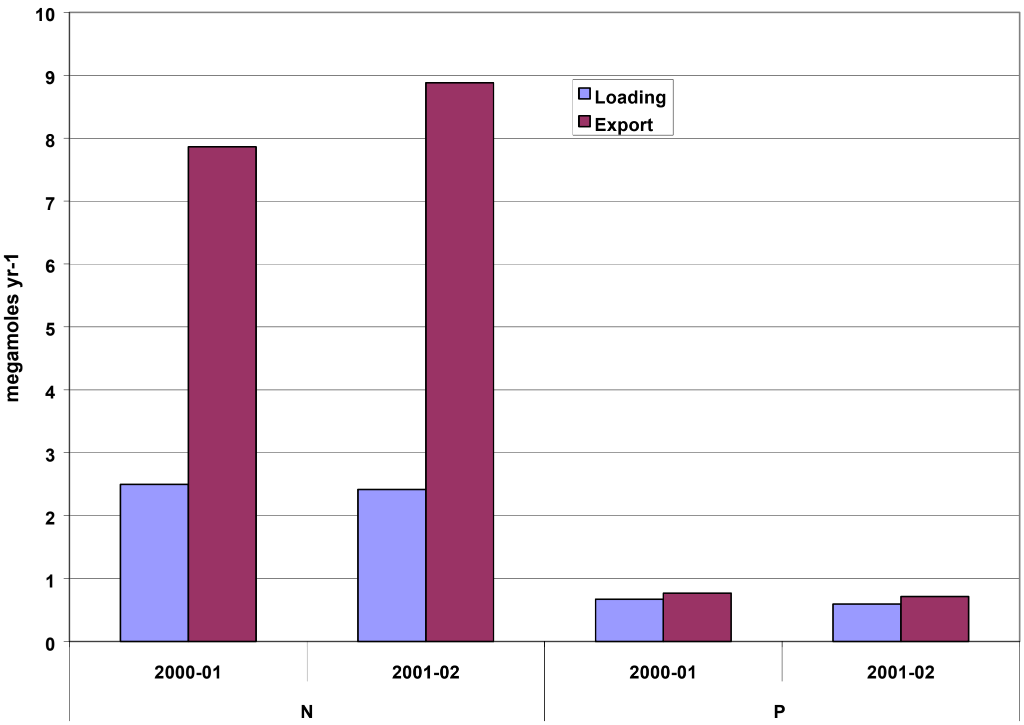
Nutrient exports from Crowley Lake

Year-round monitoring of nutrient concentrations in outflows from Crowley Lake, enabled a comparison of measured inputs to exports. Phosphorus inputs and exports are roughly in balance with exports exceeding measured inputs by 15-20%. However, exports of nitrogen greatly exceeded measured inputs (>300%) during both years (Fig. 3.14).

Discussion & Conclusion

Nitrogen and phosphorus loading to Crowley Lake is high and is dominated by the Owens River. The average annual loading during the two runoff years, April 2000 to March 2001, and April 2001 to March 2002 was 1.2 g P m^{-2} yr^{-1} and 2.1 g N m^{-2} yr^{-1}. At the average lake level observed during the study of ~6768' (2062 m), the lake area is 16.7 km^2 with a volume of 1.48 x 10^8 m^3 and thus an average depth of ~9 m. Although the actual levels of nutrient loading which can be sustained without causing eutrophication depend on a wide array of environmental factors, the P loading rates estimated in this study exceed what are generally considered acceptable. In early work, Vollenweider suggested permissible and dangerous loading levels for a lake with an average depth of 10 m to be 1.5 and 3.0 g N m^{-2} yr^{-1} and 0.10 and 0.20 g P m^{-2} yr^{-1} (see Table 13-19, Wetzel 2001). Later, Vollenweider and Kerekes (1980) suggested a slightly higher rate for excessive P loading of 25 mg P m^{-3} still well below the Crowley Lake value of 130 mg P m^{-3}.

Fig. 3.14 Crowley Lake N and P Budget: Measured Inputs versus Exports



Ninety-six percent of the measured phosphorus loading to Crowley Lake enters through the Owens River whose flows account for only half the overall water budget. Large natural springs along the upper Owens River above East Portal and along Mammoth/Hot Creek from below US highway 395 to the lower end of the Hot Creek thermal area account for nearly all of the phosphorus loading (see Chapter 4). While the Owens River also accounts for most (79%) of the total nitrogen inputs, McGee Creek also contributes significantly (13%) to overall N loading.

Marine phytoplankton show a relatively constant ratio of C:N:P of 106:16:1. This is known as the Redfield Ratio and is attributed to the nutrient sufficient growth conditions of marine plankton and the homogeneous and stable nature of the oceans. In freshwater, N:P ratios in plankton are strongly correlated with N:P loading rates and deviations from the Redfield Ratio provide an indication of the type and extent of nutrient limitation (Wetzel, 2001). In Crowley Lake, the nutrient load has low N:P ratios. The TN:TP molar ratio of inflowing nutrients is 3.9; well below the Redfield ratio of 16. Also, the nutrient loading ratio of dissolved inorganic nutrients (NO3+NH4/SRP) is even lower, 0.5. These low nutrient ratios favor the cyanobacteria (blue-greens) and nitrogen fixation. Thus, it is not surprising that Crowley Lake is eutrophic and experiences nuisance blooms of cyanobacteria (see Chapter 5).

The estimates of annual P loading are approximately equal to annual outflows. However, the export of N in the reservoir outflows is 3 to 4 times the measured inflows. The difference is partly due to unmeasured inputs via nitrogen fixation by cyanobacteria (see Chapter 5).

The high P loading rates of Crowley Lake are almost entirely due to natural sources. While land-management activities account for a portion of the N inputs observed in McGee

Creek (see Chapter 4), the eutrophic state of Crowley Lake is unlikely to be significantly altered without reducing the inputs of P derived from natural sources along Hot Creek and the Owens River.

CHAPTER 4: NUTRIENT SOURCES & LAND USE

Introduction:

The Upper Owens River watershed is approximately 380 sq. miles (984 km^2). The watershed is bounded by the Sierra Nevada crest to the west and the Glass Mountains to the east. It is defined by the Crowley Lake (Long Valley Reservoir) dam to the south and the divide north of Glass Creek. Land ownership is predominately public land administered by Inyo National Forest (INF) and the Bureau of Land Management (BLM) with the City of Los Angeles, Department of Water and Power (LADWP) owning lands immediately adjacent to the lake. The only significant private ownership occurs on the Upper Owens River north of the lake, in the town of Mammoth Lakes, and in several smaller communities (Long Valley, McGee Creek, Hilton Creek, and Aspen Springs) west and south of the lake. The primary land uses (by area) are livestock grazing, logging, and dispersed recreational uses. In addition to the Upper Owens River, four smaller tributaries flow directly into the lake from the west (McGee, Hilton, Whiskey, and Crooked Creeks).

In order to identify the general locations where nutrients accrue to the system we conducted three longitudinal surveys each year, collecting samples from each of the major tributaries. Rather than collect samples at some arbitrary distance interval up the stream, we collected samples at changes in land use that would allow us to determine whether there are measurable effects of different land-use practices on in-stream nutrient concentrations. Originally, forty-seven sampling stations were selected based on land-use patterns, springs, confluences, and other features along the various tributaries (Table 4.1).

Table 4.1 2000 Longitudinal Sampling Stations

station code	tributary	station description
OW0	Owens	Inlet to lake
OW1	Owens	Benton Crossing bridge
OW2	Owens	Downstream property line of Arcularius ranch (upper DWP property line)
OW3	Owens	Upstream property line of Arcularius ranch
OW4A	Owens	East Portal (Owens River immediately above East Portal)
OW4B	Owens	East Portal (tunnel water)
OW4C	Owens	East Portal (below confluence of East Portal and Owens River)
OW5	Owens	Downstream property line of Alper's Ranch
OW6	Owens	Upstream property line of Alper's Ranch
OW7	Owens	Culvert immediately downstream of Big Springs
OW8A	Owens	Big Springs A (easternmost of two sampled)
OW8B	Owens	Big Springs B (westernmost of two sampled)
OW9	Owens	Below confluence of Glass and Deadman Creeks
OW10A	Glass	Just above confluence with Deadman Creek
OW10B	Deadman	Just above confluence with Glass Creek
MA1	Hot	Flume below thermal area
MA2A	Hot	Immediately above confluence of Hot Creek and hatchery inputs
MA2B	Hot	Hatchery inputs immediately above confluence with Hot Creek
MA2C	Hot	Immediately below confluence of Hot Creek and hatchery inputs
MA3	Mammoth	Gaging station at US395
MA5A	Mammoth	Above confluence with Sherwin Creek

MA5B	Sherwin	Sherwin Creek at confluence with Mammoth Creek
MA5C	Mammoth	Immediately downstream of confluence with Sherwin Creek
MA6	Mammoth	Twin Lake outlet
CO0	Convict	Upstream of confluence with McGee
CO1	Convict	Downstream property line of SNARL
CO2	Convict	Upstream property line of SNARL
CO3	Convict	Outlet from Convict Lake
MG0	McGee	Inlet to lake
MG1	McGee	Below confluence with Convict
MG2	McGee	Above confluence with Convict
MG3	McGee	Just below US395
MG4	McGee	Above community
MG5	McGee	Above pack station and campground
HL0A	Hilton	Easternmost channel at inlet to lake
HL1A	Hilton	Easternmost channel at US395
HL1B	Hilton	2nd easternmost channel at US395
HL1C	Hilton	3rd Easternmost channel at US395
HL1D	Hilton	4th easternmost channel at US395
HL2A	Hilton	Easternmost channel at Old US395
HL2B	Hilton	2nd easternmost channel at Old US395
HL2C	Hilton	3rd easternmost channel at Old US395
HL2D	Hilton	4th easternmost channel at Old US395
HL3	Hilton	Above community
WH1	Whiskey	Just below US395
CR1	Crooked	Just below US395
OUT	Dam	Outlet from Crowley Lake

Fifteen sampling sites were located along the Upper Owens River. Glass Creek drains the most northern sub-unit of the Owens River watershed. It lies within Inyo National Forest and runs through both logged and un-logged parcels of mixed conifer and Jeffrey Pine forests and grazed meadow. Deadman Creek is immediately south. We sampled both these creeks just upstream of US 395 where they merge. About 4.2 km downstream from the highway, the Owens River originates where Big Springs flow into Deadman Creek. Samples were taken from the two most pronounced spring sources and below the spring's inflows. Below Big Springs the river enters private land on Alpers Ranch. The dominant land use is aquaculture with some cattle grazing. Sampling took place where the river entered the ranch, from a prominent spring source on the ranch, and where the river leaves the ranch. Next the river enters Arcularius Ranch. A former cattle ranch and fly fishing resort, the ranch is now operated as a private ranch with a very small "hobby" herd of cattle and horses. Approximately 1.2 km below Big Springs, on Arcularius Ranch, the Mono Craters tunnel delivers water from the Mono Basin as part of the Los Angeles Aqueduct system. While this flow has been recently reduced to allow restoration in the Mono Basin, flows will increase once Mono Lake reaches its target elevation. Samples were taken at the tunnel outflow to the river. Next downstream is Inaja Land Company, an enclave of private homes and cabins. Cattle were grazed here until 1999 at which time LADWP purchased some water rights from the group with the agreement that the water would go into the river (rather than spread for irrigation) and there would be no more grazing. The last private parcel belongs to Howard Arcularius, who uses it for livestock grazing. Samples were taken at the upstream and downstream ends of this property. From there to Crowley Lake the dominant land-use is grazing on LADWP lands. A longitudinal sample was taken at the Benton Crossing bridge where the bi-weekly monitoring took place and a sample was taken approximately 4 km downstream where the river channel becomes Crowley Lake.

The headwaters of Mammoth/Hot Creek originate in the Mammoth Lakes basin just west of the town of Mammoth Lakes. Mammoth Creek was sampled at the outlet of Twin Lake and below the town at the confluence of Sherwin Creek to isolate the town's contribution to the nutrient load. Between the city of Mammoth Lakes and Crowley Lake, the predominant land-use adjacent to the Creek is grazing. However, the Hot Creek fish hatchery and a series of large thermal springs are located in this reach. Samples were collected above Chance Ranch at the LADWP gage, at the confluence with Hot Creek below the Fish Hatchery, and below the Hot Creek thermal area at the USGS gage.

Convict, McGee, and Hilton Creeks all originate in steep basins of the Sierra Nevada immediately west of Crowley Lake. Land-uses along these creeks include recreational campgrounds, commercial pack stations, residential development, and horse and cattle grazing pastures. Sampling sites along Convict Creek included the Convict Lake outflow, above and below the University of California's Sierra Nevada Aquatic Research Laboratory (SNARL), and just above the confluence with McGee Creek. This will delineate any effects of the campground on Convict Creek, and grazing below SNARL. McGee Creek has a pack station and campground above an area of residential development before entering irrigated pasture in Long Valley. Samples were taken above the campground and pack station near the wilderness border above the residential development, below the residential development (at Highway 395), above and below the confluence with Convict Creek, and at the lake edge. Of these three tributaries, Hilton Creek has the largest area of residential development. Through the residential area the creek is divided into many channels. Samples were taken above the residential development in a single channel at the LADWP gage, at Crowley Lake Drive, at US 395, and where the creek enters the lake. As part of the longitudinal surveys samples were also taken from the penstock at the Crowley Lake outflow as done in the bi-weekly surveys.

Our original plan was to sample the four major Hilton Creek distributaries at each bi-weekly sampling at US395 (HL1A-D) and each of those same distributaries at US395 and Crowley Lake Drive (HL2A-D) during the longitudinal surveys. The plan was to try to detect nutrient differences resulting from differing land use practices in parts of the community. After six bi-weekly samples and one longitudinal sample, we reduced the sampling to a single channel. Not only were the concentrations of the various constituents the same in each distributary, but the various channels were too difficult to gauge. Ultimately HL0 was used for the bi-weekly sampling and HL0, HL1A, HL1C, HL2A, and HL3 were sampled during the longitudinal surveys.

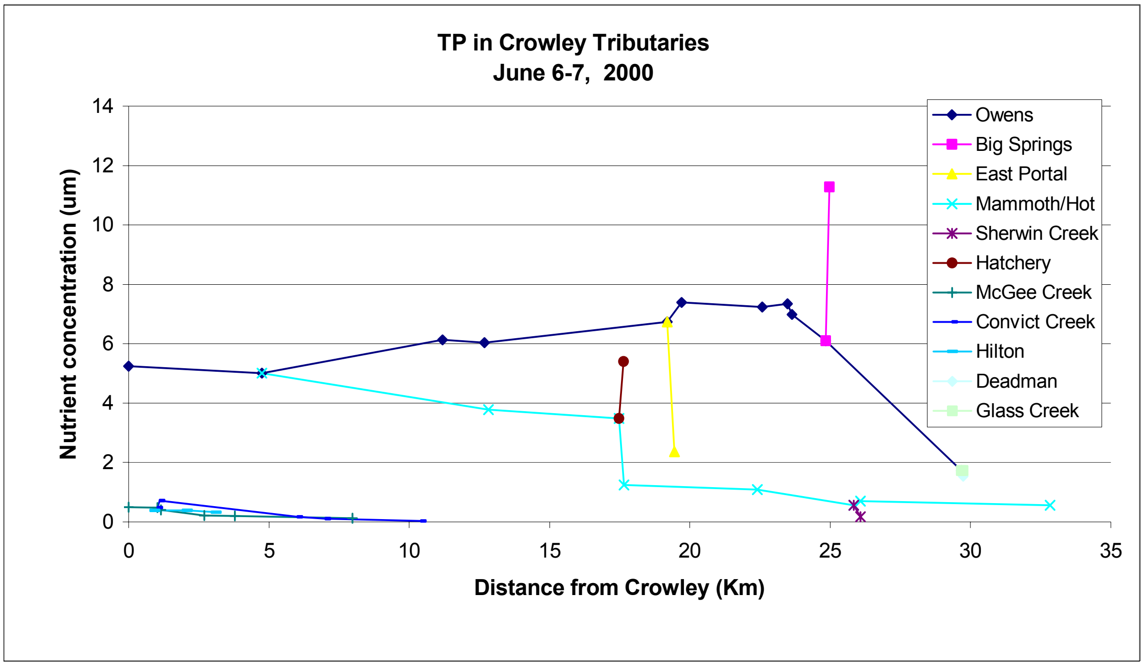
Methods:

Longitudinal sampling was conducted three times per summer during a two-day period scheduled to coincide with regular bi-weekly sampling. The methods employed in the longitudinal surveys are the same as those used for the biweekly sampling (Methods Section, Chapter 3). Constituents measured were ammonia/ammonium (NH_4), nitrate (NO_3), total nitrogen (TN), soluble reactive phosphorus (SRP), and total phosphorus (TP).

Results:

Total phosphorus in the Crowley tributaries from the June 6-7, 2000 survey, represents the typical results from the 2000 longitudinal surveys (Fig. 4.1).

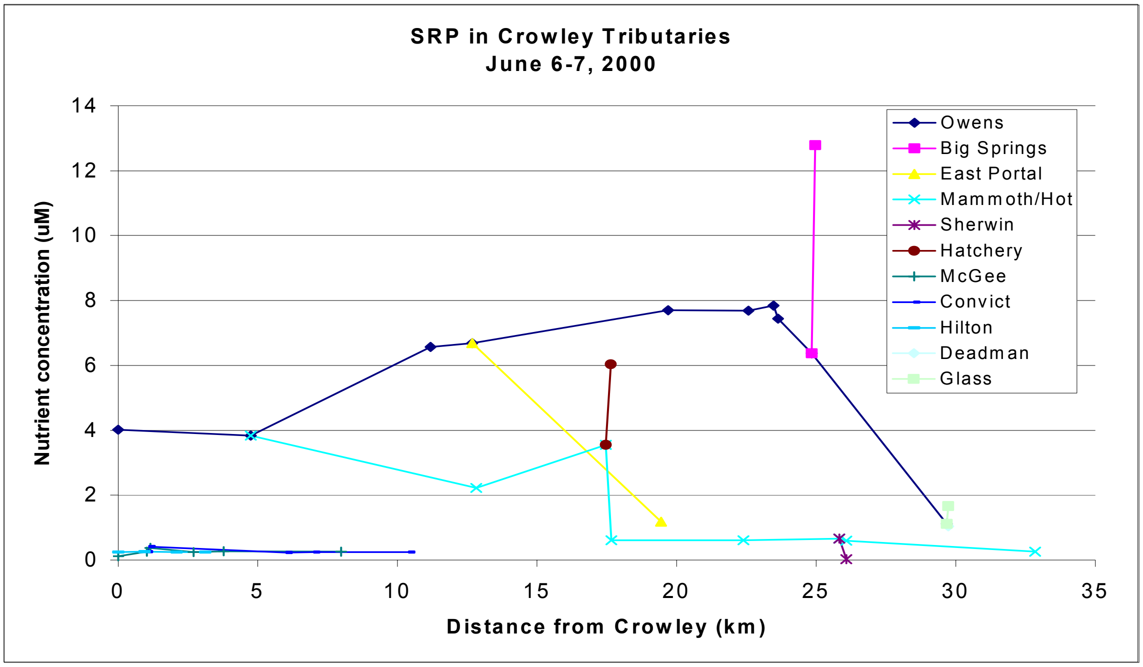
Fig. 4.1



Reading the graph from right-to-left is the equivalent to moving downstream along a tributary. For the Owens River concentrations are moderately low (<2 µM) at the confluence of Deadman and Glass Creeks. High concentrations (>11 µM) in Big Springs inflows increase the concentration in the Owens to ~6 µM. The next notable change is the input of relatively low concentration water from East Portal (>2 µM) which draws the concentration in the Owens down slightly. Phosphorus concentrations decrease slightly as we go downstream until the Owens mixes with lower concentration Mammoth Creek flows (4 µM) for a net concentration of approximately 5 µM.

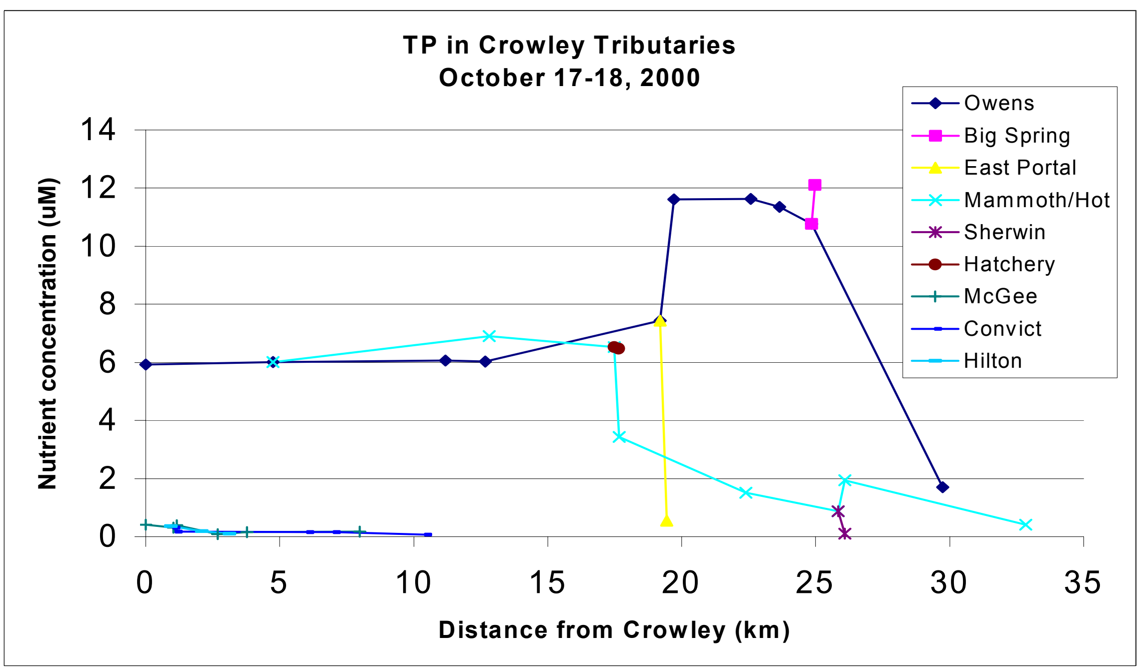
Moving downstream along Mammoth Creek shows low concentrations at the Twin Lakes outflow (< 1 µM) and little influence from the Town of Mammoth Lakes or Sherwin Creek. Phosphorus outflow from the Hot Creek Fish Hatchery is moderate (<6 µM) which brings Mammoth Creek concentrations up (<4 µM). None of the other tributaries show significant concentrations of phosphorus. Results for soluble reactive phosphorus (SRP) are very similar to those for TP indicating that almost all of the P is present as SRP (Fig. 4.2)

Fig. 4.2



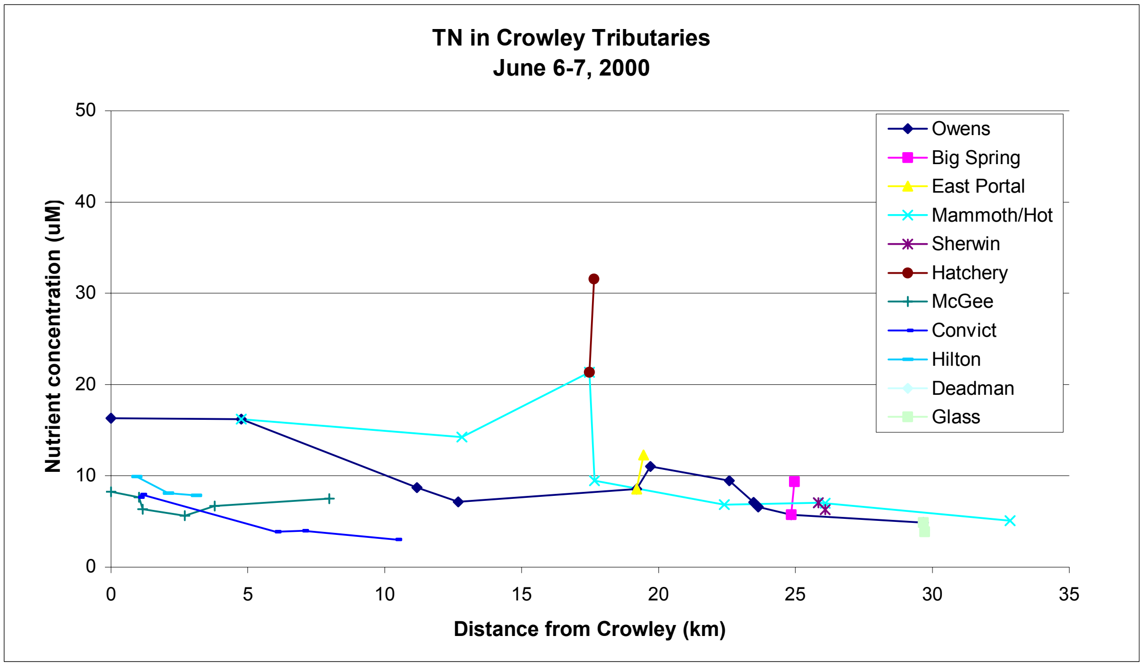
Results from the August and October surveys for phosphorus are very similar (Fig. 4.3)

Fig. 4.3



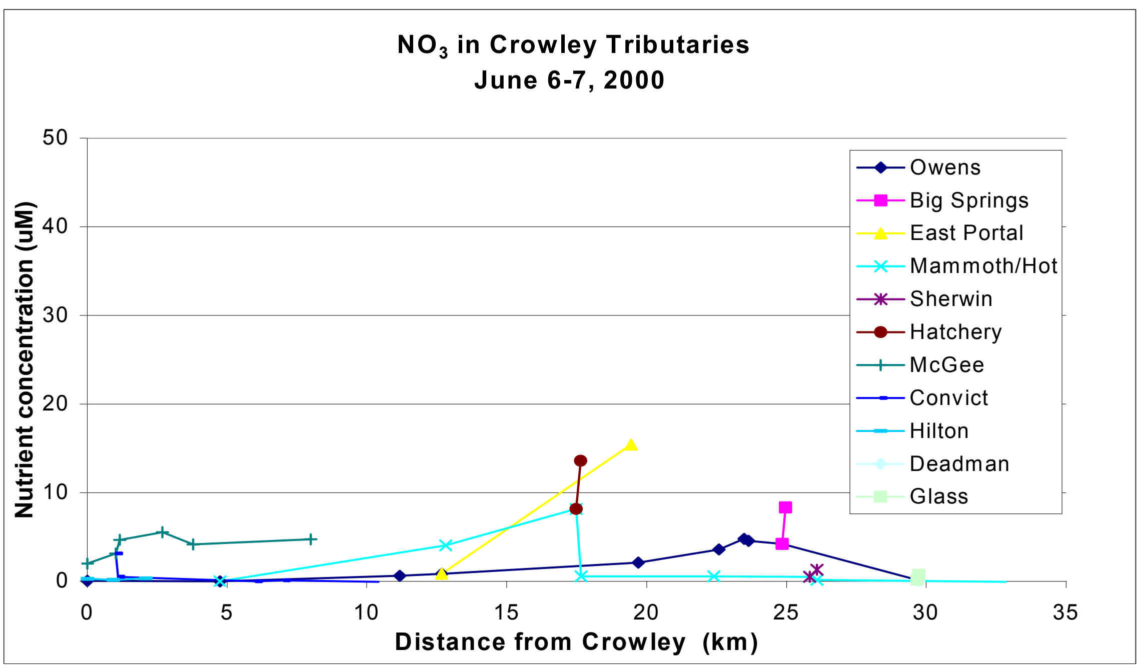
Total nitrogen inputs during the June 6-7, 2000 survey generally increased as one moves downstream (Fig. 4.4)

Fig. 4.4



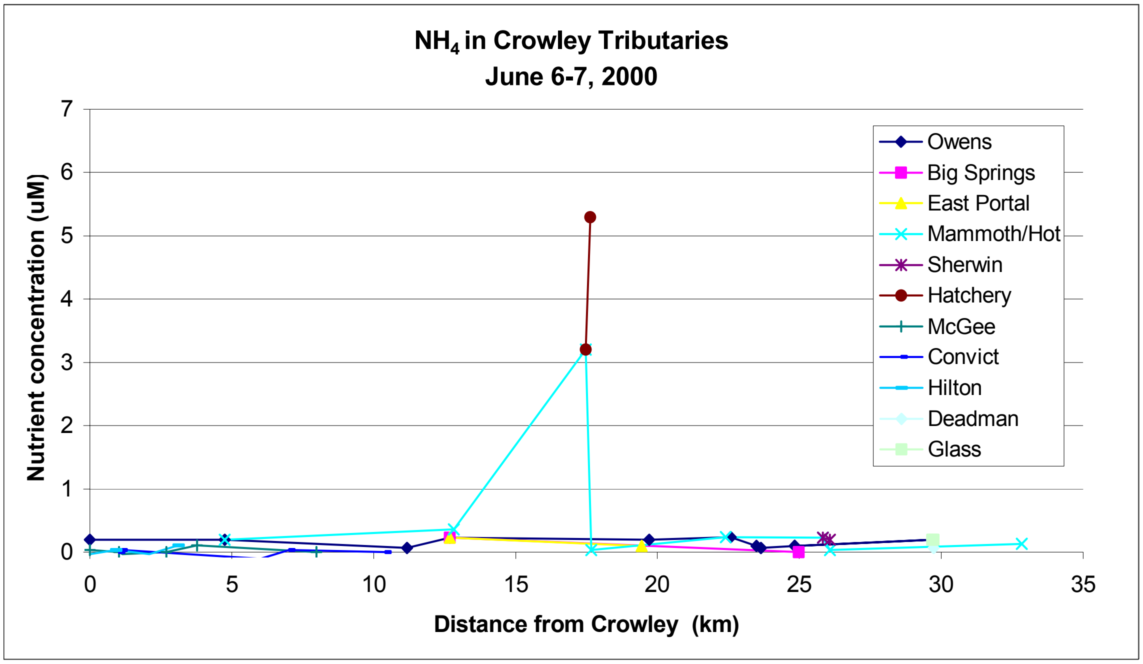
There are noticeable inputs at Big Springs, East Portal, and the Hot Creek Fish Hatchery. The inputs from Big Springs and East Portal are virtually all in the form of nitrate (Fig. 4.5).

Fig. 4.5



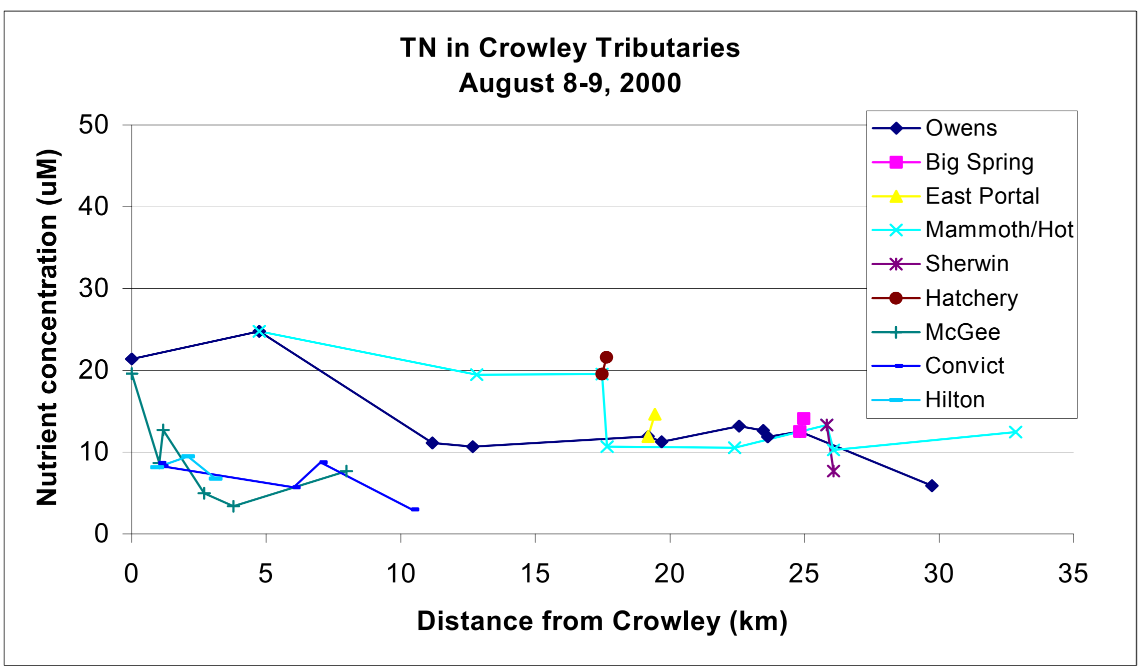
In contrast, the input from the Hot Creek Hatchery is a mixture of nitrate and ammonia, which is low everywhere in the watershed except the hatchery outflow (Fig. 4.6)

Fig. 4.6



By late-summer the profile for total nitrogen looks quite different (Fig. 4.7). While the spring sources and the hatchery are still significant inputs, there are gradual increases in TN on the lower reaches of all the tributaries suggesting, but not establishing, possible non-point influence from grazing.

Fig. 4.7



Analysis of the first year's longitudinal data suggested that additional sampling sites were needed to better understand the data. We needed to be able to distinguish between the Hot Creek Hatchery Springs and the Hot Creek Hatchery itself; and have some intermediate points between Howard Arcularius' ranch, the Hot Creek Gorge, and Benton Crossing. During the second year six sites were added (Table 4.2)

Table 4.2 New 2001 Longitudinal Sampling Stations

station code	tributary	station description
MA0	Mammoth	northernmost channel of Hot Creek just above confluence with Owens
MA2.5A	Mammoth	AB springs of Hot Creek Fish Hatchery
MA2.5B	Mammoth	CD springs of Hot Creek Fish Hatchery
OW1.5A	Owens	Owens river above confluence with northernmost channel of Hot Creek
OW1.5C	Owens	Owens river below confluence with northernmost channel of Hot Creek
CO4	Convict	inlet to Convict Lake

Results in 2001 are similar; however the addition of more sampling points makes the interpretation of some of the data simpler. 2001 results for total phosphorus and SRP show remarkable consistency (Figures 4.8 – 4.13) There are considerable P inputs from Big Springs and Alpers Spring (not sampled in 2000) which we assume are part of the same spring complex.

Fig. 4.8

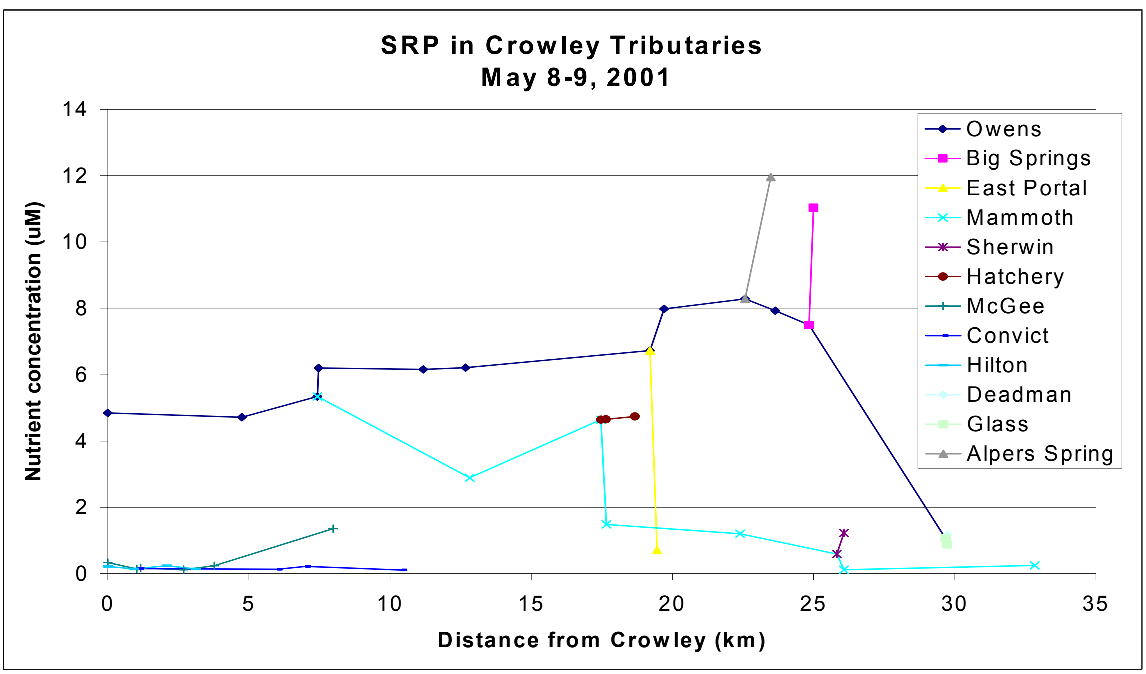


Fig. 4.9

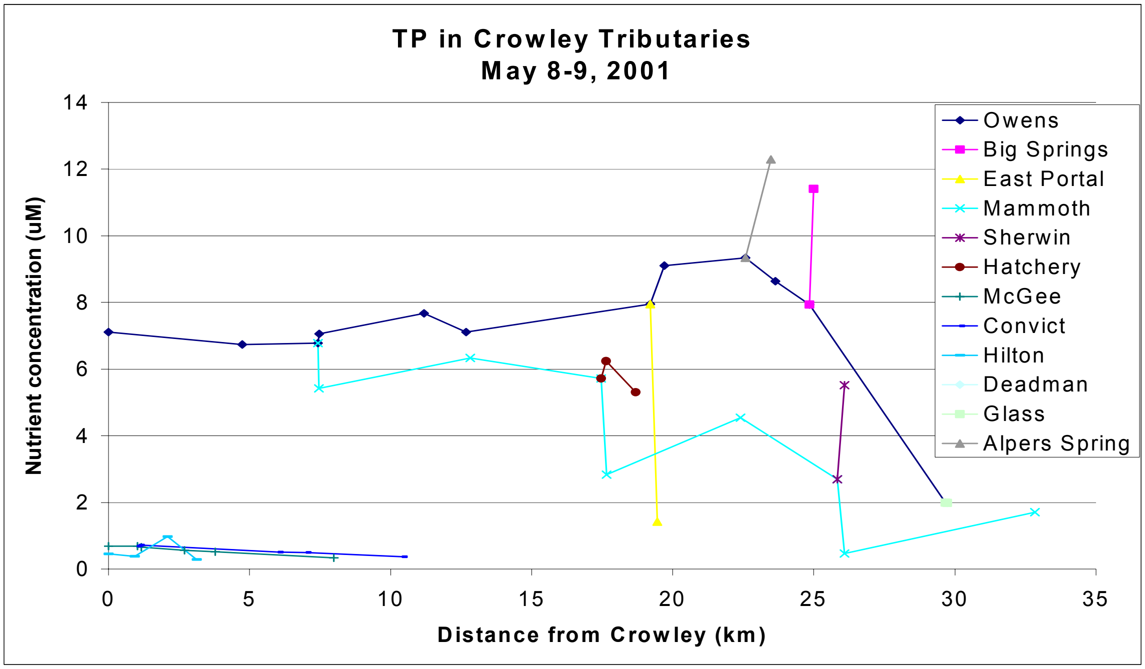
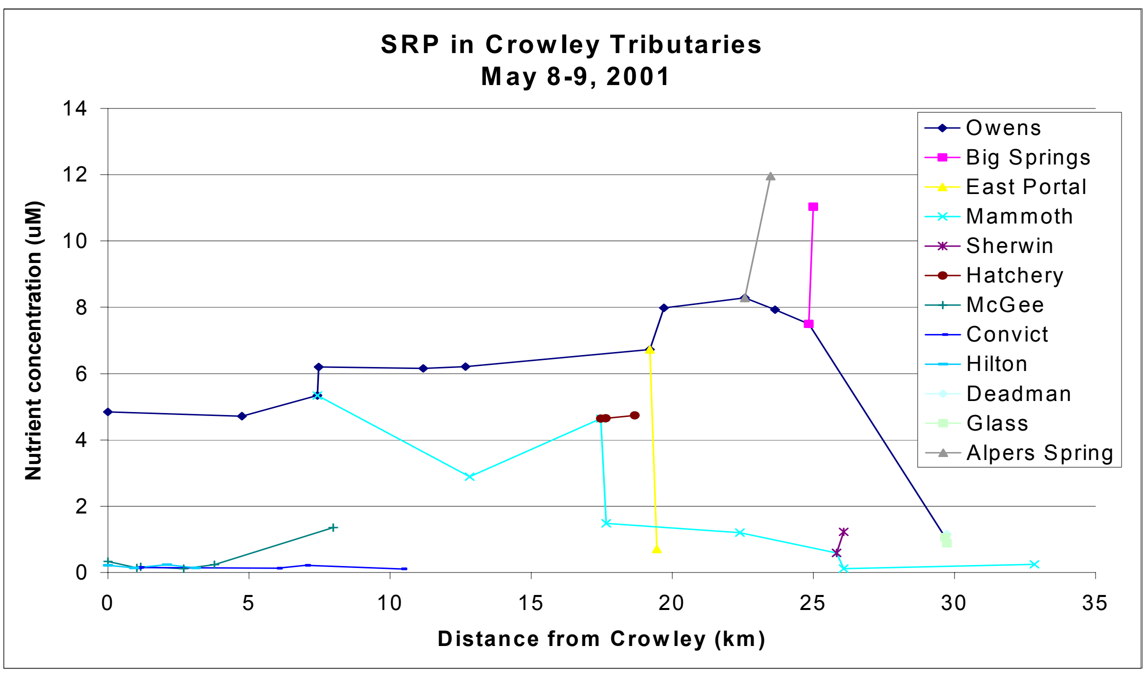


Fig. 4.10



Concentrations in the Hot Creek Fish Hatchery springs are also high (~5 µM) but increase to almost 7 µM through the Hatchery. The data show measurable increases in P in Mammoth Creek as it flows through the Town of Mammoth Lakes. TP concentrations show almost no change from East Portal and the Hatchery to the lake. As in 2000, concentrations in McGee, Convict, and Hilton Creeks are very low.

Fig. 4.11

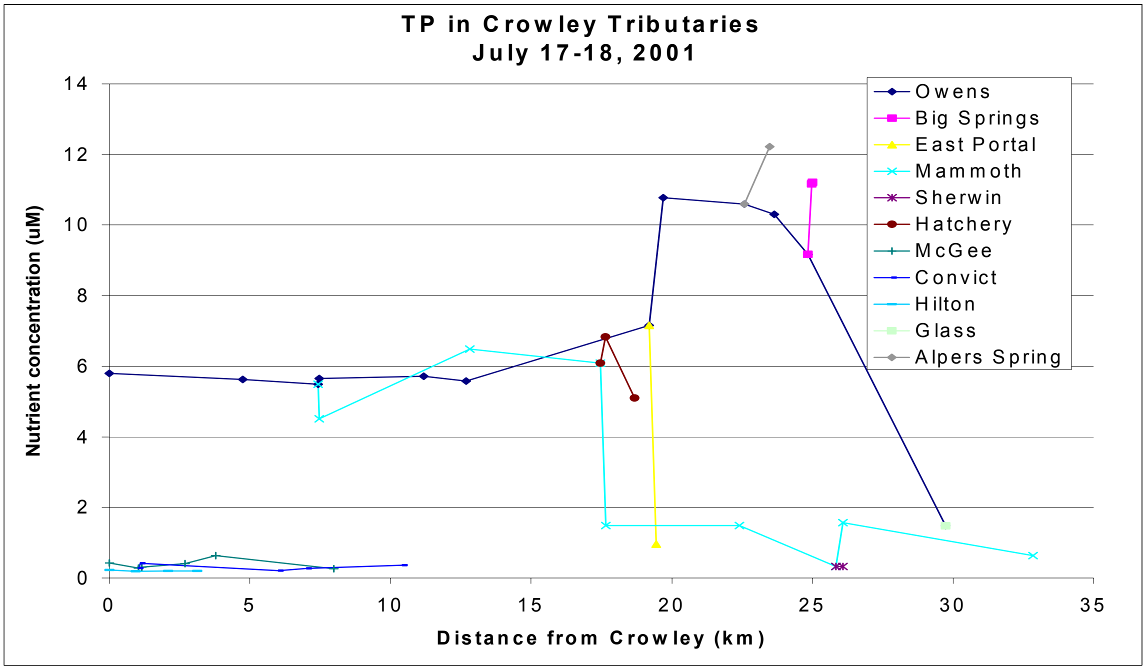
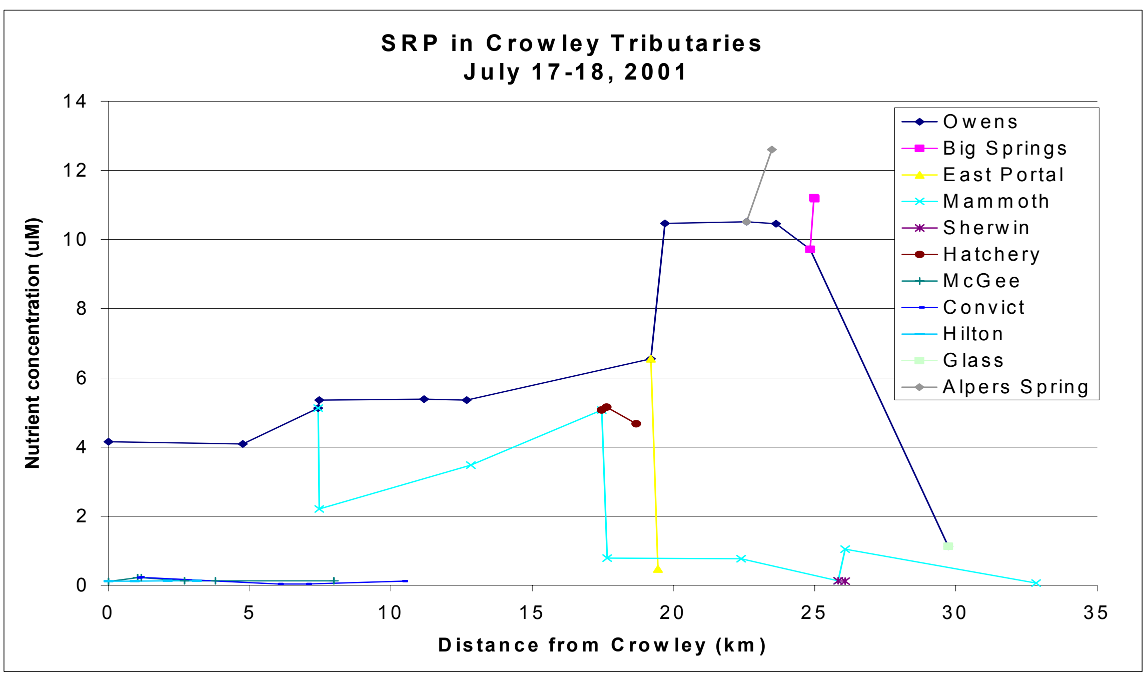
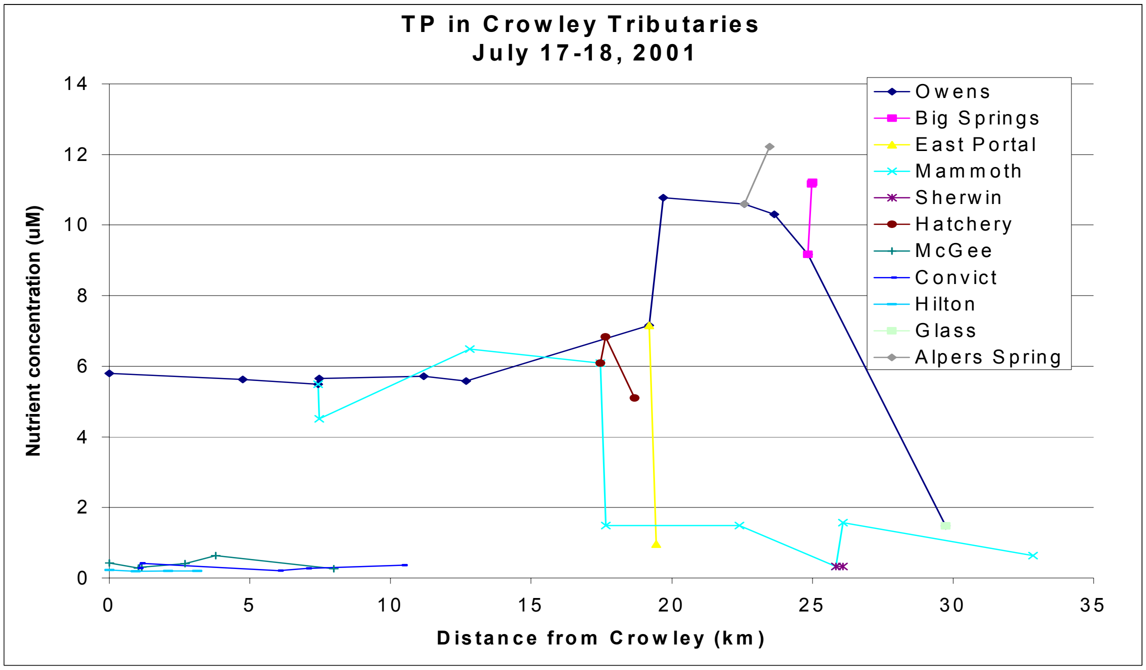


Fig. 4.12



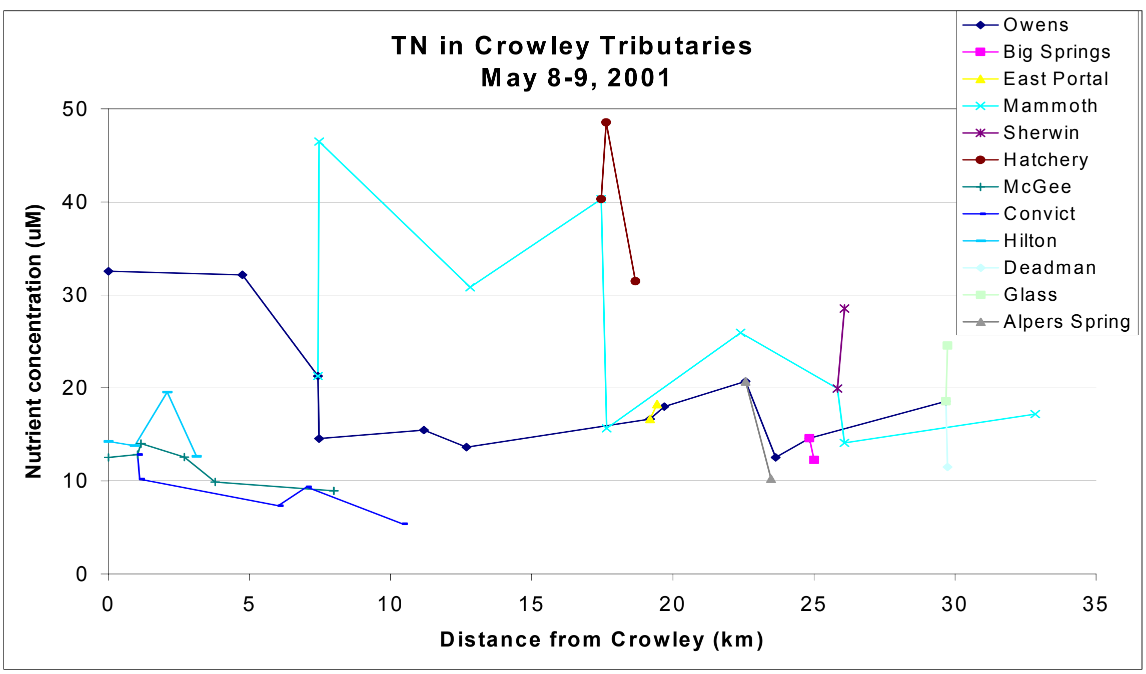
The May 2001 data show some differences (Fig. 4.8, 4.9). There is a high P input (<6 µM) from Sherwin Creek and there is less influence from the low P (~1 µM) input from East Portal, presumably due to low flows in the tunnel relative to the flow in the Owens River.

Fig. 4.13



The addition of the sampling points at the northernmost inflow of Hot Creek to the Owens River provides more detail on nitrogen inputs to the system (Fig. 4.14).

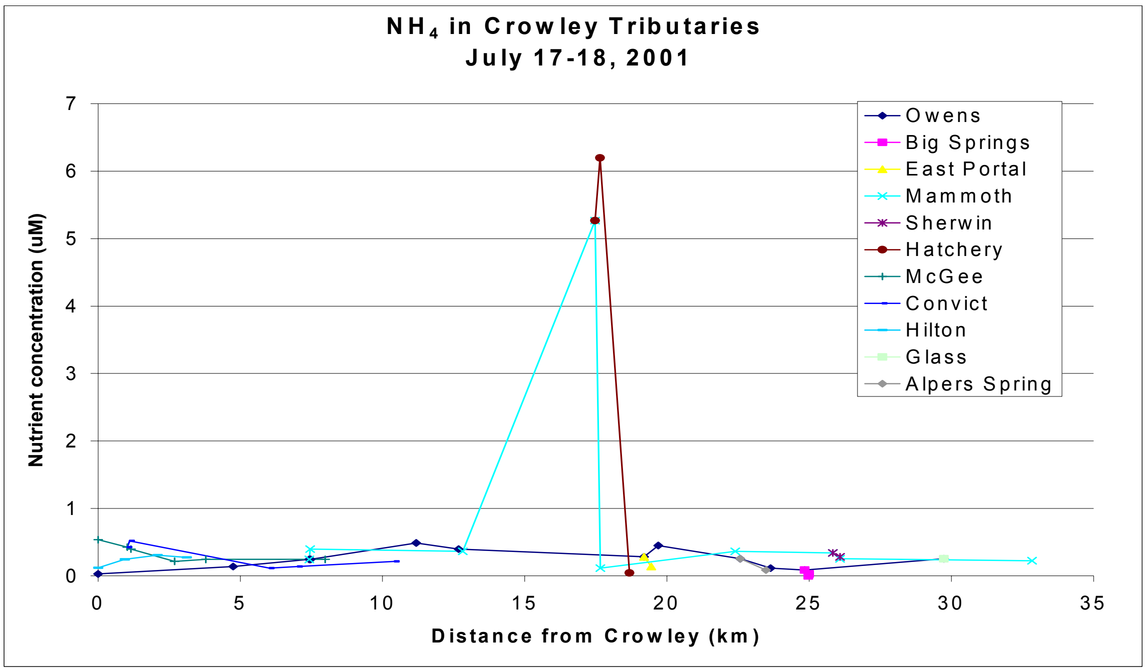
Fig. 4.14



While the hatchery springs are quite high in TN (>30 μM) there is considerable increase across the hatchery (<50 μM). This draws the concentration in Mammoth Creek up from ~15 μM to ~40 μM). From here we see a considerable decrease through the Hot Creek thermal area to ~30 μM at the USGS gauge. Without the additional sampling point, it would appear as if TN concentrations stay approximately constant until Benton Crossing. However, the additional point shows dramatic TN increases across the irrigated pastures of lower Hot Creek (>45 μM). July total nitrogen data shows this same pattern which goes away in October with the concentration almost constant (~20 uM) from below the hatchery to the confluence with the Owens.

Ammonia concentrations are low (<1 μM) everywhere except in the Hot Creek Fish Hatchery outflow (Fig. 4.15).

Fig. 4.15



The Fish Hatchery springs have almost no ammonia so this must be from hatchery operations. This increases the concentration in Mammoth Creek dramatically but virtually all of the ammonia is gone by the sampling location below Hot Creek gorge.

Spring sources are the dominant source of phosphorus in the watershed. Concentrations are reasonably constant through the summer and from year to year in the Big Springs complex (Table 4.3)

Table 4.3 P & N Concentrations (μM) in Spring Sources

Date	station code	station description	SRP	TP	NO_3	TN
06/07/2000	OW8A	Big Springs A (easternmost)	12.79	11.28	8.88	9.35
08/08/2000	OW8A	Big Springs A (easternmost)	11.38	11.26	9.45	14.09
10/17/2000	OW8A	Big Springs A (easternmost)	11.05	12.42	10.08	9.77
07/17/2001	OW8A	Big Springs A (easternmost)	11.20	11.16	12.32	11.71
10/23/2001	OW8A	Big Springs A (easternmost)	10.79	10.94	11.37	11.37

08/08/2000	OW8B	Big Springs B (westernmost)	11.41	11.20	9.66	12.67
10/17/2000	OW8B	Big Springs B (westernmost)	11.06	12.21	10.20	9.22
05/08/2001	OW8B	Big Springs B (westernmost)	11.04	11.41	11.28	12.25
07/17/2001	OW8B	Big Springs B (westernmost)	11.17	11.21	12.39	12.74
10/23/2001	OW8B	Big Springs B (westernmost)	10.66	10.65	11.38	11.20
08/08/2000	OW6B	Alpers Spring	10.51	10.36	7.63	12.62
05/08/2001	OW6B	Alpers Spring	11.96	12.29	10.91	10.24
07/17/2001	OW6B	Alpers Spring	12.60	12.23	12.38	11.78
10/23/2001	OW6B	Alpers Spring	12.02	12.43	11.43	11.52
05/09/2001	MA2.5A	AB Springs Hot Creek Fish Hatchery	4.41	4.96	28.45	30.10
07/17/2001	MA2.5A	AB Springs Hot Creek Fish Hatchery	4.42	5.01	23.35	23.81
10/24/2001	MA2.5A	AB Springs Hot Creek Fish Hatchery	4.28	4.66	22.88	24.08
05/09/2001	MA2.5C	CD Springs Hot Creek Fish Hatchery	5.06	5.65	26.70	32.87
07/17/2001	MA2.5C	CD Springs Hot Creek Fish Hatchery	4.94	5.20	24.63	24.21
10/24/2001	MA2.5C	CD Springs Hot Creek Fish Hatchery	4.91	5.12	23.67	23.81

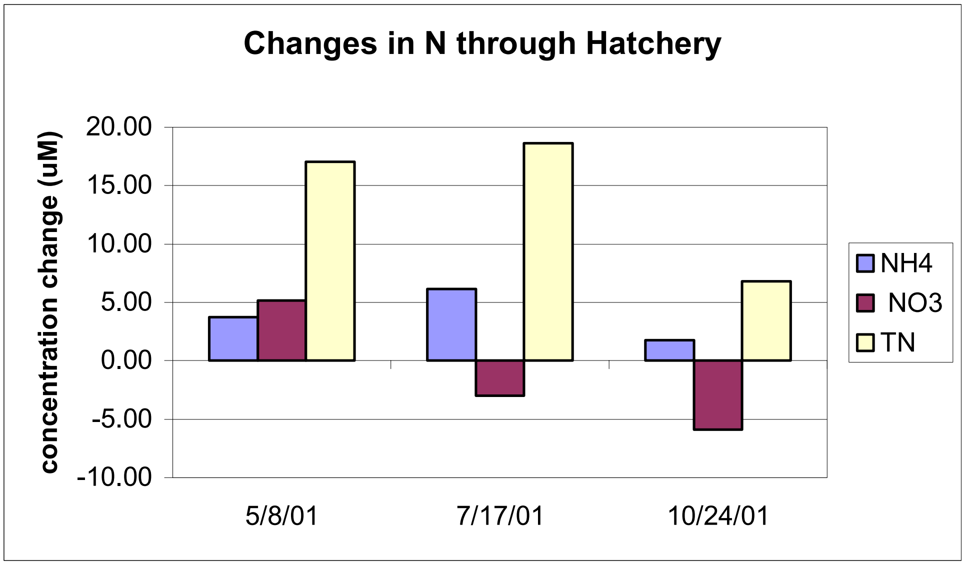
The spring sources are also major sources of nitrogen, mostly in the form of nitrate. Hatchery operations also contribute nitrogen (Table 4.4).

Table 4.4 N Concentrations (μM) at the Fish Hatchery

Date	station code	station description	NH4	NO3	TN
05/09/2001	MA2.5A	AB Springs	0.06	28.45	30.10
07/17/2001	MA2.5A	AB Springs	0.06	23.35	23.81
10/24/2001	MA2.5A	AB Springs	0.10	22.88	24.08
05/09/2001	MA2.5B	CD Springs	0.00	26.70	32.87
07/17/2001	MA2.5B	CD Springs	0.03	24.63	24.21
10/24/2001	MA2.5B	CD Springs	0.13	23.67	23.81
05/08/2001	MA2B	below hatchery	3.76	32.73	48.55
07/17/2001	MA2B	below hatchery	6.20	21.01	42.62
10/24/2001	MA2B	below hatchery	1.88	17.38	30.78

Looking at the change in concentration below the hatchery versus the average of the hatchery springs (Fig. 4.16) shows increases across the hatchery presumably due to operations.

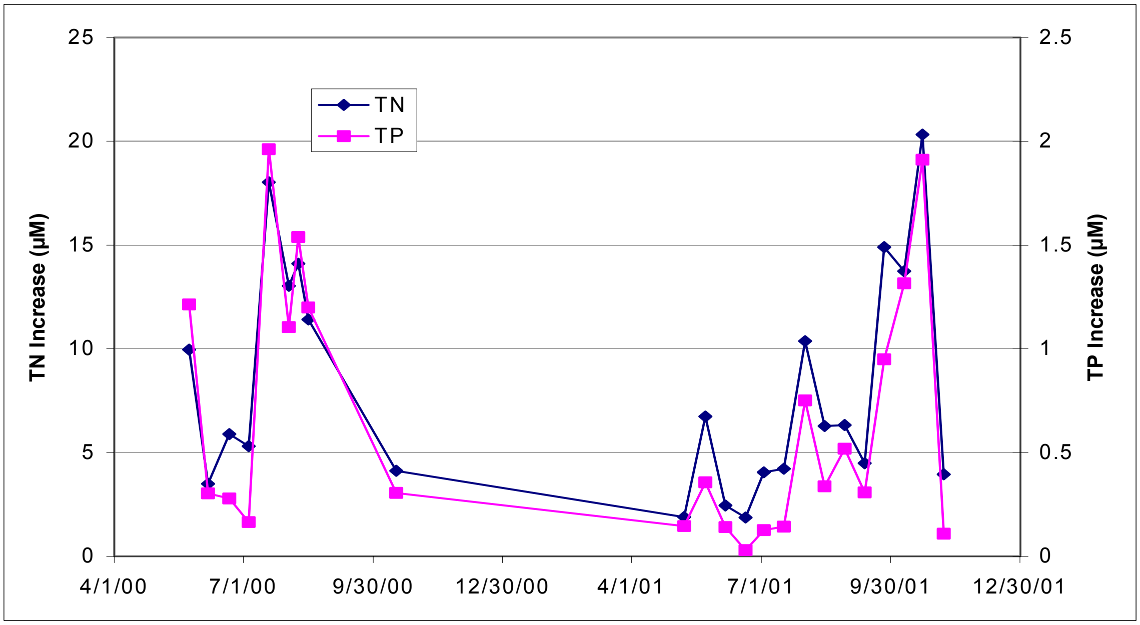
Fig. 4.16



As noted above, the dominant sources of nutrient loading to Crowley Lake are natural. However, nutrient concentrations also appeared to increase across irrigated pastures. In addition to the longitudinal surveys, paired samples were collected above irrigated pastures on McGee Creek (MG3) and Convict Creeks (CO2) and below where McGee Creek enters the lake (MG0) on 17 additional dates. Samples were also collected on the Owens River above (OW1; Benton Crossing) and below (OW0; at the lake). This is the reach that was corridor fenced as part of this project. Areas outside of the corridor fencing are non-irrigated pastures.

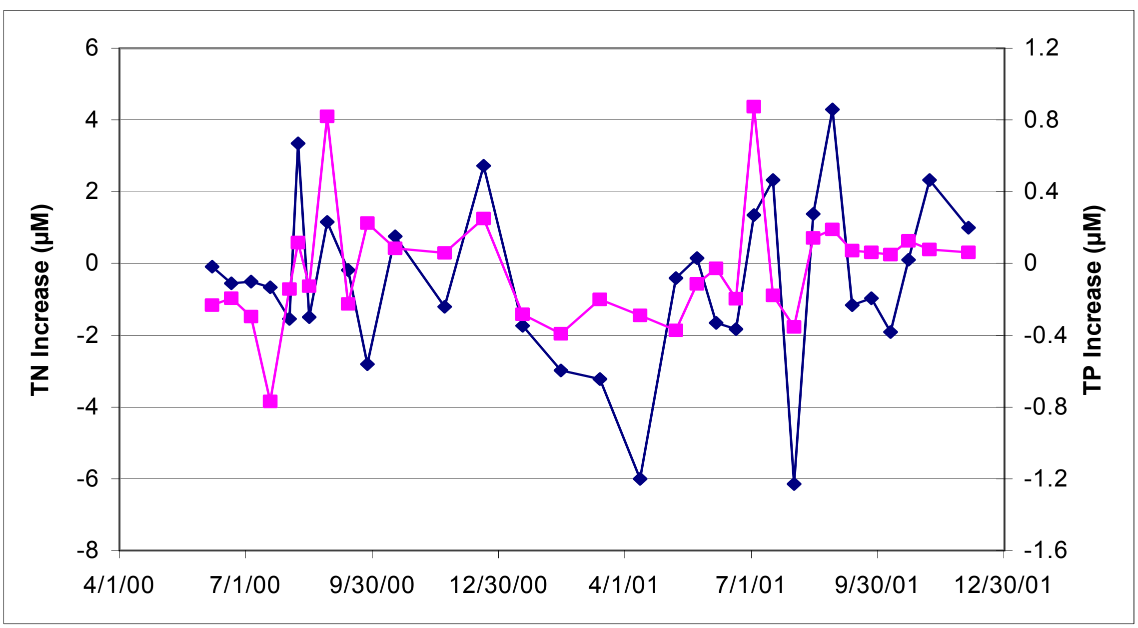
To assess nutrient changes increases across the irrigated pastures on McGee and Convict Creeks, the volume-weighted mean concentration was calculated based on MG3 and CO2 concentrations and stream flows on Convict (LADWP Station 4014) and Lower McGee (LADWP Station 4013). This could then be compared to concentrations in samples collected where McGee enters the lake. TN and TP both show significant increases along the stream reaches flowing through irrigated pastures (Fig. 4.17). The increases observed for TN and TP track each other very closely and show a strong seasonal pattern with peaks in August-September. The peak increases in TN and TP were ~20 and 1.9 µM, respectively. The mean increase in TN and TP for all 23 dates (6 longitudinal and 17 paired samplings) was 8.1 and 0.6 µM, respectively.

Fig. 4.17 TP & TN Changes across Irrigated Pasture



TN and TP concentrations showed no consistent increase across the non-irrigated stretch of grazed pastures along the Owens River between Benton Crossing and the lake (Fig. 4.18). On individual dates, the change in TN concentration along this reach ranged from +4 to -6 µM, while TP changes ranged from +0.8 to -0.8 µM. However, flow weighted concentrations (loading) show small increases through this reach.

Fig. 4.18 TP & TN Changes across Dry Pasture



On the six longitudinal samplings, the N and P changes across the McGee pastures can be subdivided to those occurring above and below the confluence of McGee and Convict Creeks. During the longitudinal surveys, samples were taken on Convict just below SNARL and just above the confluence with McGee, on McGee at highway US395 and just above the confluence with Convict, and on the lowest reach of McGee at the confluence and where it enters the lake.

Modest increases in both N and P occurred on all three reaches; Convict (Fig. 4.19) and McGee (Fig. 4.20) above their confluence, and on McGee below the confluence (Fig. 4.21).

Fig. 4.19 P & N Changes on Convict Creek

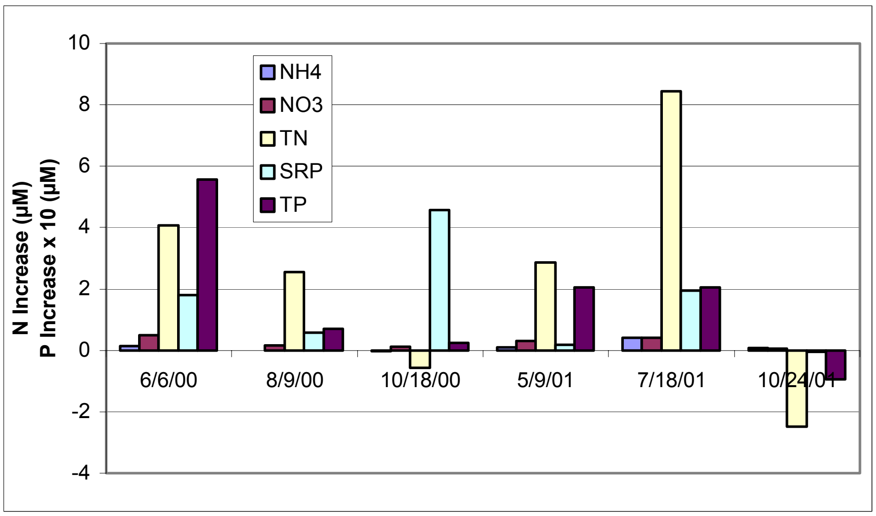


Fig. 4.20 P & N Changes on McGee Creek above Confluence

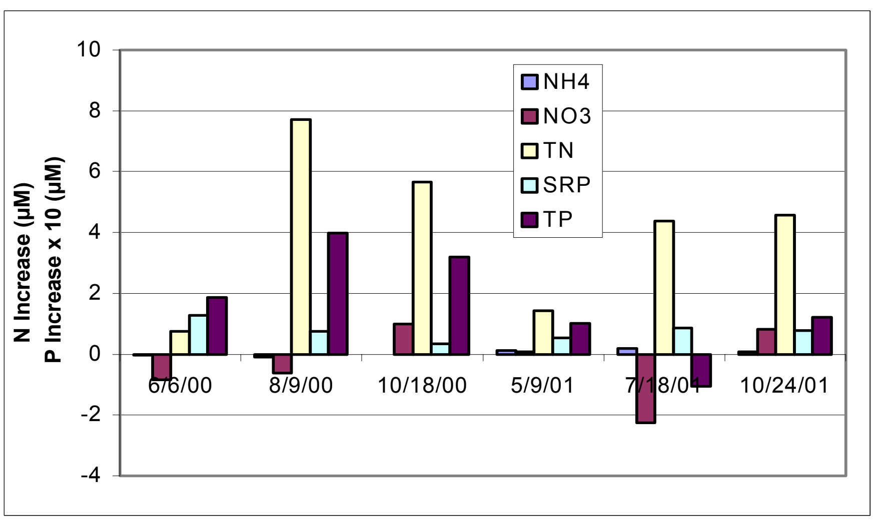
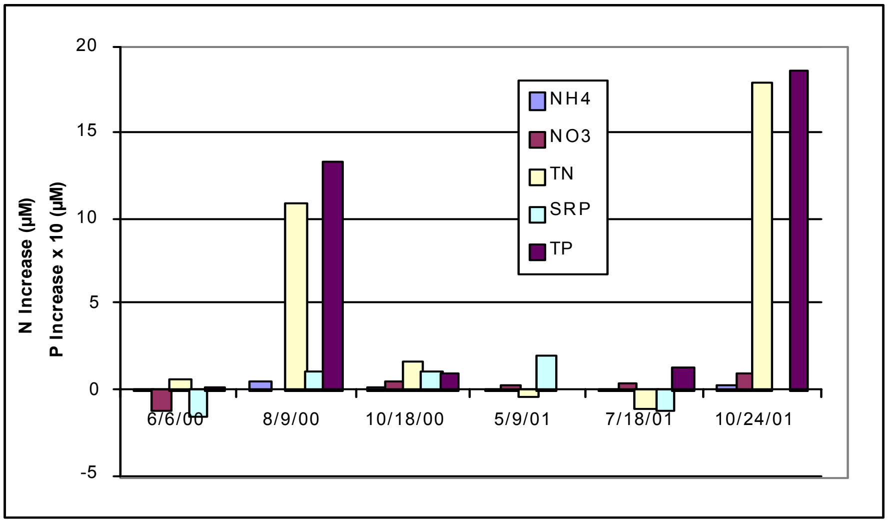


Fig. 4.21 P & N Changes on McGee Creek below Confluence



On two dates, the increase in TN on the lowest reach of McGee exceeded 11 µM. On both autumn dates there was a decrease in TN concentration on Convict, but increases on McGee both above and below the confluence with Convict. On several dates, NO_3 and SRP decreased slightly across individual reaches. Without knowledge of the irrigation practices, seeps, return flows, and actual grazing no further interpretation of these changes can be made.

Discussion:

Natural springs, originating from the Big Springs complex (which includes Alpers spring) and the Hot Creek Hatchery spring complex, are the dominant sources of nutrients in the watershed. With their high flow volume and relatively high concentrations of P and N, these natural sources dominate nutrient loading to Crowley Lake. Both SRP and TP concentrations are low in all tributaries except the Owens River and Mammoth/Hot Creek. Similarly, NH_4, NO_3, and TN concentrations are relatively low in all other tributaries except that modest (0-20 µM) increases in TN are observed across irrigated pastures on McGee and Convict Creeks.

While the Hot Creek Hatchery springs are high in both NO_3 and TN, hatchery operations apparently contribute significant amounts of NH_4 and TN. The only significant (>6 µM) concentration of NH_4 in the watershed occurs immediately downstream of the hatchery.

The communities of Mammoth Lakes, McGee Creek, and Hilton Creek show surprising little effect on instream nutrient concentrations. On several sampling dates, points above and below the influence of the Town of Mammoth Lakes show TP and SRP increases of ~1 µM. The May 2001 longitudinal sampling show small increases of TN (~7 µM) and TP (~1 µM) as Hilton Creek flows through the community of the same name. These increases and associated nutrient loads are quite small in comparison to the other nutrient sources.

Nutrient concentrations were generally lower in Convict Creek than in McGee Creek. This is probably due to sequestering of nutrients in Convict Lake. The two watersheds lie side by side, are approximately the same size, and include older metamorphic rocks in addition to granite. However, the McGee Creek drainage has no large moderate elevation lake as does the Convict drainage.

There is a small but consistent increase of TN and TP in McGee and Convict Creeks as they flow through irrigated pasturelands. The mean increase in TN and TP for all 23 dates (6 longitudinal and 17 paired samplings) was 8.1 and 0.6 µM, respectively. As the peaks in these increases correspond closely with the irrigation and grazing season, and increases are seen in Convict Creek and McGee Creek above and below its confluence with Convict, it seems likely that the increase is due to grazing operations rather than to spring or seep input. While irrigation return flows were observed on occasion entering McGee Creek, no measurements of nutrient concentration in return flows were taken. Furthermore, similar increases were not observed on the Owens River in a reach where it was corridor fenced and running through dry pasture. TN and TP increases track each other very closely over time in an approximate ration of 10:1, suggesting the increases across the irrigated pastures may be due to increased soil erosion. There was no corresponding increase in NO_3 or SRP across irrigated pastures. While the observed increase in N loading across the McGee pastures is significant, it only accounts for 6.1% of total measured N loading. Measured N loading is only 30% of measured export of N from the lake. A fraction of total N inputs to the lake are from nitrogen fixation with the remainder probably coming from sediment release (see Final Report for contract SWRCB # 00-196-160-0).

CHAPTER 5: LIMNOLOGY OF CROWLEY LAKE

Introduction

The most common impairment of surface waters in the United States is eutrophication caused by excessive inputs of phosphorus (P) and nitrogen (N) (Carpenter et al. 1988). Impaired waters are defined as those that are not suitable for designated uses such as drinking, irrigation, industry, recreation, or fishing. Crowley Lake (Long Valley Reservoir) is a valuable aquatic resource identified by the CA Water Resources Control Board as impaired by nutrients. The lake is eutrophic and is characterized by an ample supply of nutrients and significant summer algal blooms (Melack and Lesack, 1982; EPA, 1978). Adverse impacts of increased eutrophication at Crowley Lake have included de-oxygenation of the hypolimnion and downstream fish kills (Milliron, 1997), and decreased water quality as indicated by taste, odor, and large areas of floating algal mats.

In preparation for designing and implementing TMDL's for Crowley Lake and its tributaries, limnological sampling was conducted to assess the lake's trophic status, phytoplankton and zooplankton communities, and overall nutrient content. Lakewide surveys were conducted after ice-off, midsummer, and autumn during both years (2000 and 2001) and in April 2003. Here, we describe limnological conditions over this two-year period, April 2000 – April 2002.

MTBE (methyl tertiary butyl ether) contamination of lakes and groundwater aquifers is a serious environmental concern (Keller et al. 1998) and the state legislature has mandated the elimination of MTBE as a gasoline additive (Title 13 California Code of Regulations, 2003). As relatively few measurements were available for lakes, the Lahontan RWQCB requested we determine MTBE concentrations in Crowley Lake. These results are also presented here.

Methods

Field Sampling

Limnological surveys were conducted following ice-off (April/May), in late summer (mid-August) during the period of maximum thermal stratification and during autumn (November) following the breakdown of thermal stratification or "turnover". These times were chosen the facilitate assessing seasonal changes in the overall nutrient budget. A final survey was conducted in April 2002 to provide conditions over two complete run-off years. Additional summer samples were collected at a single deep station (S) on four dates in 2000 and biweekly through the stratified period in 2001 to better assess seasonal changes.

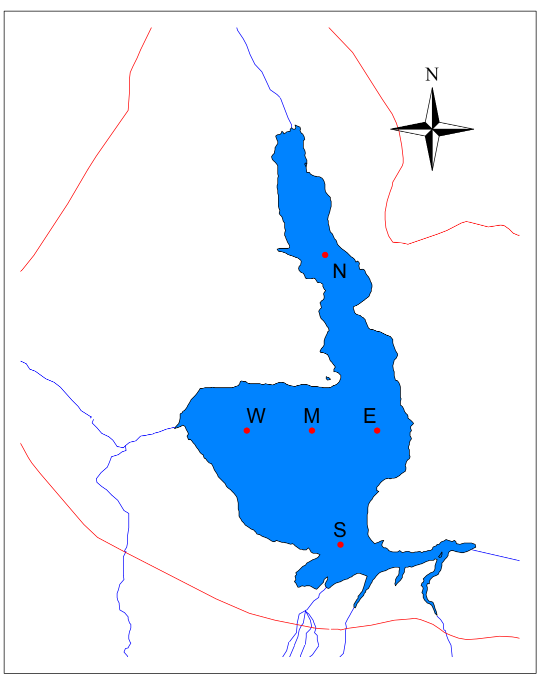
Vertical profiles were taken in each major sector of the lake (Fig. 5.1). The main sectors consist of the north arm (30-ft depth), the western basin (25-ft depth), the central portion (50-ft depth), the eastern portion (60-ft depth) and the southern deep arm (75-ft depth). A 5-m integrated water sample was collected from the upper water column with a 1 inch diameter tygon tube. Additional water samples were collected at 5-m intervals from 5 m depth to the bottom at each station.

The physical/chemical environment was characterized by dissolved oxygen (DO), temperature, transparency, photosynthetically available radiation (PAR) and a suite of nutrient concentration determinations. Dissolved oxygen concentration was measured at 1-m intervals at each sampling location with a Yellow Springs Instruments temperature-oxygen meter (YSI, model 58) and probe (YSI, model 5739). The oxygen meter was calibrated in water-saturated air prior to each use. Transparency was measured with a 20-cm white Secchi disk and PAR was measured with a hand-lowered cosine-corrected PAR sensor (LI-COR, model LI-192S). The LI-COR sensor is calibrated annually by LI-COR.

The suite of nutrient determinations included ammonia (NH_4), nitrate (NO_3), total dissolved nitrogen (TDN), particulate nitrogen (PN), total nitrogen (TN), soluble reactive phosphorus (SRP), total dissolved phosphorus (TDP), particulate phosphorus (PP), total phosphorous (TP) and particulate carbon (PC). All sample bottles were rinsed with 10% HCl before DIW soaking and rinsing. Filtered samples were filtered in the field with plastic syringes fitted with Gelman A/E filters (1 micron) which were rinsed with at least 150 ml of DIW or sample water. Samples were kept cool and in the dark during transport. For medium-term storage, samples were frozen.

Analytical methods for NH_4, NO_3, TN, SRP, and TP were identical to those used for analyzing stream nutrient concentrations. Table 5.1 indicates the method and detection limit for each method employed. Detection limits are reported as two times the standard deviation of replicate analyses. Detection limits for total and total dissolved fractions were more variable because of the digestion step. TDN and TDP concentrations were derived by using TN and TP methods on samples filtered through a Whatman GF/F glass fiber filter. Particulate nitrogen and carbon were determined with an automated organic elemental analyzer (Model CEC440HA), Dumas combustion method. Particulate phosphorous was determined by Valderrama (oxidation/phospho-molybdate).

Fig. 5.1 Crowley Lake sampling stations



The phytoplankton and zooplankton communities were characterized through species identification and enumeration. For phytoplankton analysis, 10 ml of well mixed 5-meter integrated sample was allowed to settle for 24 h in a 10 ml Hydro-Bios Utermohl chamber. A few drops of Lugol's Solution were added to aid in settling. The samples were analyzed on a Carl Zeiss inverted microscope at 160X magnification. To ensure capture of rare species, the entire sample was counted and each organism identified to genus. For a more accurate estimate of the larger species, 30 ml was analyzed under a Wild Heerbrugg dissecting scope at 12X magnification. Biovolume was calculated using the methods of Hillebrand et al. (1999). Identification keys included Prescott, 1978; Dillard, 1999; and Canter-Lund and Lund (1995).

Chlorophyll *a* concentrations were also used to characterize the phytoplankton. Chlorophyll *a* was extracted in 90% ethanol using the method of Sartory and Grobbelaar (1984). Following clarification by centrifugation, absorption was measured at 750 and 665 nm on a spectrophotometer (Milton Roy, model Spectronics 301), calibrated once a year by Milton Roy Company. The sample was then acidified in the cuvette, and absorption was again determined at the same wavelengths to correct for phaeopigments. Absorptions were converted to phaeophytin-corrected chlorophyll *a* concentrations with the formulae of Golterman (1969). During periods of low phytoplankton concentrations (<5 μg chl *a* l^{-1}), the fluorescence of extracted pigments was measured on a fluorometer (Sequoia-Turner, model 450) which was calibrated against the spectrophotometer using fresh lettuce.

Chemical

For the purposes of this project, DIW is used to refer to filtered, de-ionized, reverse osmosis treated water. This is our primary washing and rinse water with a specific conductance of approximately 5 μS cm^{-1}. For reagent and standard preparation this water is further polished by ion exchange to a specific conductance of approximately 0.5 μS cm^{-1}.

All apparatus and bottles used in surface water sampling were soaked in de-ionized water (DIW) and then rinsed 3 times with DIW. Sample collection bottles were rinsed with 10% HCl before DIW soaking and rinsing.

Laboratory Methods

Immediately following sample collection, samples were transported cold and in the dark to the Sierra Nevada Aquatic Research Laboratory (SNARL) for processing and analysis. pH measurements were done on unfiltered subsamples immediately upon return to the laboratory using a Fisher Acumet digital pH meter and Ross (Orion) combination electrode. The meter was calibrated in a two-point calibration with NRS-traceable buffers near room temperature. After calibration the accuracy of the calibration was checked using dilute solutions of HCl (10^{-4} and 10^{-5} N). The electrode was then rinsed with stirred DIW for several minutes before the pH of the quiescent sample was measured. Specific conductance of unfiltered subsamples was measured on a YSI Model 32 digital conductance meter (cell constant=1.0) corrected to 25°C. A 10^{-4} M KCl conductivity standard, which has a theoretical specific conductance of 14.7 μS cm^{-1} at 25°C was measured at the beginning of each laboratory session.

NH_4 and SRP were analyzed on each field sample on the same day as collection. Remaining filtered field samples were frozen and analyzed for NO_3, TDN, and TDP within two months of collection. Unfiltered samples for TN and TP were frozen upon return to the laboratory and kept frozen until analysis within two months of collection. NO_3, TN, TP, TDN, and TDP were analyzed at the SNARL.

Table 5.1 Chemistry Methods and Detection limits

Species	Method	Reference:	Detection Limit (µM)
NH_3 + NH_4^+	phenol-hypochlorite colorimetric	Strickland and Parsons, 1972 Wetzel and Likens, 1991	0.30
SRP	phospho-molybdate colorimetric	Strickland and Parsons, 1972 Wetzel and Likens, 1991	0.06
NO_3	Cd reduction followed by azo dye colorimetric	Strickland and Parsons, 1972 Wetzel and Likens, 1991	0.20
TP	Valderrama (oxidation/phospho-molybdate)	Valderrama, 1981	0.4
TN	Valderrama (oxidation/Cd reduction/azo dye)	Valderrama, 1981	0.4
TDN	Valderrama (oxidation/Cd reduction/azo dye)	Valderrama, 1981	0.4
TDP	Valderrama (oxidation/phospho-molybdate)	Valderrama, 1981	0.4
As	As(V)$\rightarrow$As(III) reduction/phospho-molybdate	Johnson, 1971	0.02
MTBE	EPA Method 8260A	EPA Manual SW846	1 ppb

Results & Discussion

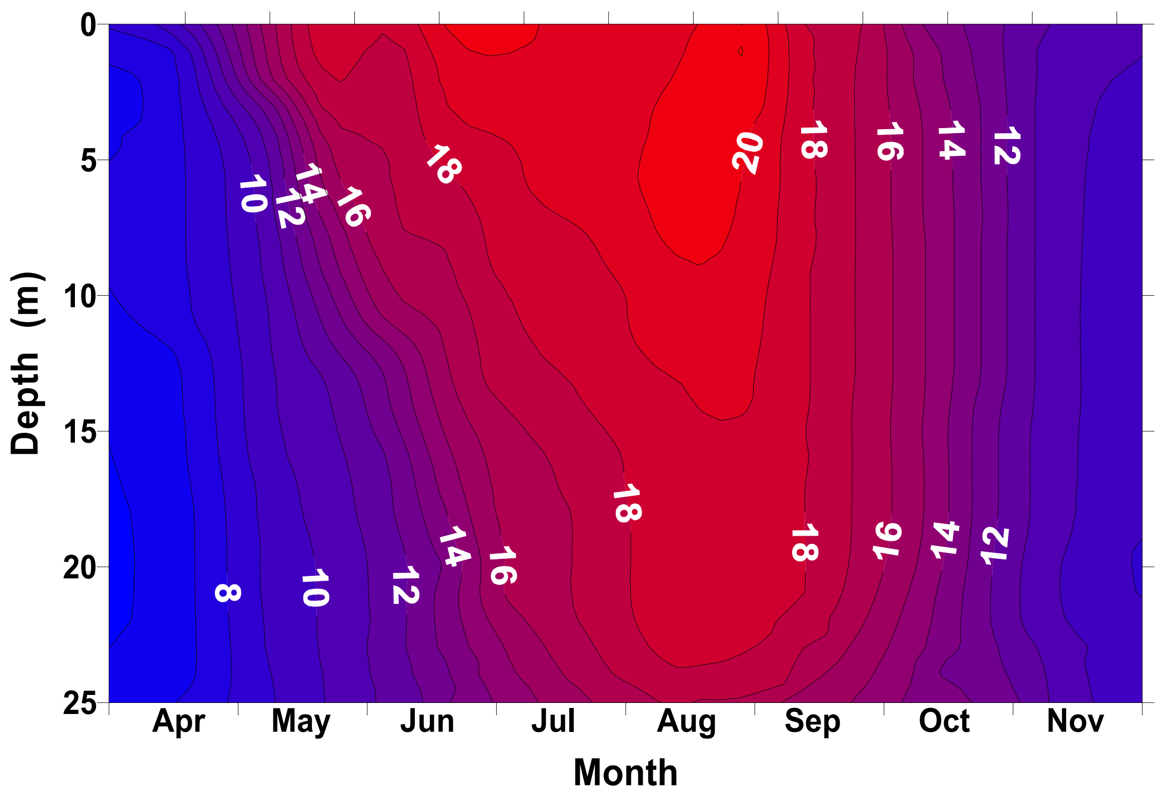
Seasonal Thermal stratification

Crowley Lake undergoes a regular seasonal pattern of thermal stratification. Ice cover disappears in April and is followed by spring turnover in which the entire water column is well-mixed and near 4°C. However, warmer air temperatures and increasing insolation result in heating and the rapid onset of seasonal thermal stratification in early May. The epilimnion (upper mixed layer) warms rapidly during May through July, while the hypolimnion warms somewhat more slowly. With cooler air temperatures and decreased insolation, the epilimnion begins to cool in late August. Continued cooling results in an autumn period of mixing prior to the lake becoming ice-covered in late December.

The approved sampling design specified lakewide surveys were to be conducted following ice-off, in late midsummer, and following autumn turnover during both 2000 and 2001. These surveys were conducted on 31 May, 14 August, and 8 November in 2000 and on 18 April, 15 August, and 7 November in 2001. Additional profiles were taken at selected stations while collecting water samples from McGee Creek where it enters the lake and an additional final survey was conducted on 3 April 2002 to allow an assessment of changes in the nutrient budget across two complete runoff years.

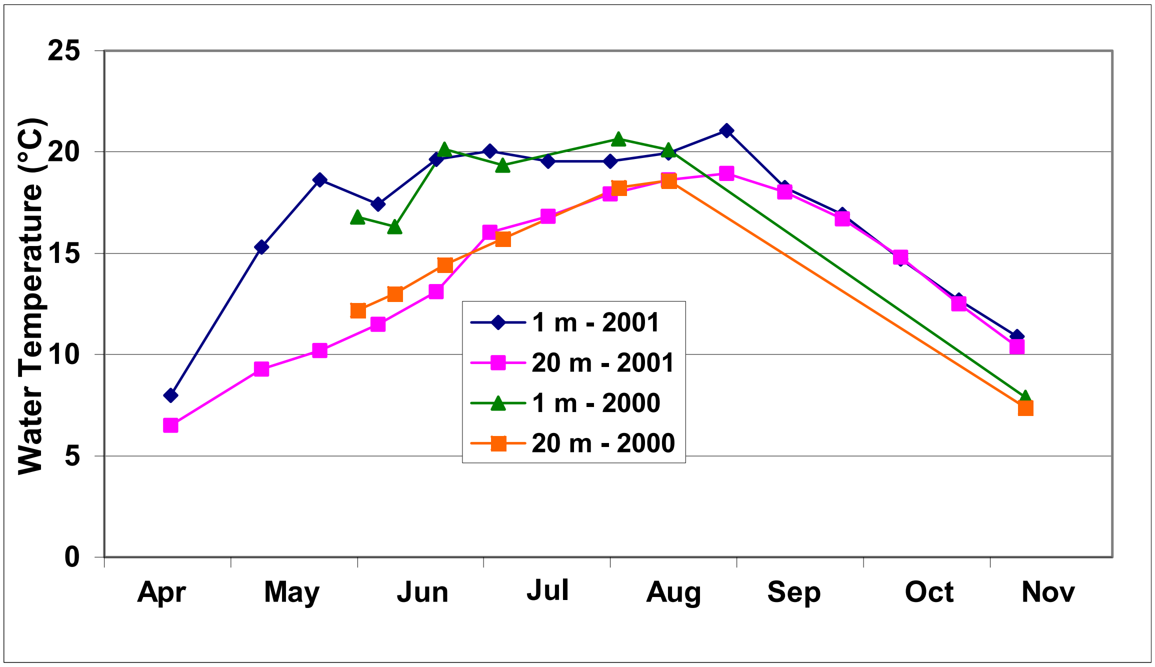
In 2001, fifteen approximately biweekly temperature profiles were taken beginning on 18 April and continuing through 7 November at Station S, a central deep station (Fig. 5.2). Ice-off occurred in late March and by 18 April the water column was slightly stratified; 8°C and 6.5°C at 1 and 20 m, respectively. The epilimnion (upper mixed layer) warmed rapidly during May and June resulting in temperature differences between 1 and 20 m of 6 to 8.5°. By 20 June, the epilimnion was near 20°C and the hypolimnion (at 20 m) had warmed to 13°C. Temperatures at 1 m remained between 19.5 and 21.0°C through 29 August. During this period, the thermocline was mixed downward and bottom temperatures (20 m) increased to almost 19°C. The epilimnion began to cool in early September and by 12 September the near surface temperature (18.2°C) was only slightly higher than the bottom temperature (18.0°C at 20 m). On 10 October, the water column was isothermal at ~15°C and cooled further to ~11° by 7 November 2001.

Fig. 5.2 Seasonal Thermal Stratification in Crowley Lake during 2001



Although we collected fewer temperature profiles in 2000, a comparison of 1 and 20 m temperatures show the seasonal regime of thermal stratification was very similar between the two years (Fig. 5.3). In May 2001, the water column was more thermally stratified than in May 2000. In 2001, the 1-m water temperature was 1-2° warmer and the 20-m temperature 1-2° colder than in May 2000. However, from June through August the two years are virtually identical. In 2000, no profiles were taken between August and November, therefore no comparison is possible during this period. However, by November the lake was almost 3°C warmer in 2001 compared to 2000.

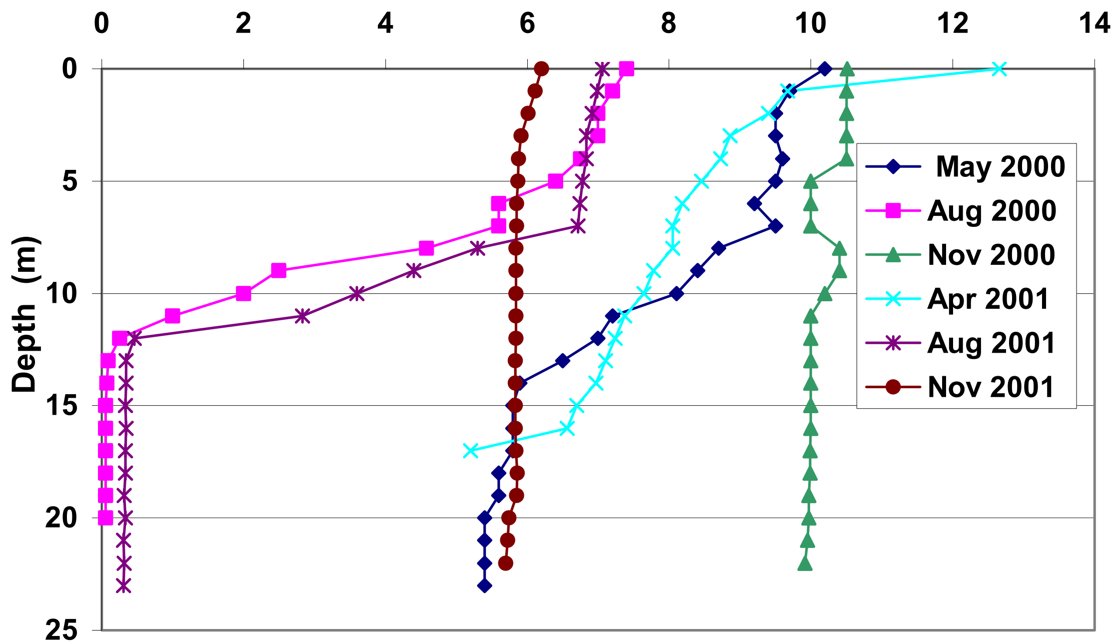
Fig. 5.3 Comparison of 1 and 20-m water temperatures between 2000 and 2001



Seasonal variation in dissolved oxygen

Dissolved oxygen concentrations showed marked seasonal variation typical of eutrophic temperate lakes (Fig. 5.4). During the spring sampling of both years, DO increased from 5-6 mg l^{-1} nearer the bottom to 9-10 mg l^{-1} in the upper mixed layer. By August, dissolved oxygen had been depleted (<0.4 mg l^{-1}) beneath 12 m. On the autumn surveys, DO was relatively high and nearly uniform with depth indicative of mixing during autumn overturn. While the two years were similar on the spring and summer surveys, DO concentration on the November 2000 was significantly higher than in 2001 (~10 versus 6 mg l^{-1}).

Fig. 5.4 Dissolved oxygen concentration in Crowley Lake



Spatial variability in temperature and oxygen

Five stations were sampled to assess spatial variability and obtain better lakewide estimates of various properties. The northern, eastern, and southern sampling stations lay along the main stem (submerged river) of the reservoir forming a north-south transect. The northern station is located in the relatively shallow (8-10 m) long narrow portion of the reservoir into which Owens River flows. The eastern, middle, and western stations form an east-west transect where the western station is fairly close to McGee Creek inputs. The middle, eastern, and southern stations are relatively deep (18-23 m) and represent the main portion of the lake. The northern and western stations are shallow (<10 m) and were chosen to detect regional influences of the two main tributaries, Owens River and McGee Creek.

The shape and relatively high flushing rate combined with the dominance of Owens River inflows result in north-south longitudinal gradients in Crowley Lake. This is clearly evidenced on the 1st lakewide survey (Fig. 5.5) when epilimnetic temperatures and dissolved oxygen concentrations increased from north to south by 1-2°C and 2 mg l^{-1}, respectively.

Fig. 5.5 Spatial variability in temperature (°C) and oxygen (mg l^{-1}), 31 May 2000

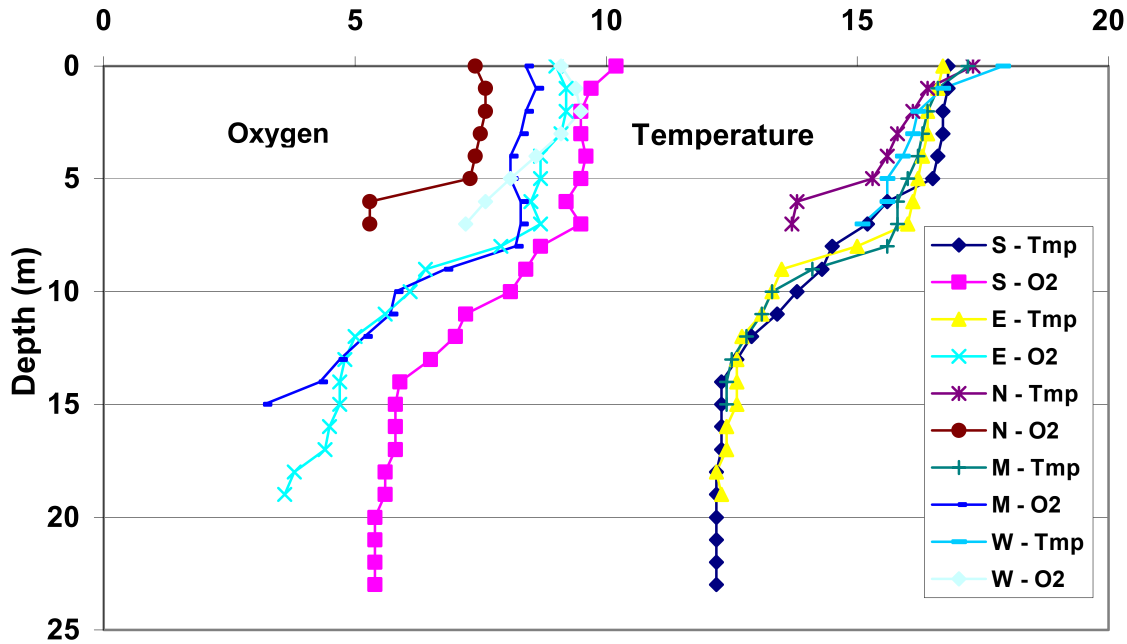


Fig. 5.6 Spatial variability in temperature (°C) and oxygen (mg l^{-1}), 14 August 2000

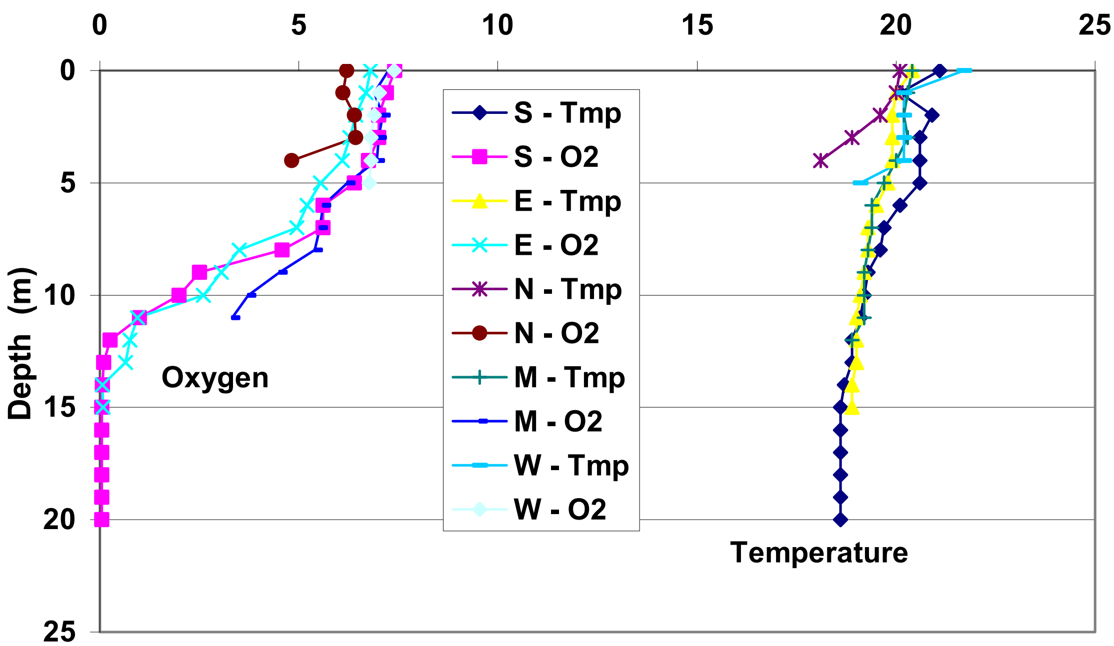
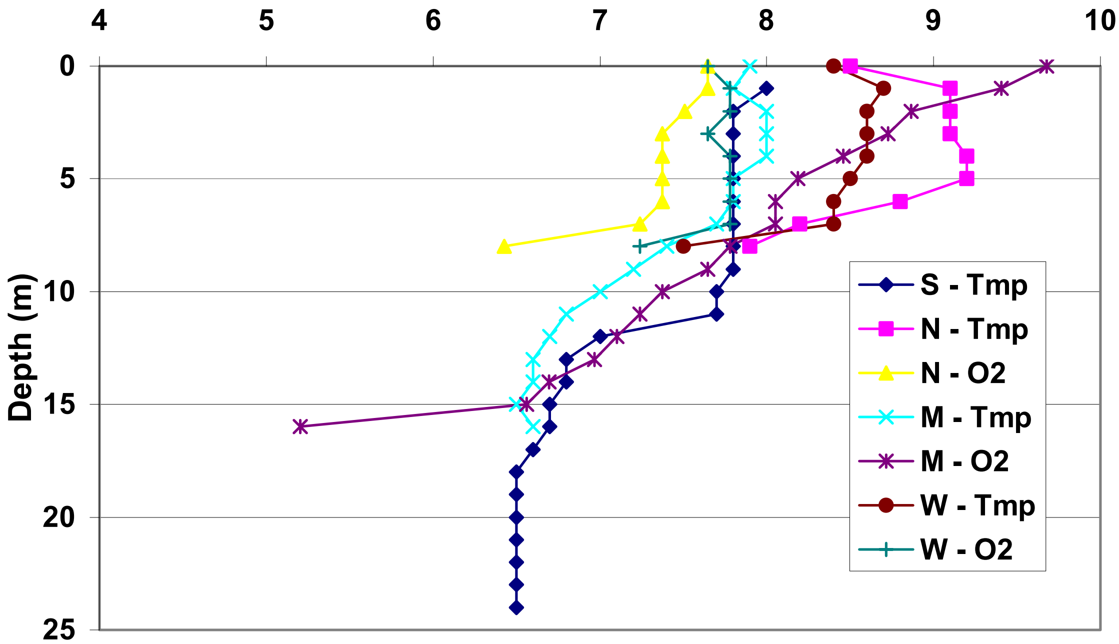


Fig. 5.7 Spatial variability in temperature (°C) and oxygen (mg l^{-1}), 17 April 2001

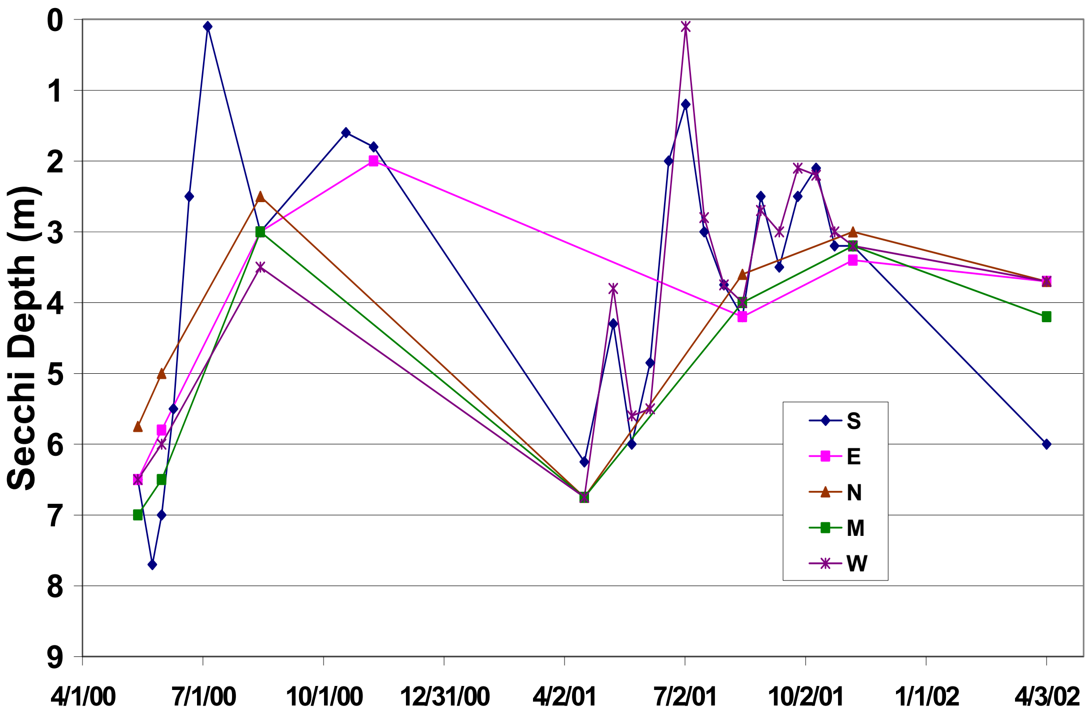


On 17 April 2001, the north and west stations are significantly warmer than the more central stations (Fig. 5.7). Dissolved oxygen was almost always lower at the northern station.

Transparency

Transparency as measured by Secchi depth varied from high values (6-7 m) following ice-off to 1.5-4.1 m during summer/autumn (Fig 5.8). In early July in both years, massive algal blooms were encountered where Secchi depths were reduced to near zero due to floating mats of phytoplankton. During 2001, measurements were taken at bi-weekly intervals at two stations, S and W. Variation in transparency at the two stations tracked each other closely and the biweekly data clearly show the development and collapse of an algal bloom in late June-early July and a subsequent bloom in early October.

Fig. 5.8 Spatial and temporal variability in lakewide transparency (Secchi depth)



Temporal and spatial variation in dissolved and particulate N and P

Dissolved and particulate concentrations of N and P were determined at 5 stations on 3 dates (following ice-off, midsummer, and after autumn turnover) during 2000 and 2001. The sample dates were 31 May, 14 August, and 8 November in 2000 and 18 April, 15 August, and 7 November in 2001. Inclement weather prevented sampling all stations on two occasions; only the two deep stations were sampled on 18 November 2000 and station E was not sampled on 18 April 2001. An additional date on 3 April 2002 was included to complete the 2001-02 runoff year. A 0-5 m integrated sample to represent the mixed layer and additional samples were collected at 5, 10, 15, 20, and 25 m as depth allowed. The 5-m integrated sample is plotted as 2.5 m in all the following plots and is referred to as "surface waters".

Ammonia

Although we had hoped to begin sampling shortly after ice-off, we were unable to conduct the first lakewide survey until 31 May 2000 at least 6 weeks after ice-off. By that time pronounced hypolimnetic ammonia accumulations were already present and thus this first sampling does not represent conditions during vernal mixing. Ammonia concentrations were nearly uniform at stations (S, E, M, and W) and increased from 0.2 µM in the upper mixed layer to 12.1 µM at 20 m at station S (Fig. 5.9). Ammonia concentrations in the surface and 5 m samples were higher (0.9-1.3 µM) at station N located in the long, narrow northern portion of the lake influenced by the Owens River. By mid-August, hypolimnetic ammonia concentrations had increased to 47 µM and the same uniformity across stations S, E, M, and W was present with slightly higher concentrations at station N (Fig. 5.10).

Fig. 5.9 Ammonia concentrations, 31 May 2000.

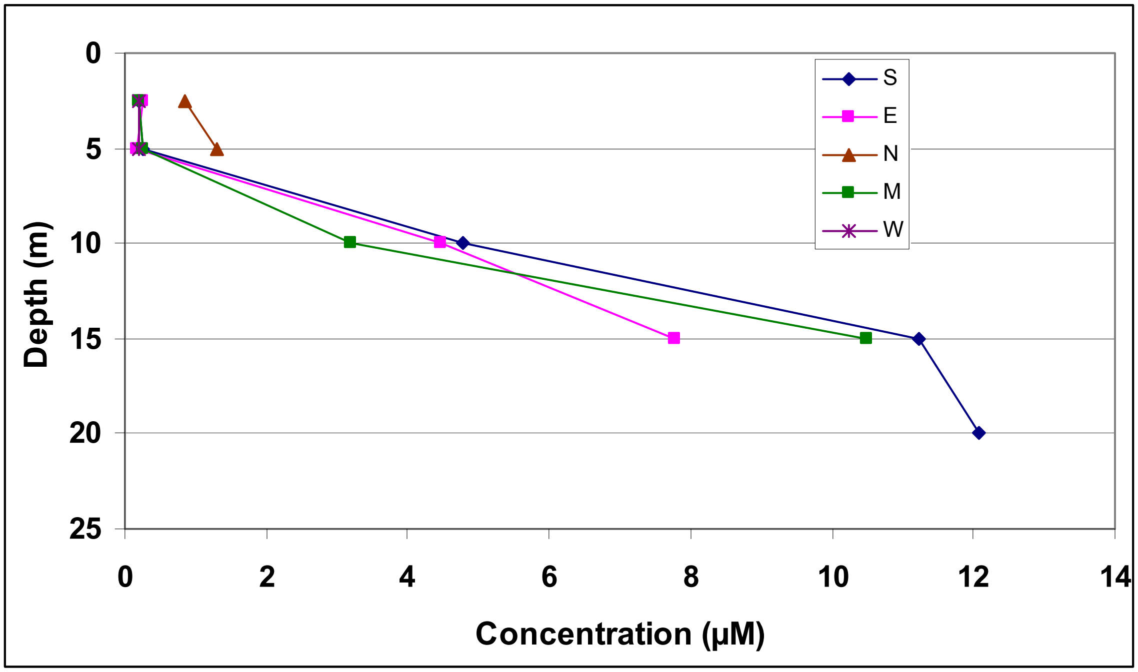
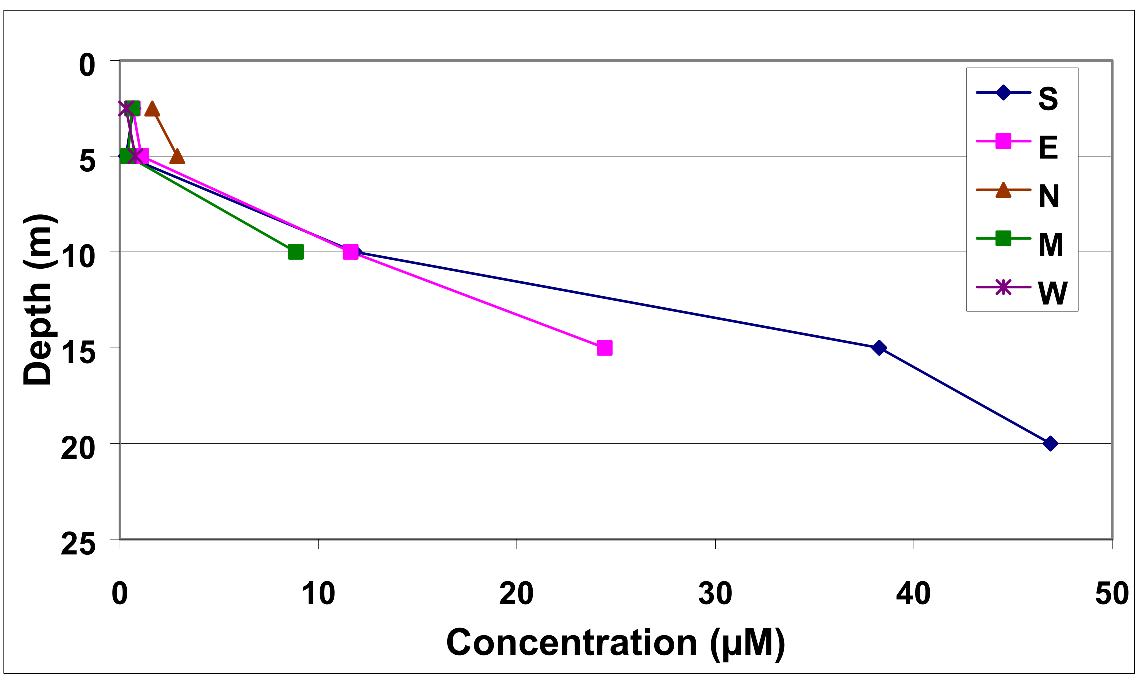


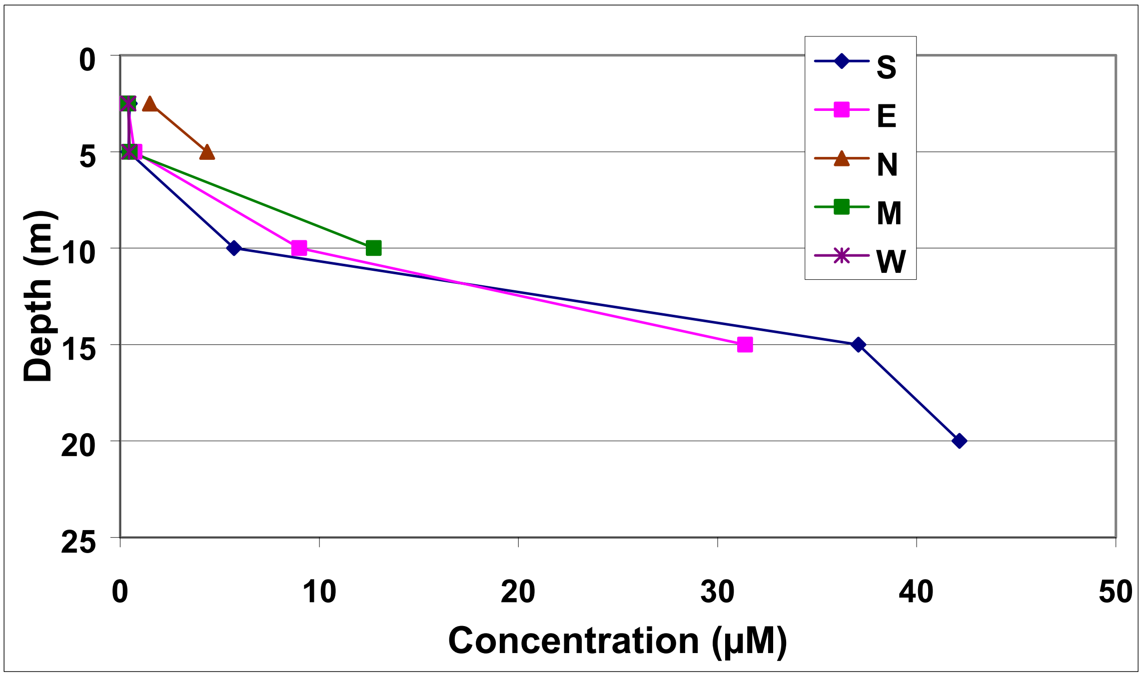
Fig. 5.10 Ammonia concentrations, 14 August 2000.



Following autumn overturn, ammonia concentrations were low (<1 µM) throughout the water column with a mean concentration of 0.5 µM.

The first sampling in 2001 was conducted on 18 April shortly after ice-off and ammonia concentrations were fairly high ranging from 7.3 to 10.3 µM at the 4 main lake stations and slightly less than 5.8-6.0 µM in the northern arm (station N). At the deep station S, concentrations increased slightly from 8.9 µM in the surface to 10.3 µM at 20 m. Surface concentrations at station M and W were intermediate to those at the northern and southern station. By mid-August, ammonia concentrations were almost identical to those observed in August 2000 (Fig. 5.11). Hypolimnetic concentrations had increased to 42 µM at 20 m at station S, all 4 central lake stations were similar, and the northern station had slightly higher ammonia concentrations.

Fig. 5.11 Ammonia concentrations, 15 August 2001

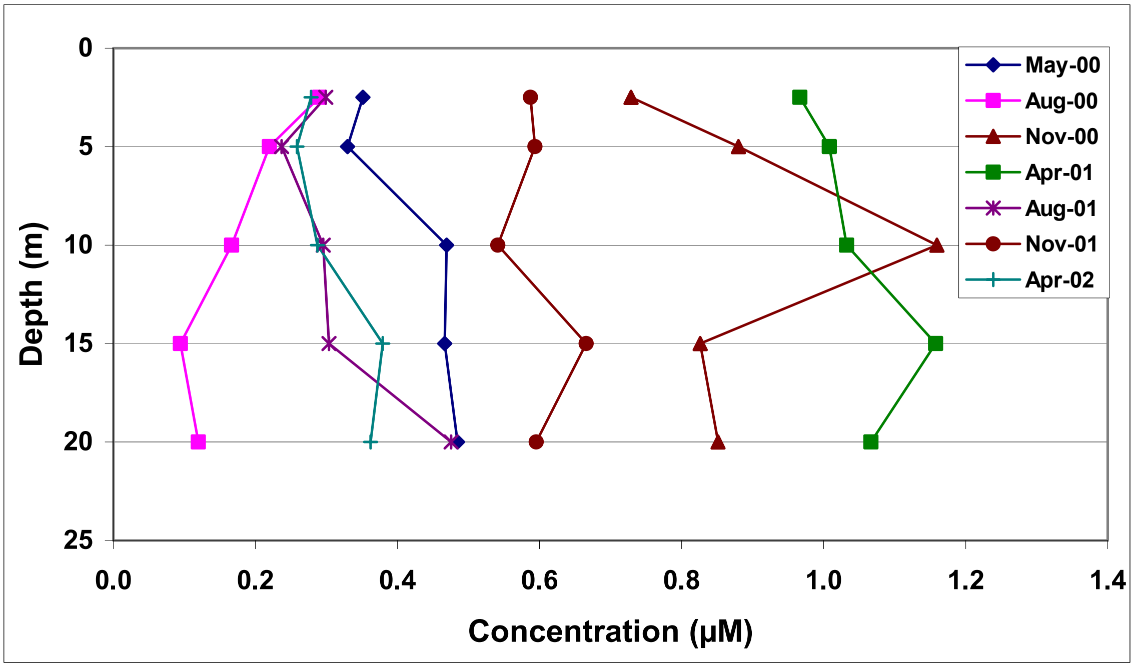


On 7 November, following autumn overturn ammonia concentrations ranged from only 2.1 to 3.1 µM except for a single value of 6.2 µM at 15 m at station E. This elevated concentration is likely due to being very near the bottom. On the following spring survey on 3 April 2002, ammonia concentration ranged from 0.1-0.2 µM in surface waters to 4.4 µM at 20 m at station S. Ice-off was earlier than normal and thus a vertical gradient was already established by the first week of April.

Nitrate

Nitrate was generally low (<1.2 µM) throughout the water column (Fig. 5.12). It was highest immediately following periods of vernal (April 2001) or autumnal mixing (November 2000 and 2001) and lowest in midsummer. Both the late May 2000 and April 2002 surveys were more than 4 weeks after vernal holomixis and were intermediate in value.

Fig. 5.12 Lakewide average nitrate concentrations.



<u>Total dissolved nitrogen (TDN)</u>

Total dissolved nitrogen (organic and inorganic) concentrations ranged from 18 to 103 µM with an overall mean of 33 µM. On 31 May 2000, TDN concentrations were fairly uniform across the lake ranging from 18-21 µM in the upper 5 m to 31 µM at 20 m station S (Fig. 5.13). As with ammonia, TDN accumulated rapidly beneath the thermocline and by mid August had reached 84 µM at 20 m at station S (Fig. 5.14). In mid August 2000 all stations except N showed a slight decrease between the upper 5-m integrated sample and the 5 m sample before increasing with depth. Following autumn turnover, concentrations showed no trend with depth and varied between 20 to 29 µM, except for a single slightly higher value in the near surface sample at S (35 µM). Following ice-off, TDN was nearly uniform with depth varying only from 35 to 42 µM on 18 April 2001. Mid August concentrations in 2001 were very similar to 2000 except that they were slightly lower in the upper water column and higher at depth (Fig. 5.15). Also, they showed no near surface increase as seen in 2000. Both the November 2001 and April 2002 profiles of TDN were nearly uniform with an overall average concentration of 33 and 26 µM, respectively.

Fig. 5.13 Total dissolved nitrogen (TDN) concentrations on 31 May 2000.

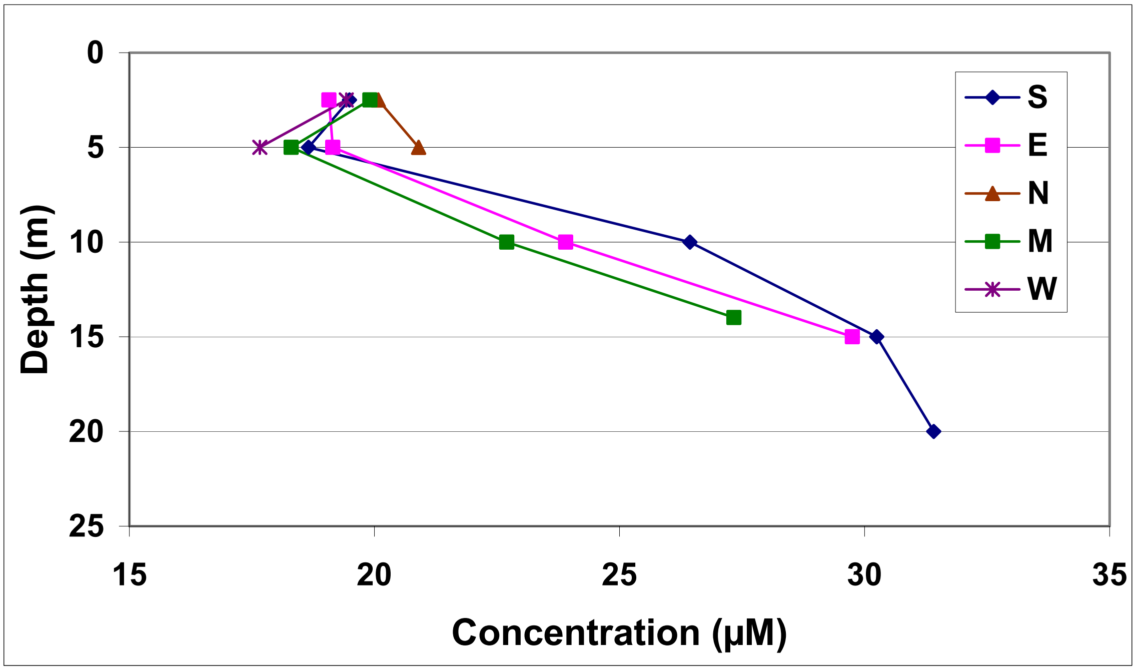


Fig. 5.14 Total dissolved nitrogen (TDN) concentrations on 14 August 2000.

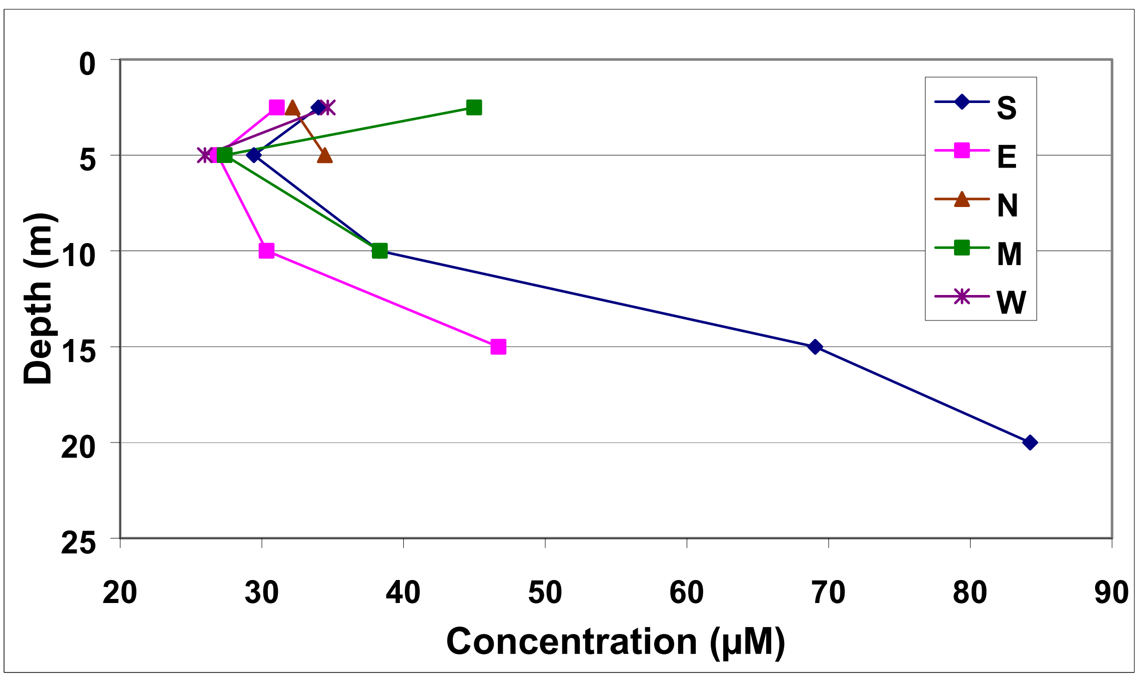
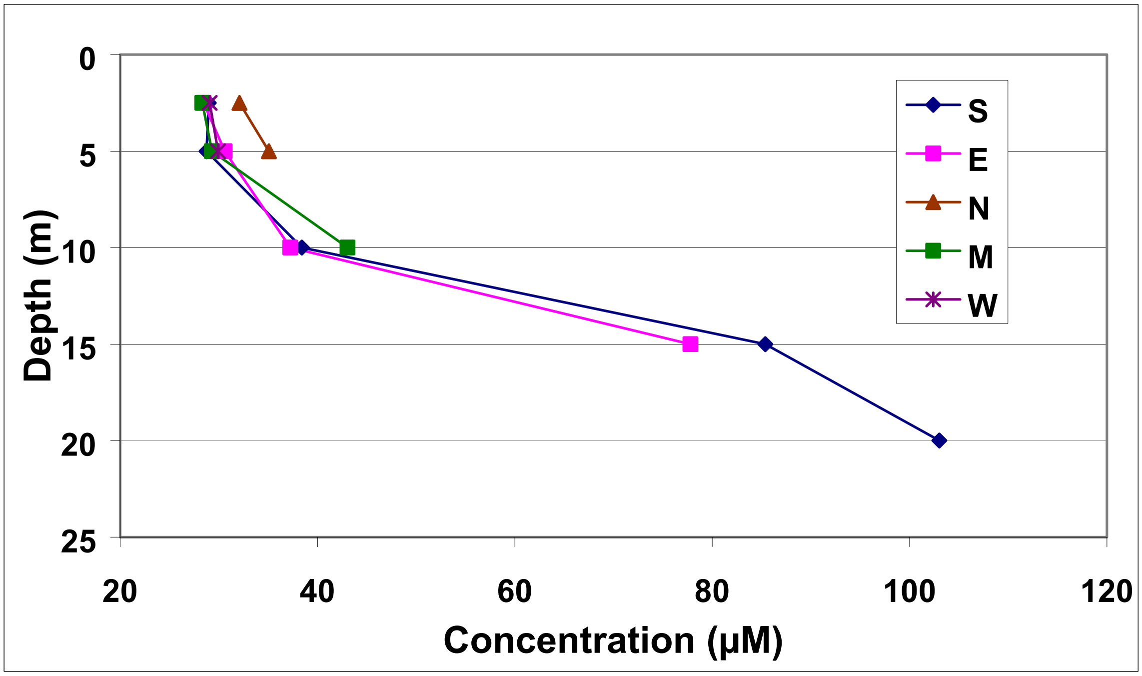


Fig. 5.15 Total dissolved nitrogen (TDN) concentrations on 15 August 2001



<u>Soluble reactive phosphorus (SRP)</u>

Soluble reactive phosphorus concentrations ranged from 0.2 to 4.8 µM. By the first survey on 31 May 2000, SRP concentrations had already been reduced to <2 µM in near surface waters at the M, E and S stations and accumulated to 3.5-3.7 µM beneath the thermocline (15+ m)(Fig. 5.16). There was a clear north-south decrease (N - E & M – S) in near surface concentrations reflecting major inputs from the Owens River and subsequent utilization by phytoplankton with the lake. Concentrations were also higher at the west station close to inflows from McGee Creek. The somewhat anomalous high concentration at 14 m station M most likely reflects being very close to high gradients at the sediment-water interface. Depletion in the euphotic zone continued and by mid August, concentrations were <0.4 µM in near surface and 5 m samples except at the northern station where they were ~1 µM (Fig. 5.17). On the November survey following autumn overturn concentrations were uniform at 2.4 µM. Following ice-off in April 2001, concentrations were nearly uniform at S and M ranging between 2.4 to 2.8 µM, but as observed in May 2000 were higher at N (3.6-3.7 µM) and W (3.3-3.5 µM). SRP profiles in mid August, 2001 were very similar to those observed in 2000 except that they were slightly lower throughout the water column (Fig. 5.18). On the autumn survey, concentrations were uniform at 1.6 µM at S, slightly lower at W (1.4-1.5 µM), slightly higher at M and E (1.6-1.8 µM), and near 2 µM at N. Following ice-off in April, 2002 concentrations ranged between 1.1 and 1.3 µM in all samples except the near surface sample from the northern station which was 1.8 µM.

Fig. 5.16 Soluble reactive phosphorus (SRP) concentrations on 31 May 2000

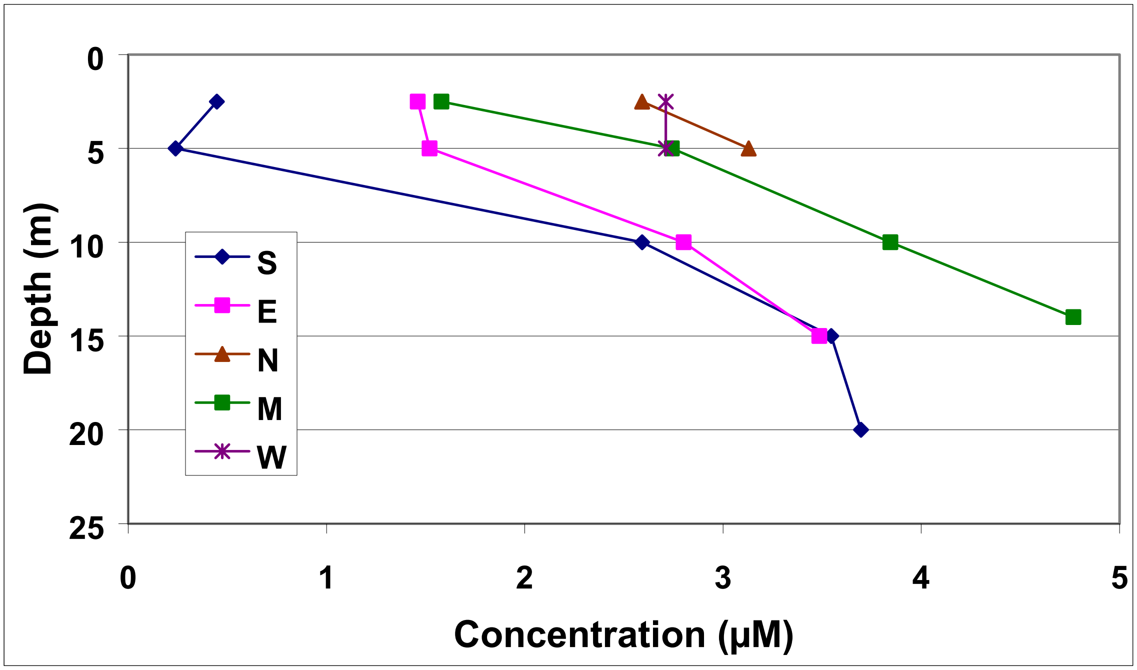


Fig. 5.17 Soluble reactive phosphorus (SRP) concentrations on 14 August 2000

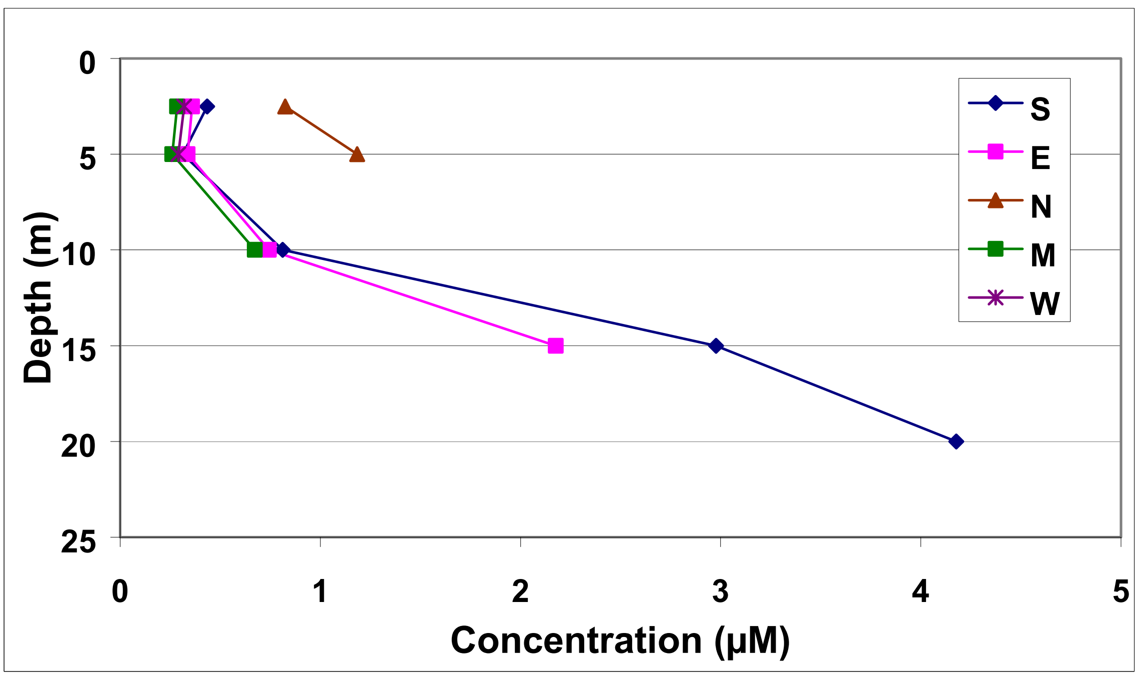
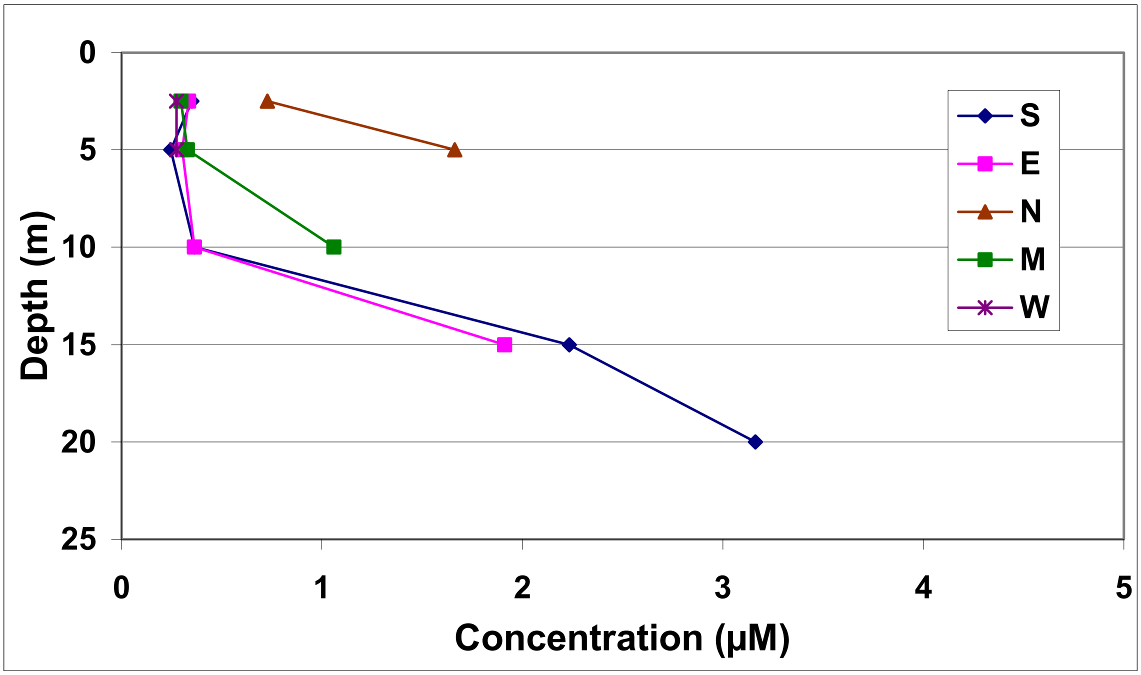


Fig. 5.18 Soluble reactive phosphorus (SRP) concentrations on 15 August 2001



Total dissolved phosphorus (TDP)

Total dissolved phosphorus (organic and inorganic) concentrations ranged from 0.8 to 4.6 µM with an overall mean of 2.7 µM. On 31 May 2000, TDP ranged from ~2 µM in near surface waters to 3-4 µM at depth and exhibited lakewide and depth variation similar to that of SRP (Fig. 5.19). As with SRP, near surface concentrations were markedly higher at the northern station. By mid August, concentrations had decreased slightly in the upper water column and the same minima at 5 m as observed for SRP was present (Fig. 5.20). The concentration at the deepest sample (20 m at S) was 4.2 µM. Following autumn overturn, the mean concentration was 3.2 µM and increased slightly to 4.1 µM on the following spring survey (April 2001). By mid August 2001, TDP concentration in 0-5, 5, and 10 m samples had decreased to 1.4-1.6 µM at all but the northern station and increased at the deepest depth (20 m) to 4.5 µM (Fig. 5.21). Lakewide mean concentrations were 3.1 and 2.5 µM on the autumn 2001 and spring 2002 survey, respectively.

Fig. 5.19 Total dissolved phosphorus (TDP) concentrations on 31 May 2000

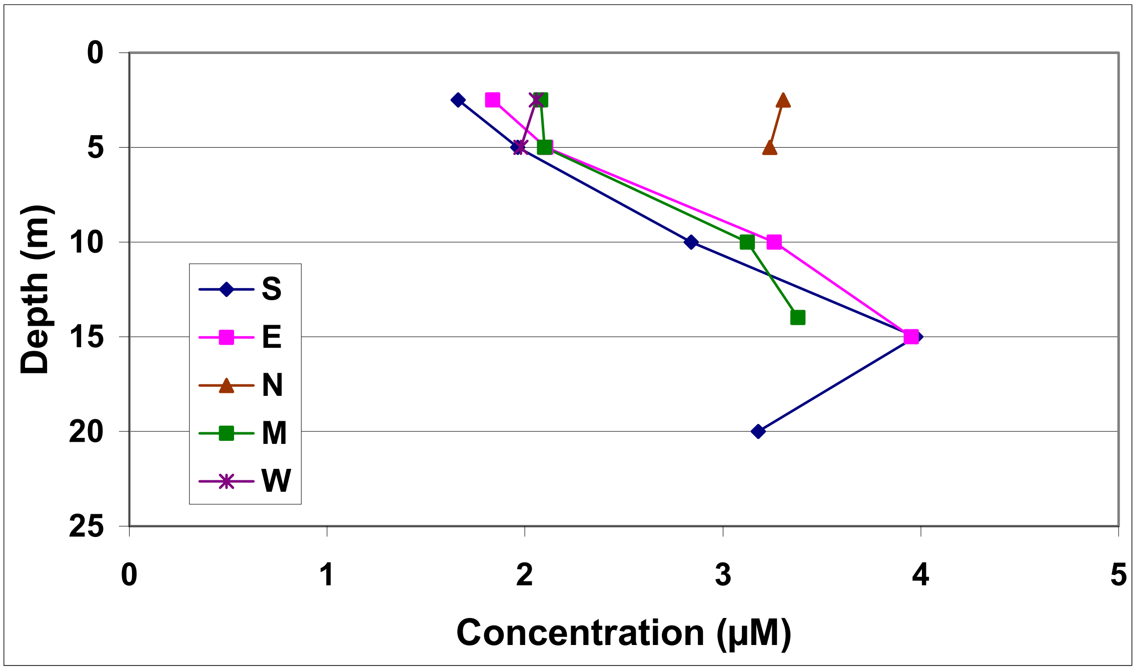


Fig. 5.20 Total dissolved phosphorus (TDP) concentrations on 14 August 2000

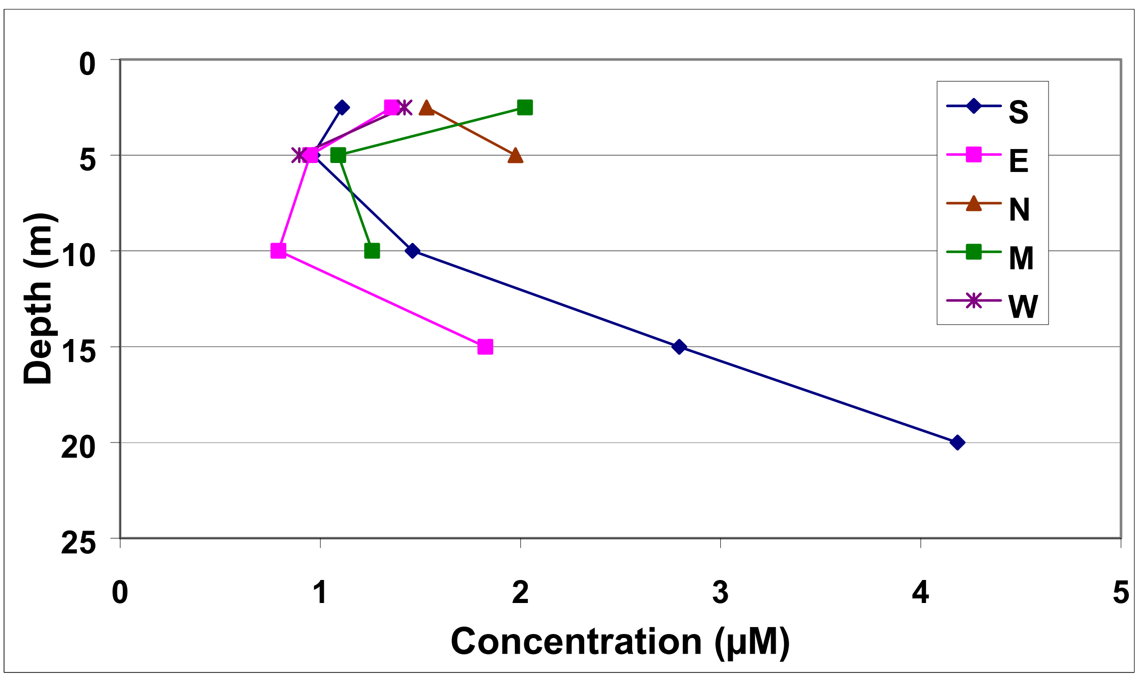
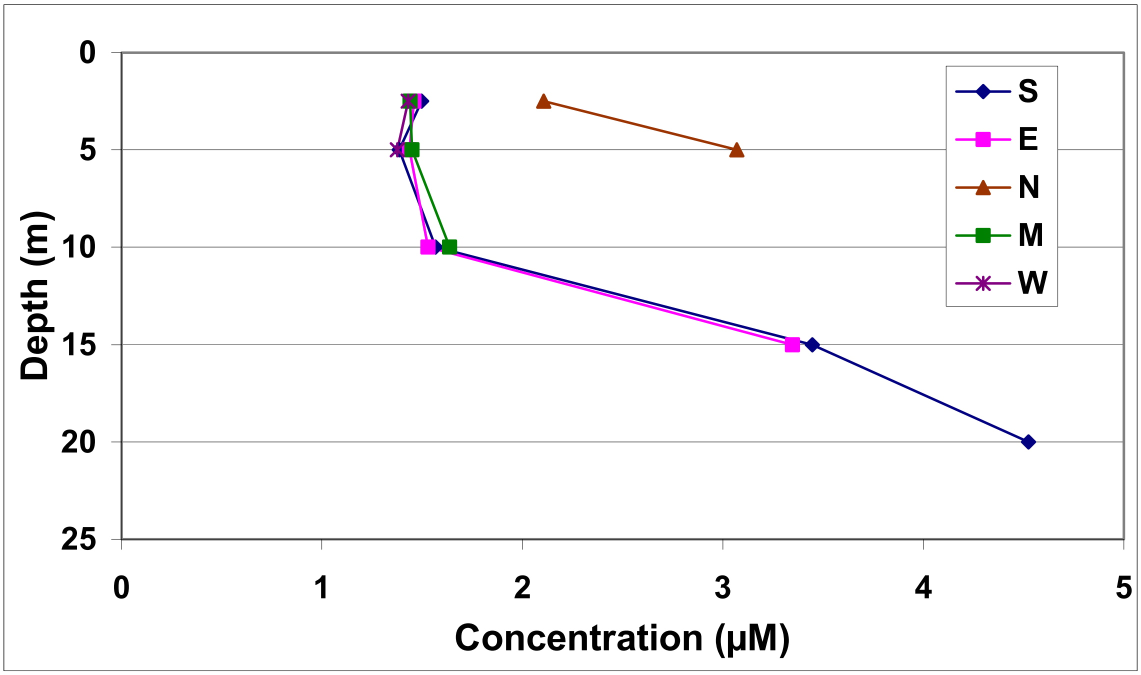


Fig. 5.21 Total dissolved phosphorus (TDP) concentrations on 15 August 2001



Total nitrogen (TN) and total phosphorus (TP)

Total nitrogen and phosphorus include dissolved inorganic (NH_3 and NO_3 or SRP), dissolved organic (TDN or TDP), and particulate fractions in phytoplankton, zooplankton and detrital pools. Total phosphorus varied from 1.4 to 6.3 µM with an overall mean of 3.3 µM (n, 126) while total nitrogen varied from 20 to 113 µM with an overall mean of 44 µM (n, 126). While 2000 and 2001 were similar in many respects, the total phosphorus concentrations differ between the two years (Fig. 5.22). Spring concentrations in 2000 and 2001 are not directly comparable as sampling was not initiated until 31 May in 2000. However, lakewide mean August 2001 TP concentrations are lower at all depths and November 2001 TP is about 20% less than in November 2000. There is a decline in TP during both winters (November – April) of about 20%. Total nitrogen also showed winter declines during both years, but the decline was somewhat larger in winter 2000-01 (~40%) (Fig 2.23).

Fig. 5.22 Lakewide mean (of five stations) total phosphorus (µM).

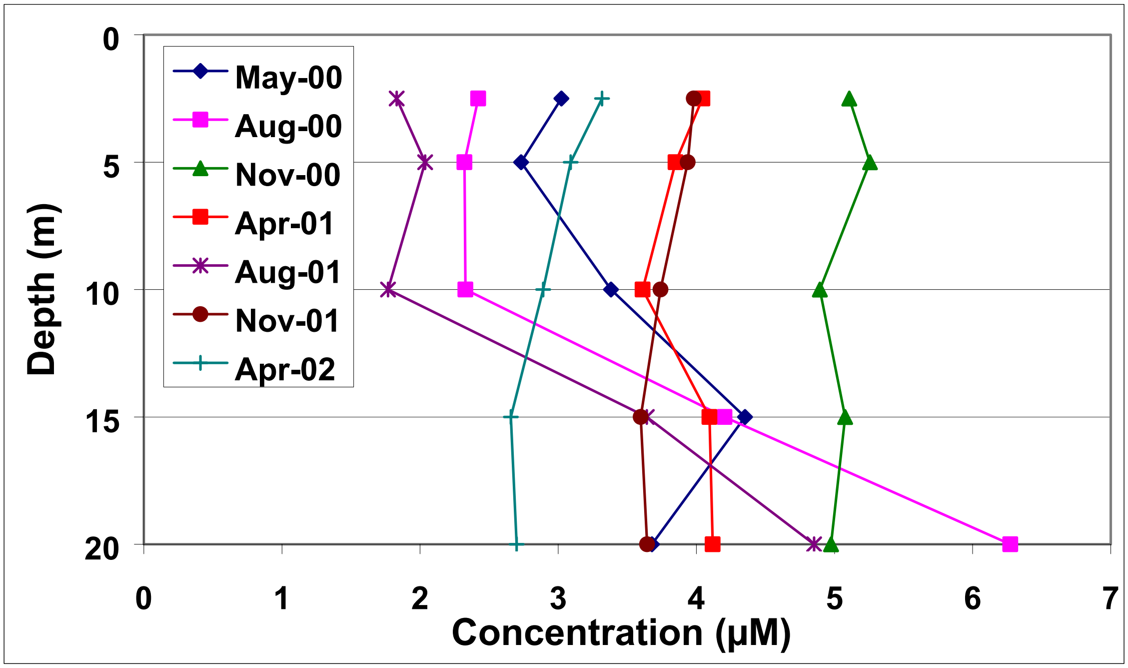
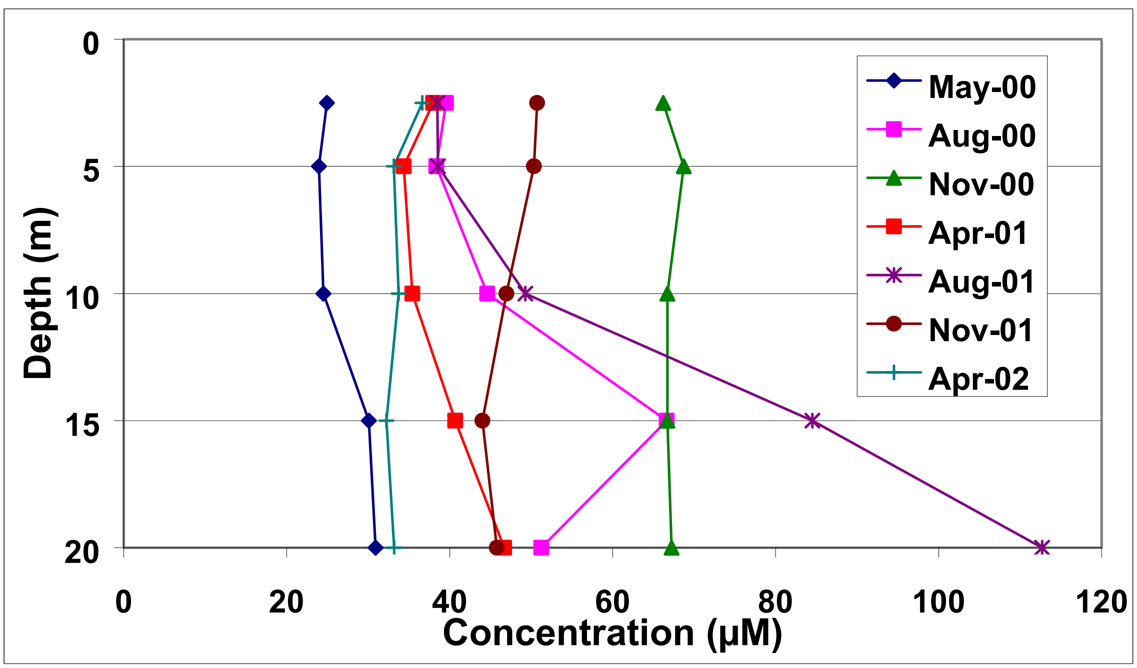


Fig. 5.23 Lakewide mean (of five stations) total nitrogen (µM).



Change in the partitioning of N and P between various pools

The overall sample average of SRP:TDP, TDP:TP, and PP:TP were 0.61, 0.80, and 0.22. Particulate (PP) and total dissolved (TDP) phosphorus totaled just slightly more, 2%, than the total phosphorus measured with the Valderrama oxidation indicating that nearly all the particulate P was oxidized by this method. The overall sample average of DIN:TDN, TDN:TN, and PN:TN were 0.13, 0.80, and 0.35 where DIN is the sum of NO_3 and NH_4. As the sum of PN and TDN was 15% greater than measured, a significant fraction of PN was not oxidized by Valderrama oxidation. Thus in reporting the fraction of inorganic and dissolved N and P components, we use TDP plus PP and TDN and PN as the estimates of TP and TN, respectively.

Overall, soluble reactive phosphorous constituted 45% of the total phosphorus in the 0-5 m integrated samples. Dissolved inorganic phosphorus, calculated as the difference between TDP and SRP, constituted 33% with particulate phosphorus as the remaining 22% (Fig. 5.24). In both 2000 and 2001, the SRP pool was largest during the spring survey and a minimum in August. In midsummer, both the particulate and dissolved organic pools were relatively larger. The phosphorus partitioning among pools was relatively constant among the five stations except that the SRP pool constituted more and the DOP pool less at the N and W stations which are heavily influenced by the inflowing Owens River and McGee creek (Fig 5.25).

Fig. 5.24 Percent fractions of SRP, DOP, and PP in the 5-m integrated samples by date.

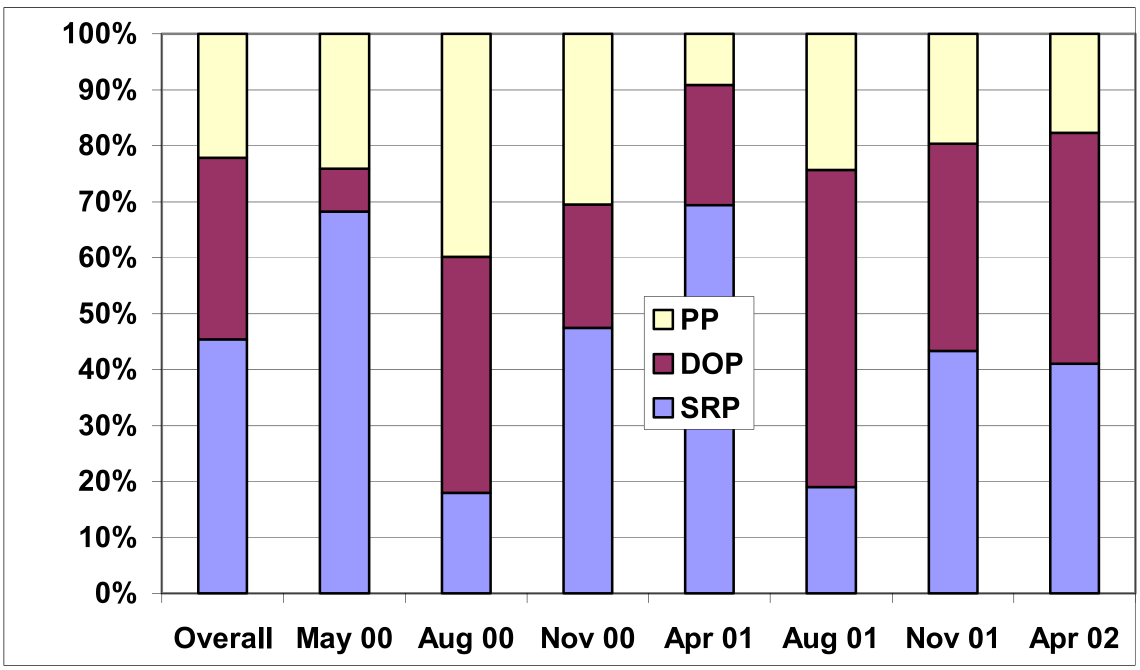
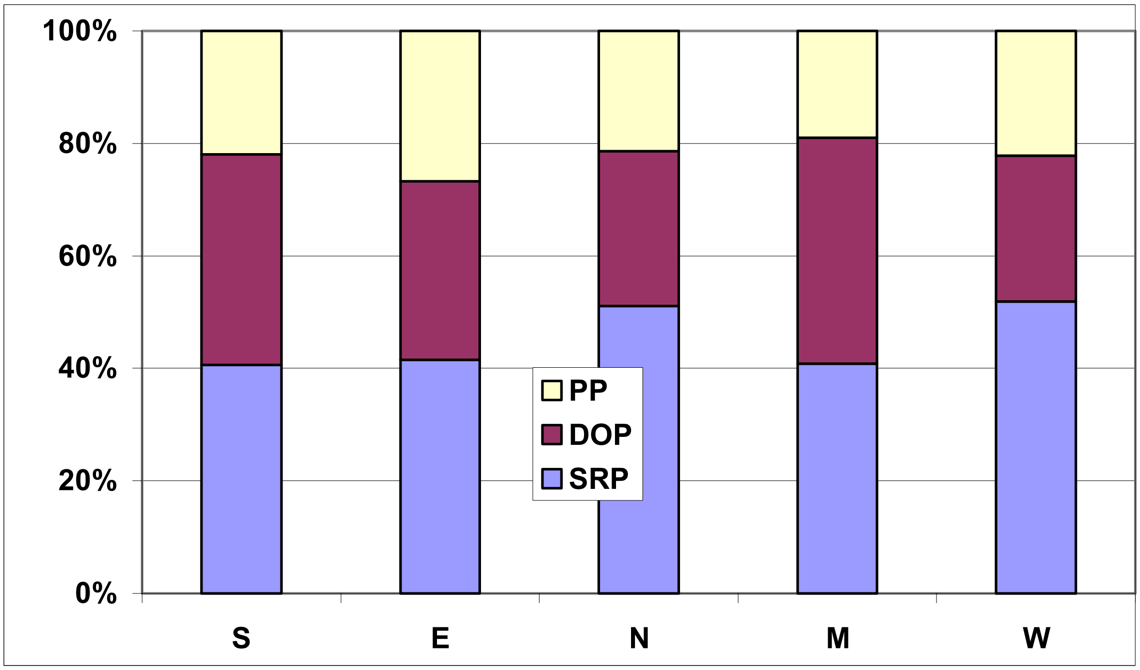


Fig. 5.25 Percent fractions of SRP, DOP, and PP in the 5-m integrated samples by station.



The dissolved inorganic nitrogen pools (NH_3 and NO_3) constituted a much smaller portion of the total (5%) than phosphorus (Fig. 5.26). Only on the April 2001 survey which occurred shortly after ice-off was the DIN pool much larger (19%). The majority (60%) of nitrogen was in the dissolved organic pool. Only during the November 2000 survey was the fraction in the DON pool less than 40%. The particulate pool constituted from 18 to 61% of the total, but was generally 30-40%. Unlike phosphorus, The DIN pool was not higher at N and W than the rest of the stations, but DON constituted 10% more of the total pool at W and M compared to S and E with the pool of DON at N intermediate (Fig. 5.27).

Fig. 5.26 Percent fractions of DIN, DON, and TN in the 5-m integrated samples by date.

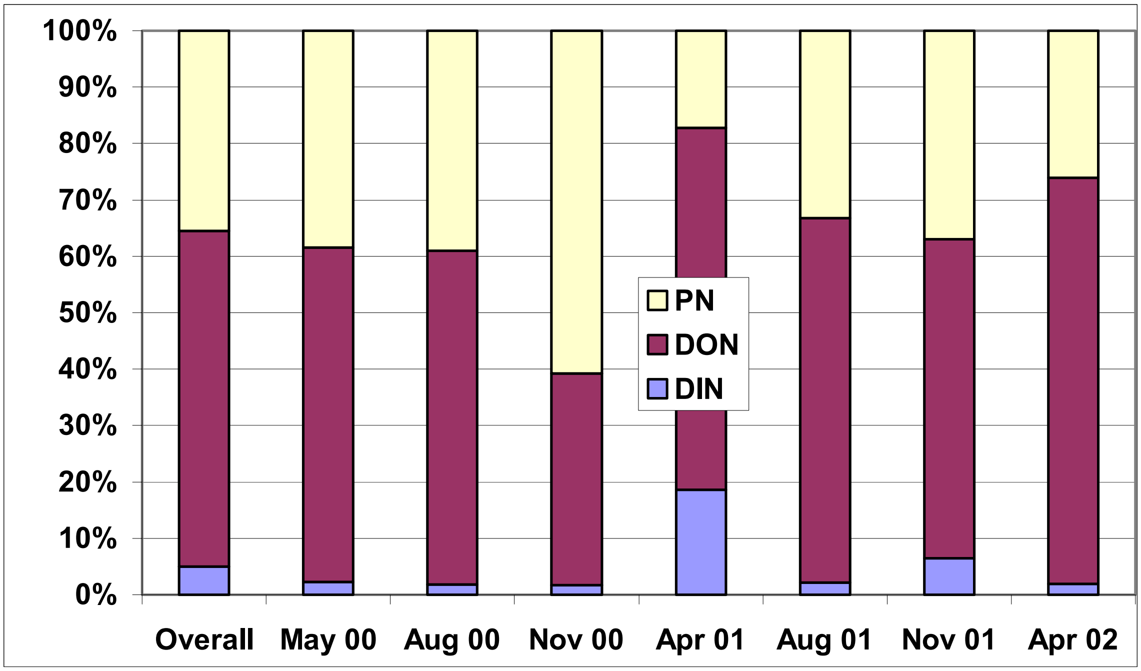
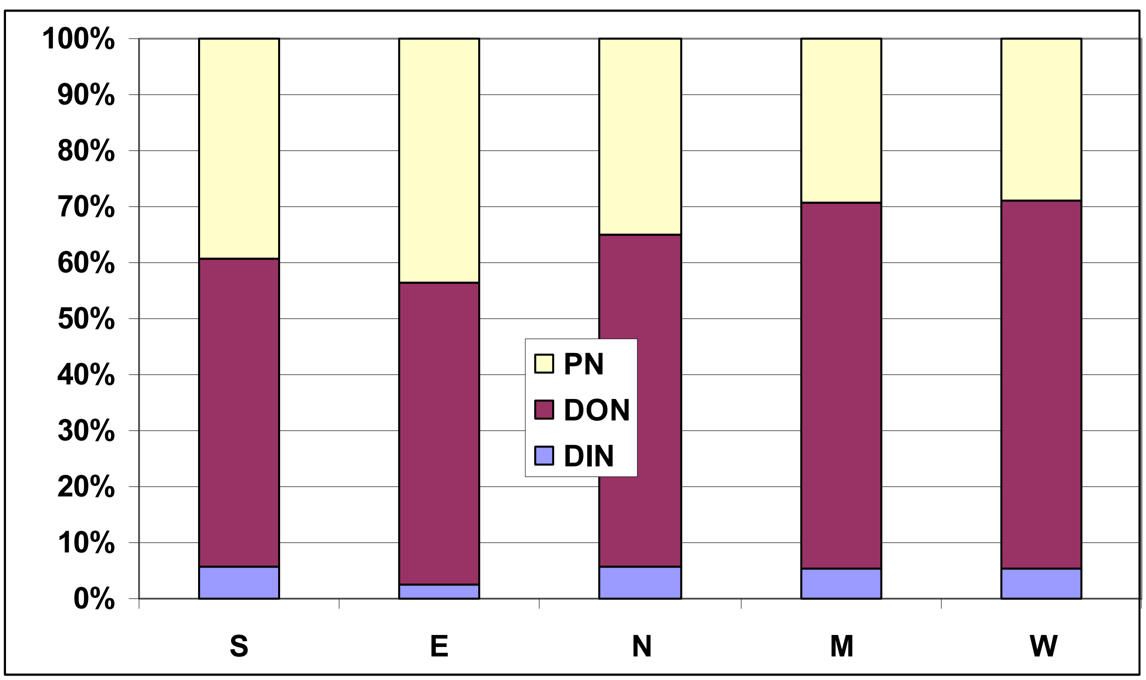


Fig. 5.27 Percent fractions of DIN, DON, and TN in the 5-m integrated samples by station.



Departure of sestonic (particulate) ratios of C:N and N:P from the Redfield ratio (106:16:1) can provide an indication of nutrient limited growth of phytoplankton (Wetzel and Likens, 1991). The particulate C:N molar ratios varied from 5.0 to 8.4 with an overall mean of 6.3 very close to the Redfield molar C:N ratio of 6.6. Particulate N:P ratios varied from 9 to 36 with an overall mean of 22.4. This is slightly higher than the Redfield ratio of 16, but not indicative of strongly P-limited growth. There was no significant correlation between C:N or N:P and depth.

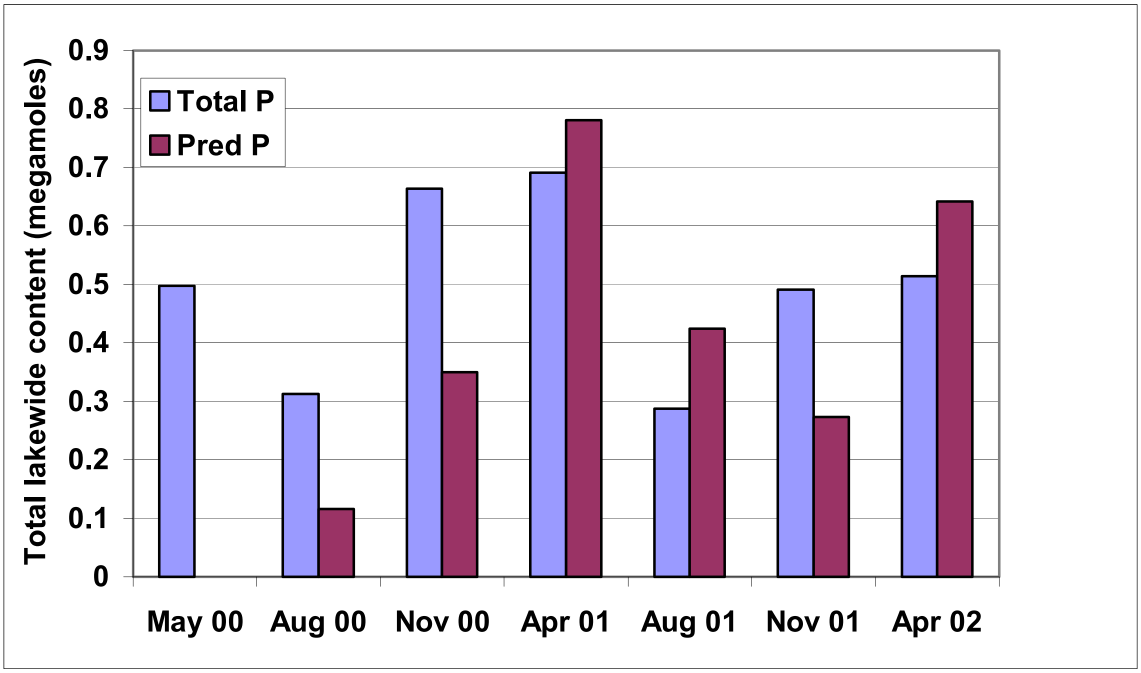
Mixed-layer samples (0-5 m integrated) were also collected at station W near the inflows of McGee and the central south station (S) at biweekly intervals during summer 2001 to determine if there were detectable differences in sestonic ratios associated with the increased nitrogen inputs from McGee Creek. The mean C:N and N:P sestonic ratios were 6.3 and 28.4 at W and 6.5 and 26 at S. Thus, no significant differences were observed in the sestonic ratios between these two stations.

Seasonal changes in lakewide inventories of N and P

Total lakewide inventories were calculated based on volume-weighted means of the 5 station lakewide average. Concentrations were interpolated to 1-m intervals between sampled depths, multiplied by the corresponding volumes of 1-m intervals, and summed.

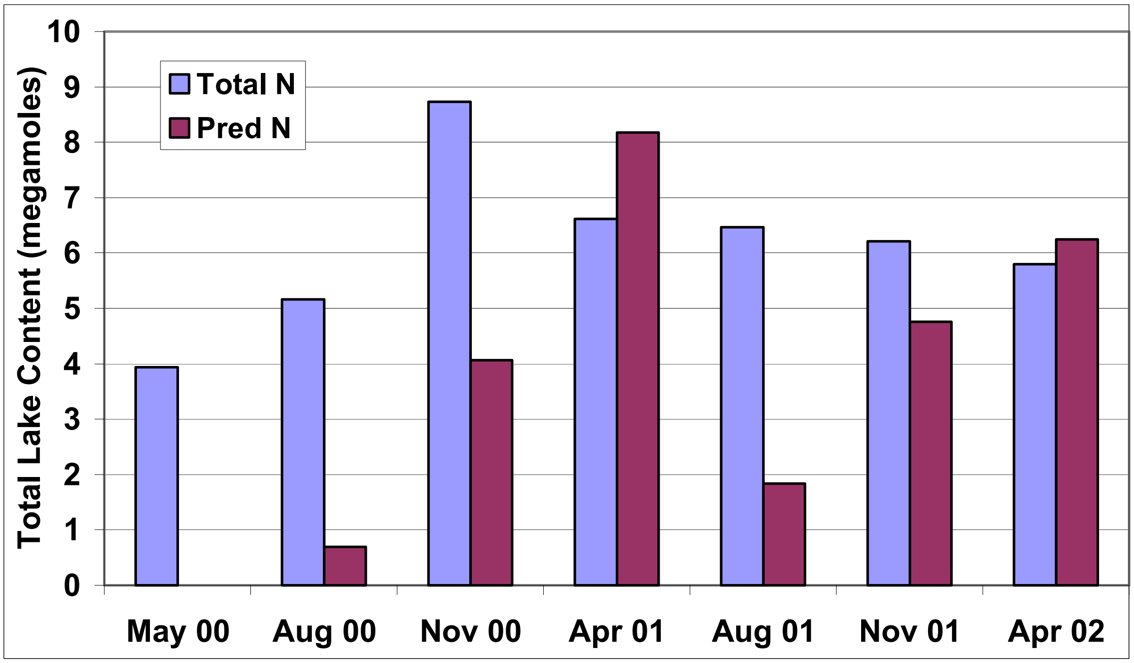
The estimated total lakewide content of phosphorous varied between 0.3 and 0.7 megamoles (Fig. 5.28). Estimates of total P loading and exports of P are almost the same (see chapter 4) and the total lakewide P content in May 2000 was the same as at the end of the study period in April 2002. Values were a minimum in August of both 2000 and 2001 and a maximum during the fall/spring 2000/01. Measured loading in tributaries and exports from dam outflows were integrated over the periods between lake surveys and added to the previous survey total to predict the lakewide content on subsequent surveys. This could potentially show when sediments or other unmeasured sources and sinks were important. When the total lakewide P exceeds the prediction sediment release or other unmeasured inputs may be important. Total P exceeded the predicted P during both August and November 2000 and November 2001 suggesting sediment release during the August and November period in both years and May through August 2000.

Fig. 5.28 Estimated total lakewide content of P



The estimated total lakewide content of nitrogen varied between 4 and 8.8 megamoles (Fig. 5.29). After increasing through 2000 to its peak in November, total lakewide N declined to between 5.8 and 6.7 for the entire period April 2001-April 2002. Estimates of N exports in outflows greatly exceed measured inputs in stream inflows (see Chapter 4). As done for lakewide P above, measured loading in tributaries and exports from dam outflows were integrated over the periods between lake surveys and added to the previous survey total to predict the lakewide content on subsequent surveys. As expected due to the imbalance between measured inputs and exports, the measured lakewide N exceeded predicted N on all but the two April surveys. The largest differences occurred on August and November 2000 and August 2001 surveys suggesting large unmeasured inputs between spring and autumn in 2000 and between spring and summer in 2001.

Fig. 5.29 Estimated total lakewide content of N



MTBE

Surface samples were collected in duplicate and sent overnight to Babcock Laboratories for analysis by gas chromatography/mass spectrometry (EPA 8260). For the first survey, samples were analyzed at a reporting limit (RL) of 3.0 µg l^{-1} and a minimum detection limit (MDL) of 1.2 µg l^{-1}. The north station sample was reported as ND and the remaining stations as "trace". At our request, Babcock went back and estimated the trace concentrations; these values are reported but suspect. Samples taken in subsequent surveys were analyzed at RL = 1.0 µg l^{-1} and MDL = 0.02 µg l^{-1}. Only one sample (8/16/2000, station S) showed any MTBE. Samples were taken on 3 September 2001, Labor Day, after 3 days of very intense boating activity on the lake. All stations were below detection limits. With the approval of the program manager, MTBE sampling was suspended.

Table 5.2 Concentration (µg l^{-1}) MTBE in Crowley Lake surface water by sampling station

Date	North	South	East	West	Mid
5/31/2000	ND*	3.0*	1.3*	1.6*	1.3*
8/16/2000	ND	1.2	ND	ND	ND
11/8/2000		ND	ND		
4/18/2001	ND	ND		ND	ND
9/3/2001	ND	ND	ND	ND	ND

ND = none detected at RL (reporting limit) = 1.0 µg l^{-1} and MDL (minimum detection limit) = 0.21 µg l^{-1} for all dates except 5/31/2000

*The first set of analyses were conducted at an RL=3.0 µg l^{-1} and an MDL = of 1.2 µg l^{-1}. Measured concentrations between these values are reported as trace and estimated.

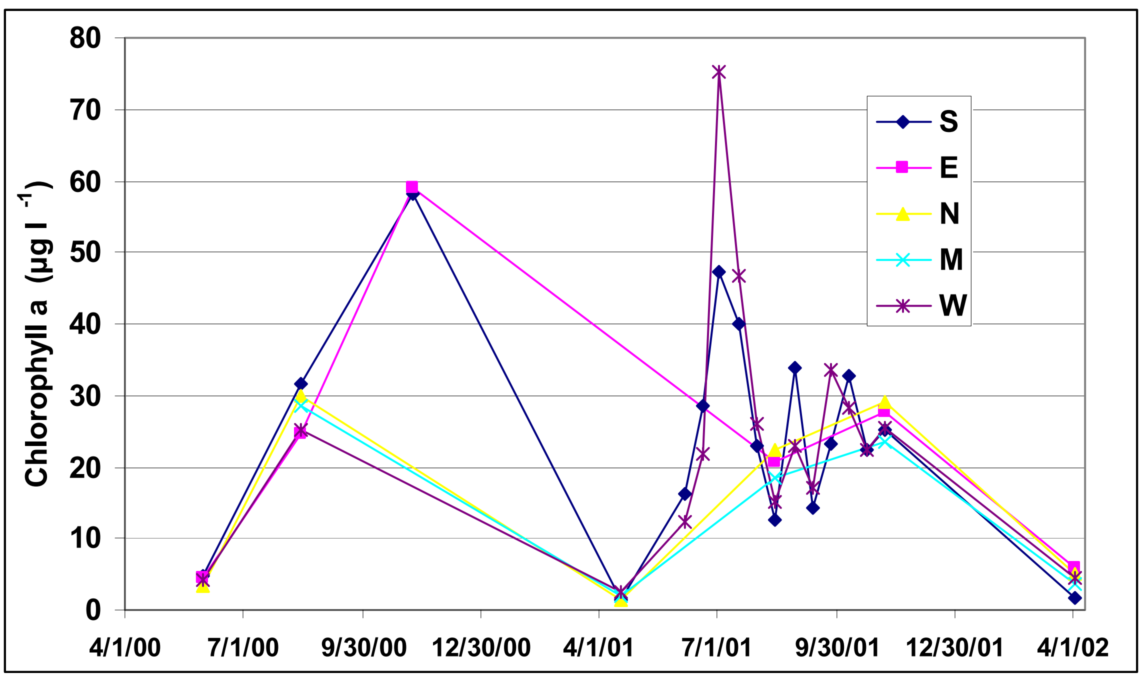
Plankton

The plankton community was assessed at all five stations during spring, summer, and autumn surveys in which chlorophyll *a* measurements and species identification and enumeration of the phytoplankton and zooplankton were made. Additionally in 2001, biweekly mixed-layer (0-5 m integrated) samples were collected at the west and south stations to determine if there were any significant differences between the central portion of the lake and the area receiving inputs from McGee Creek.

Chlorophyll *a*

Chlorophyll *a* concentration varied seasonally from 0.6 to 75 µg chl l^{-1} (Fig. 5.30). Marked seasonal variation was observed with minima occurring during the April/May surveys, high (12-32 µg chl l^{-1}) summer values and pronounced peaks during the November 2000 and July 2001 surveys. The biweekly sampling at W and S conducted in 2001 illustrate the pronounced temporal variation associated with the spring bloom. Two-fold midsummer variation is also evident in 2001. Although only two stations (S and E) were sampled on the November 2000 survey due to inclement weather, it is clear that the 2000 autumn bloom (60 µg chl l^{-1}) was more pronounced than in 2001. The average summer (June-September) chlorophyll *a* concentration in 2001 for which more frequent data were collected was 22.4 µg chl l^{-1}.

Fig. 5.30 Chlorophyll *a* concentration in Crowley Lake, 2000-2001.



Phytoplankton Community

The phytoplankton community was dominated by cyanophytes (blue-greens) except for periods of increased nutrient supply during vernal and autumnal mixing when bacillariophytes (diatoms) dominated (Figs. 5.31-33).

The early spring samples collected shortly after ice-off on April 18, 2001 and April 3, 2002 are completely dominated by Bacillariophytes (diatoms) (Figs. 5.32, 5.33). In 2001, the south, middle and western stations were dominated by *Fragilaria* while the north station was dominated by *Asterionella*. In 2002, *Asterionella* dominated at all stations. This trend was not seen in 2000, likely due to the lateness of the sampling which occurred on 31 May of that year (Fig. 5.31). The 31 May 2000 data are much more representative of those collected during August. Surface temperatures had already reached17°C, much more comparable to the average of the August sampling dates (20°C) vs. April (9°C), and nutrient gradients had already started to form with depth. Also, total and dissolved nitrogen are both lower on May 31, 2000 than other dates indicating that nitrogen fixers such the Cyanophyta may have had a competitive advantage.

Cyanophytes dominated all stations on all dates in 2000 with the exception of the mid station in May where nine *Volvox* colonies were counted in a 10 ml sample. *Volvox*, the largest colonial Chlorophyte, can contain up to 50,000 cells and attain a size up to 1 mm in diameter. *Volvox* occurs in nitrogen rich waters and in summer can produce blooms of short duration. In Crowley Lake, it appears early in the season, but decreases in abundance by August, and is not found in autumn samples. The cyanophyte *Lyngbya* dominated in May 2000 as well as in August samples during both years. With the exception of the April samples, it was present at most stations throughout the rest of the sampling period. The cyanophyte *Gloeotrichia* rivals *Lyngbya* as a dominant in August. *Gloeotrichia* colonies consist of radiating filaments with heterocysts at their base. These colonies reach up to 2 mm in diameter and may form large algal blooms. *Gloeotrichia* was only present during the August sampling.

In November 2000, the cyanophyte *Coelosphaerium* produced extensive blooms at the two stations sampled. It comprised 70% of biovolume at the S station and 65% at the E station. While the bloom may have occurred in 2001, it was not present on the sampling date. While *Coelosphaerium* was present at all stations, it only constituted between 5-22% of the biovolume. The bacillariophyte, *Stephanodiscus* dominated at all five sites. The *Coelosphaerium* bloom in November 2000 coincided with a low ammonia level (<1 μM) compared to 2.1 – 3.1 μM in 2001. Diatoms dominated in both the spring and autumn of 2001 when ammonia concentrations were much higher.

The cyanophyte *Anabaena* was present during May and August 2000 but was absent in November 2000. During May, *Anabaena* contained large numbers of heterocysts (nitrogen-fixing cells), indicating that N may have been limiting during this period. No heterocysts were found in the August samples. However, *Anabaena* was present throughout 2001 and in April 2002 and heterocysts were noted in samples from all 4 surveys.

The nitrogen fixing cyanophyte, *Aphanizomenon,* was not identified in the 2000 samples. It appeared in the November 8, 2001 samples. This cyanophyte may have been excluded by the large bloom of *Coelosphaerium* at the time of sampling. However, it may have occurred before or after the November sampling date. *Aphanizomenon* has been reported in the literature as present late in the season (Melack and Lesack 1982, Warner 1965, EPA 1978).

The chrysophyte *Dinobryon* tends to occur under relatively poor nutrient conditions and was present in May 2000 samples but was not counted in August or November 2000. In 2001, it was noted in at least 2 stations from each date and in April 2003 it appeared in all 5 samples.

The dinophyte *Ceratium* was found mainly in the August samples. It is reported in 2 November 2001 samples but the numbers were declining. *Ceratium* is common to lakes rich in nutrients and is often found with cyanophytes.

A complete list of the phytoplankton identified in Crowley Lake during this study lists 42 genera (Table 5.3).

Table 5.3 Phytoplankton genera identified in Crowley Lake during the period May 31, 2000 to April 3, 2002.

PHYLUM	GENERA
CYANOPHYTA (blue-green algae)	*Oscillatoria, Lyngbya, Coelosphaerium, Anabaena, Gloeotrichia, Aphanothece, Microcystis, Aphanizomenon, Merismopedia*
PYRRHOPHYTA (dinoflagellates)	*Ceratium, Gymnodinium*
CHRYSOPHYTA Sub-Phylum Bacillariophyceae (diatoms)	*Stephanodiscus, Asterionella, Fragilaria, Melosira, Synedra, Rhoicosphenia, Cocconeis, Navicula, Gomphonema, Nitzschia, Anomoeoneis, Cymbella, Pinnularia, Gyrosigma*
CHRYSOPHYTA Sub-Phylum Chrysophyceae	*Dinobryon, Mallomonas, Uroglena*
CHLOROPHYTA (green algae)	*Eudorina, Pediastrum, Volvox, Staurastrum, Cosmarium, Pandorina, Closterium, Crucigenia, Phacotus, Sphaerocystis, Oocystis, Schroederia*
CRYPTOPHYTA	*Rhodomonas, Cryptomonas*

Fig. 5.31 Crowley Lake phytoplankton community composition during 2000.

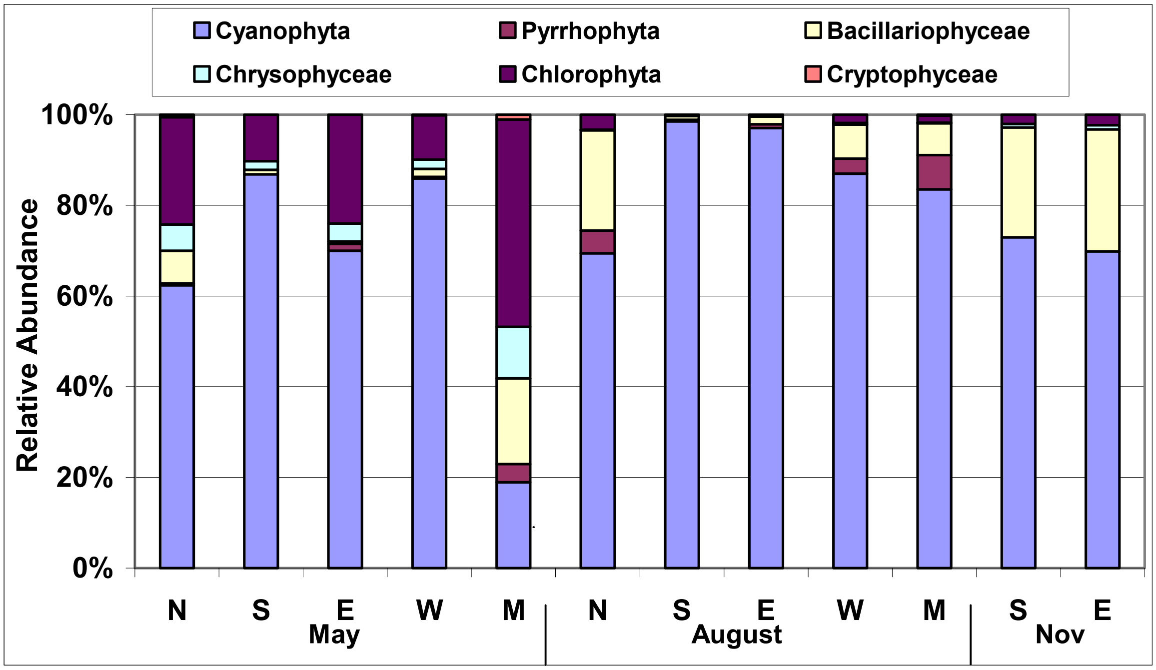


Fig. 5.32 Crowley Lake phytoplankton community composition during 2001.

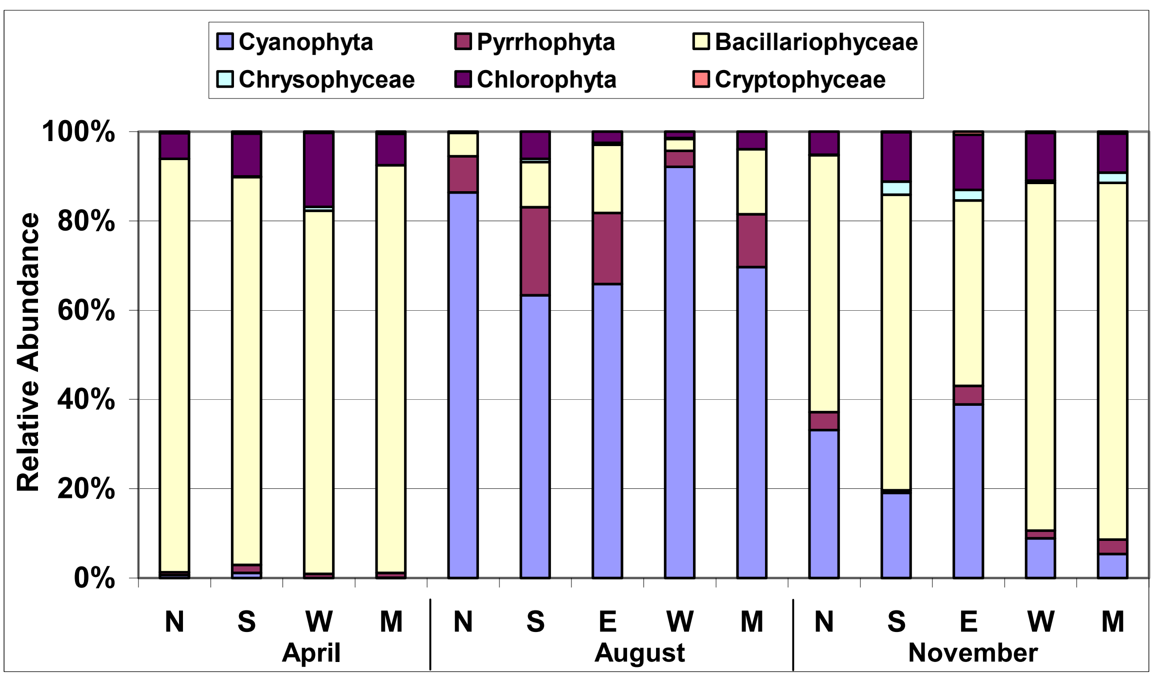
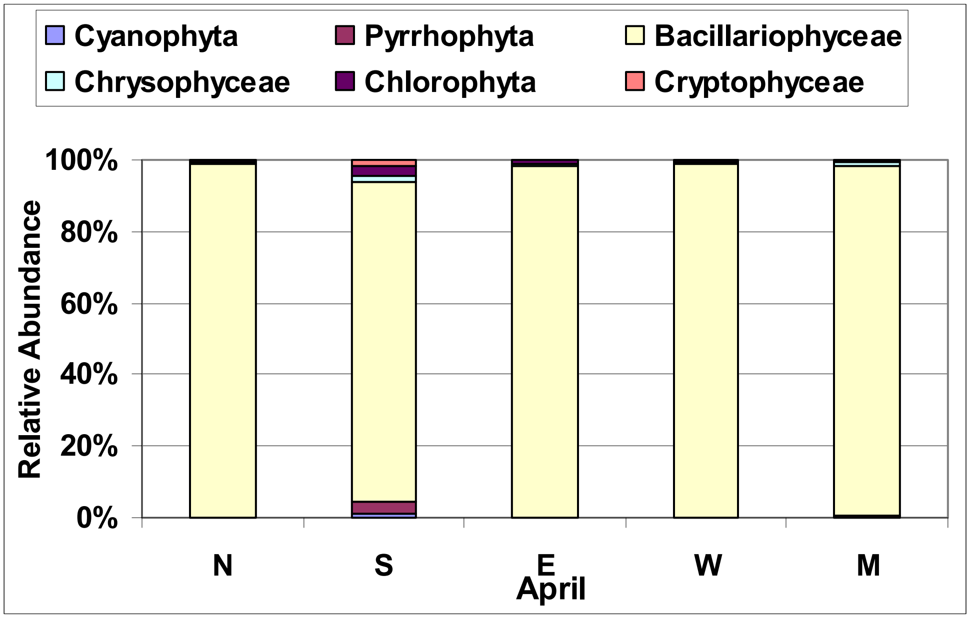


Fig. 5.33 Crowley Lake phytoplankton community composition during 2002.



Zooplankton

Sixteen species of zooplankton were enumerated in samples collected during spring, summer, and autumn surveys at five stations (Table 5.4).

Table 5.4 List of all zooplankton identified in Crowley Lake samples from May 31, 2000 to April 3, 2002.

Order Cladocera	*Daphnia pulex, Daphnia galeata mendotae, Ceriodaphnia quadrangula, Chydorus sphaericus, Leptodora kindtii, Alonella sp.*
Order Copepoda	*Leptodiaptomus tyrelli, Paracyclops fimbriatus poppei, Orthocyclops modestus,* nauplii
Phylum Rotifera	*Keratella quadrata, Keratella taurocephalus, Keratella cochlearis, Brachionus, Tetramastix, Filinia, Polyarthra*

Spring samples are dominated by the larger species of zooplankton (Table 5.5). In early April, the copepod *Leptodiaptomus tyrelli* and the cladoceran *Daphnia galeata mendotae* are dominant. *Daphnia pulex* succeeds *D. galeata mendotae* as the dominant cladoceran, possibly as early as May, but by the August sampling it is the smaller Rotifers which have become the dominant zooplankter. Species of the genus *Brachionus* are dominant in both summers at all stations with the exception of East. By fall, the copepod, *Leptodiaptomus tyrelli* coupled with the small cladoceran *Chydorus sphaericus* are dominant. Figs. 5.34 – 5.39 show abundance of zooplankton by species and by group.

Table 5.5 List of dominant two zooplankton species at each station for each sampling date.

Dominant/ 2nd dominant	Mid	West	North	South	East
May 31/00	*D. pulex* *L. tyrelli*	*L. tyrelli* *D. pulex*	*L. tyrelli* *D. pulex*	*D. pulex* *L. tyrelli*	*D. pulex* *L. tyrelli*
Aug 14/00	*Brachionus* *D. pulex*	*Brachionus* *D. pulex*	*Brachionus* *Chydorus*	*Brachionus* *Chydorus*	*D. pulex* *Paracyclops*
Nov 8/00				*L. tyrelli* *Chydorus*	*Chydorus* *L. tyrelli*
Apr 18/01	*L. tyrelli* *nauplii*	*D. mendotae* *L. tyrelli*	*D. mendotae* *nauplii*	*L. tyrelli* *K. quadrata*	
Aug 15/01	*Brachionus* *Ceriodaphnia*	*Brachionus* *D. pulex*	*Brachionus* *D. menotae*	*Brachionus* *D. pulex*	*Ceriodaphnia* *D. pulex*
Nov 7/01	*Chydorus* *L. tyrelli*	*L. tyrelli* *Chydorus*	*L. tyrelli* *Chydorus*	*Chydorus* *Paracyclops*	*Chydorus* *L. tyrelli*
Apr 3/02	*L. tyrelli* *nauplii*	*L. tyrelli* *D. mendotae*	*nauplii* *L. tyrelli*	*L. tyrelli* *K. cochlearis*	*K. quadrata* *nauplii*

While most species of cladocerans appear to be present throughout the year, their numbers indicate a pattern of succession. *D. galeata mendotae* starts out the season with relatively high numbers. It is succeeded by *D. pulex* whose numbers start to dwindle during the summer months and then increase slightly in the fall. However, the smallest species, *Chydorus sphaericus* increases steadily over the season. *Leptodora kindtii*, a large (up to 17 mm long) predatory cladoceran was captured in two samples in 2000. Due to its large size, it is likely fewer individuals co-exist in the water column. Therefore, it is quite possible it was present in the lake during 2001 and 2002 and simply avoided capture in the sampling nets. Similarly, one water mite (Hydracarina) was captured at the East station in August, 2000.

There are two copepod species present throughout the year. The calanoid *Leptodiaptomus tyrelli* is consistently among the top two dominants in the spring and fall. However, its numbers drop significantly during summer. The cyclopoid *Paracyclops fimbriatus poppei*, follows a similar seasonal pattern but is generally not as abundant as *Leptodiaptomus tyrelli*. A second cyclopoid, *Orthocyclops modestus*, was noted in a few samples but never in high abundance. The nauplii were counted but not separated by genera.

Rotifers also follow a seasonal pattern. *Keratella* spp. are the most numerous rotifers in the spring while *Brachionus* spp. become the dominant zooplankters throughout the summer. By fall, very few rotifers are present.

In terms of overall abundance, spring and fall tend to be higher than summer. Combine this with the trend for rotifers to dominate in the summer, we would expect to see a large decline in zooplankton biomass in summer months. The year 2001 showed the highest abundance of zooplankton during the spring and summer, however 2000 was higher in the fall.

In contrast to the zooplankton, overall biovolume of phytoplankton is highest during summer months. The year 2000 showed the highest biovolume with the exception of spring, 2002. The high biovolume in spring 2002 is mainly due to a bloom of the bacillariophyte, *Asterionella*. The high biovolume of diatoms may have been missed in 2000 due to the late sampling date (May 31 vs. Apr 3) (Figs. 5.40 – 5.42).

Fig. 5.34 Crowley Lake zooplankton community composition during 2000.

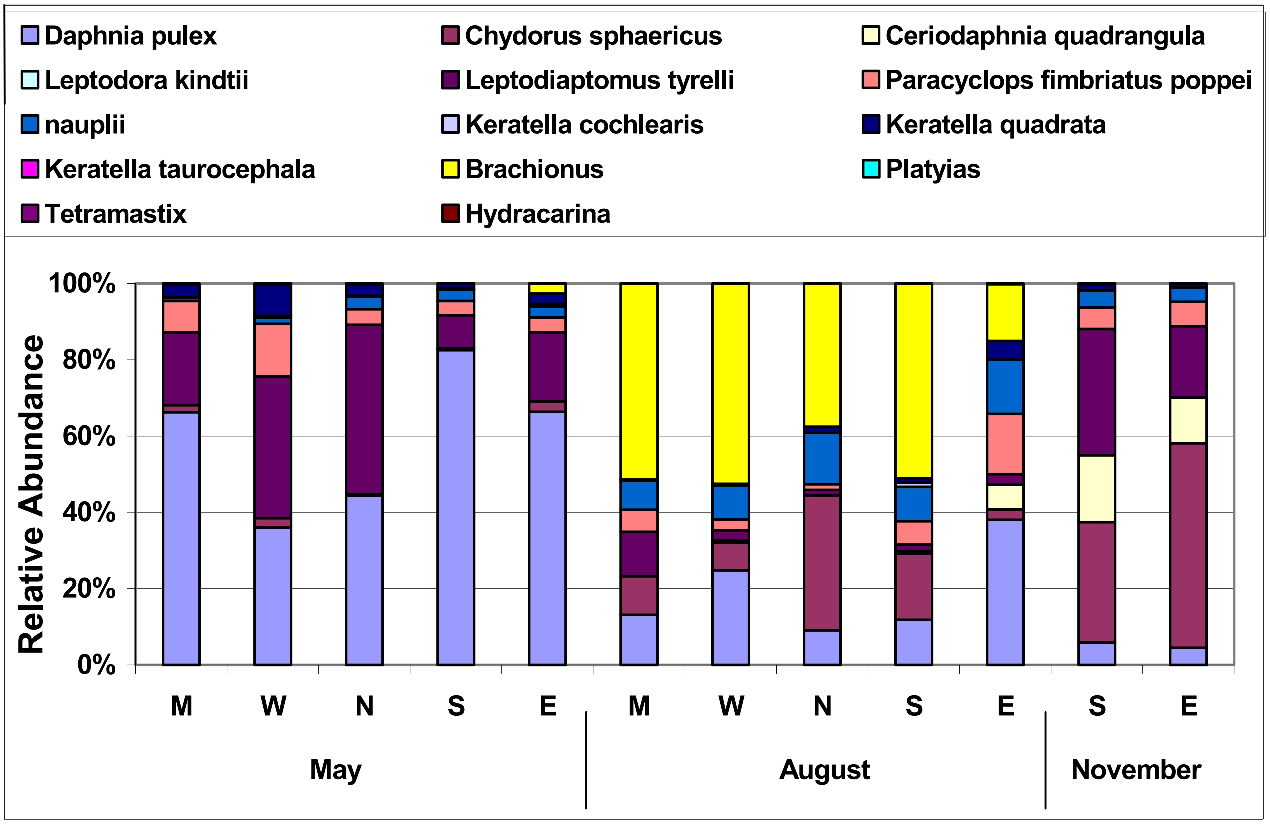


Fig. 5.35 Crowley Lake zooplankton community composition during 2001.

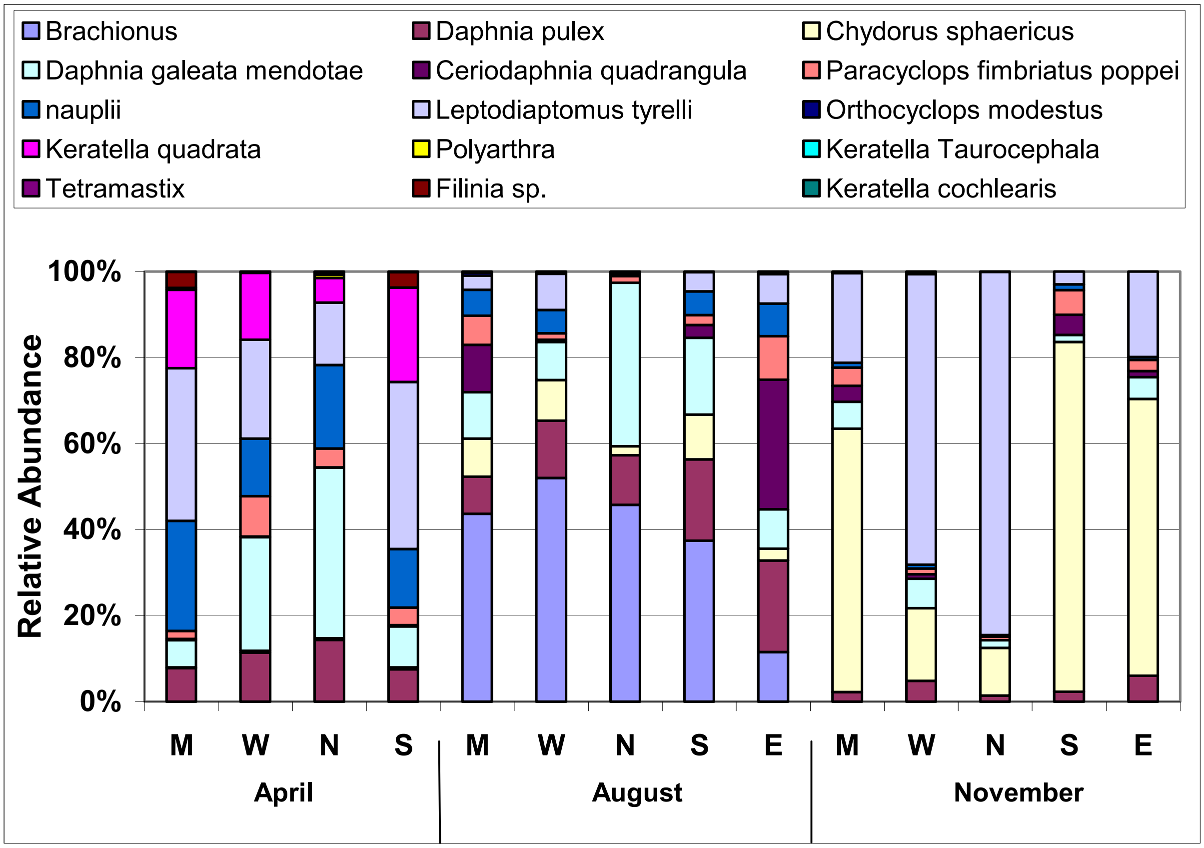


Fig. 5.36 Crowley Lake Zooplankton composition during April 2002.

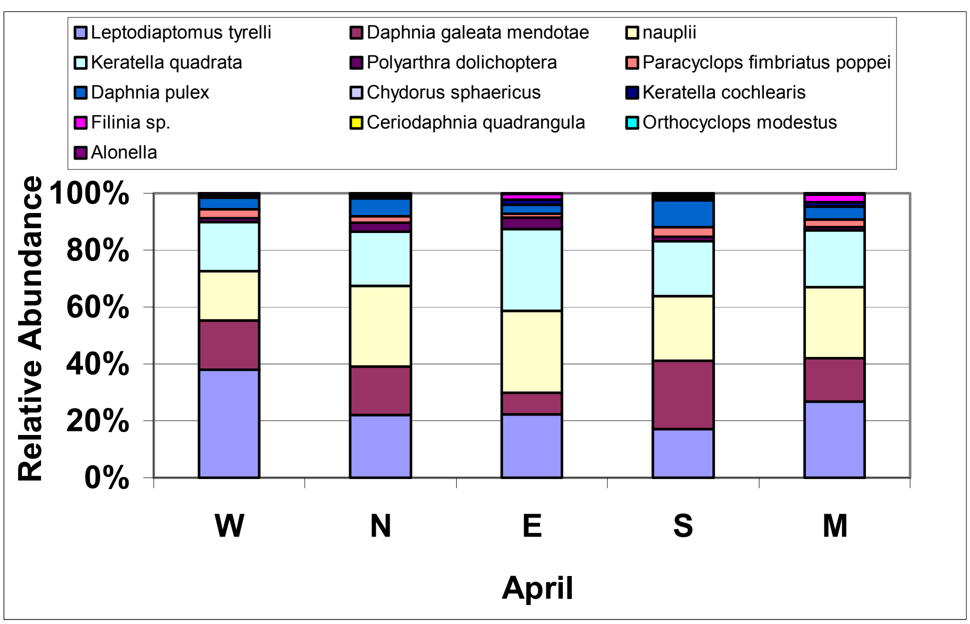


Fig. 5.37 Crowley Lake Zooplankton community by group, 2000

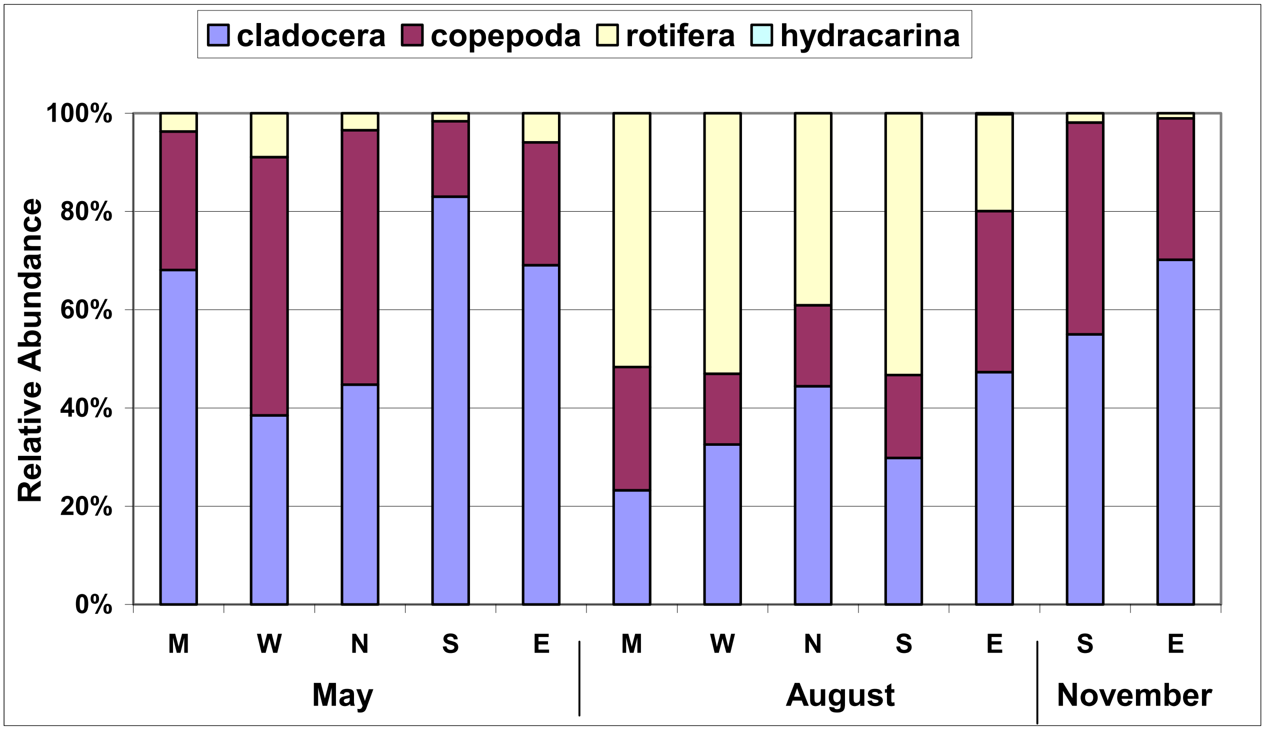


Fig. 5.38 Crowley Lake Zooplankton community by group, 2001

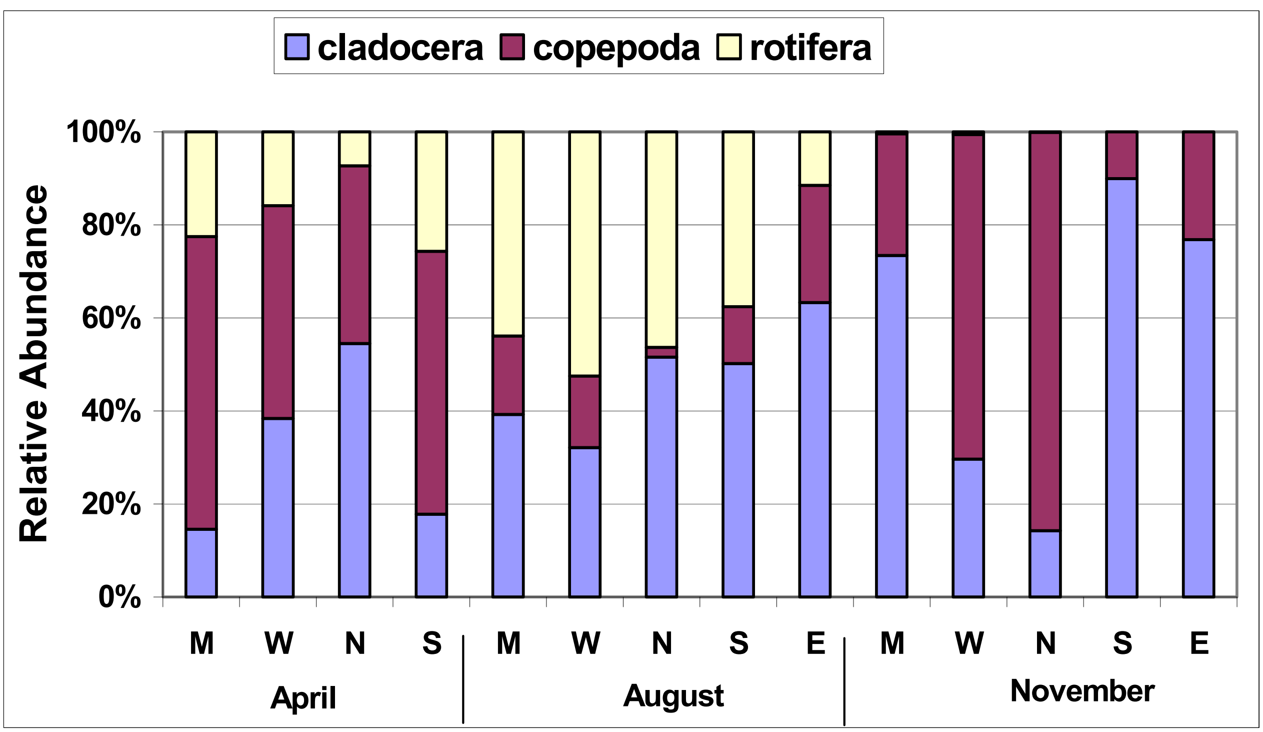


Fig. 5.39 Crowley Lake Zooplankton community by group, 2002.

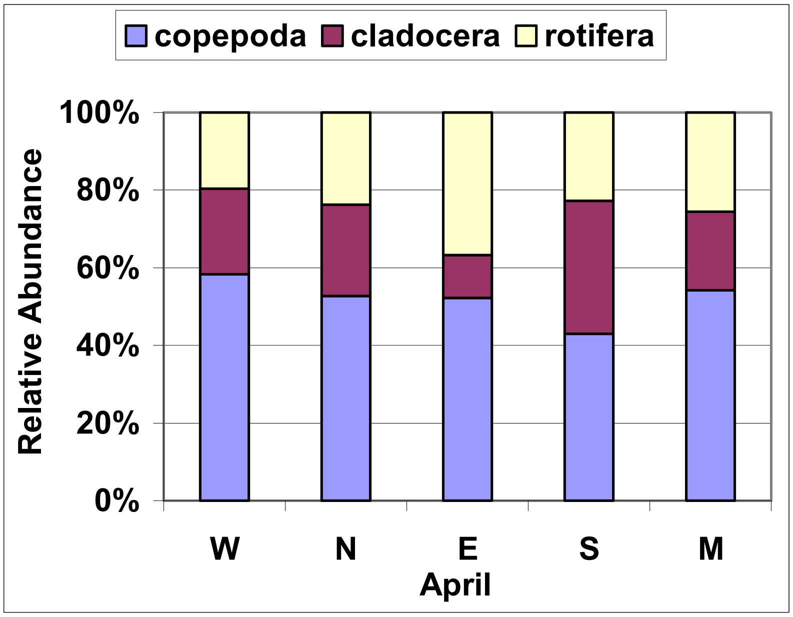


Fig. 5.40 Crowley Lake zooplankton abundance, 2000

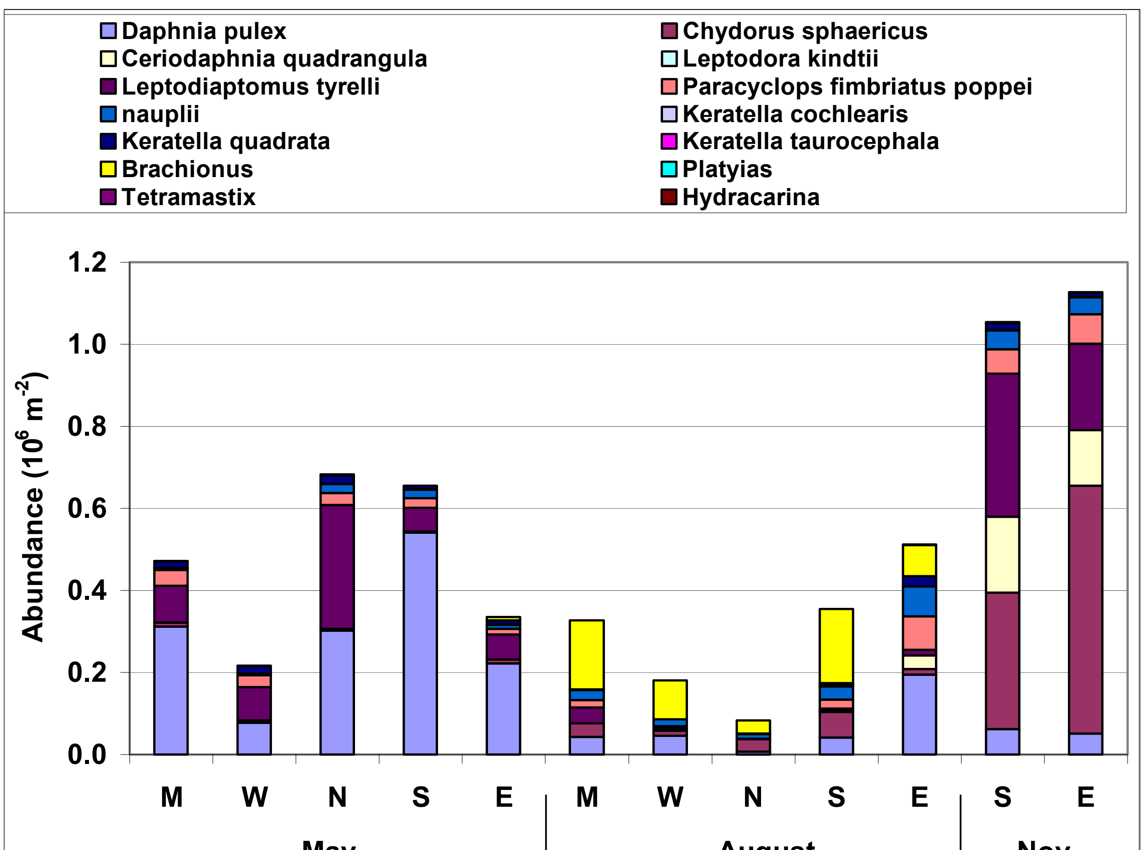


Fig. 5.41 Crowley Lake zooplankton abundance, 2001.

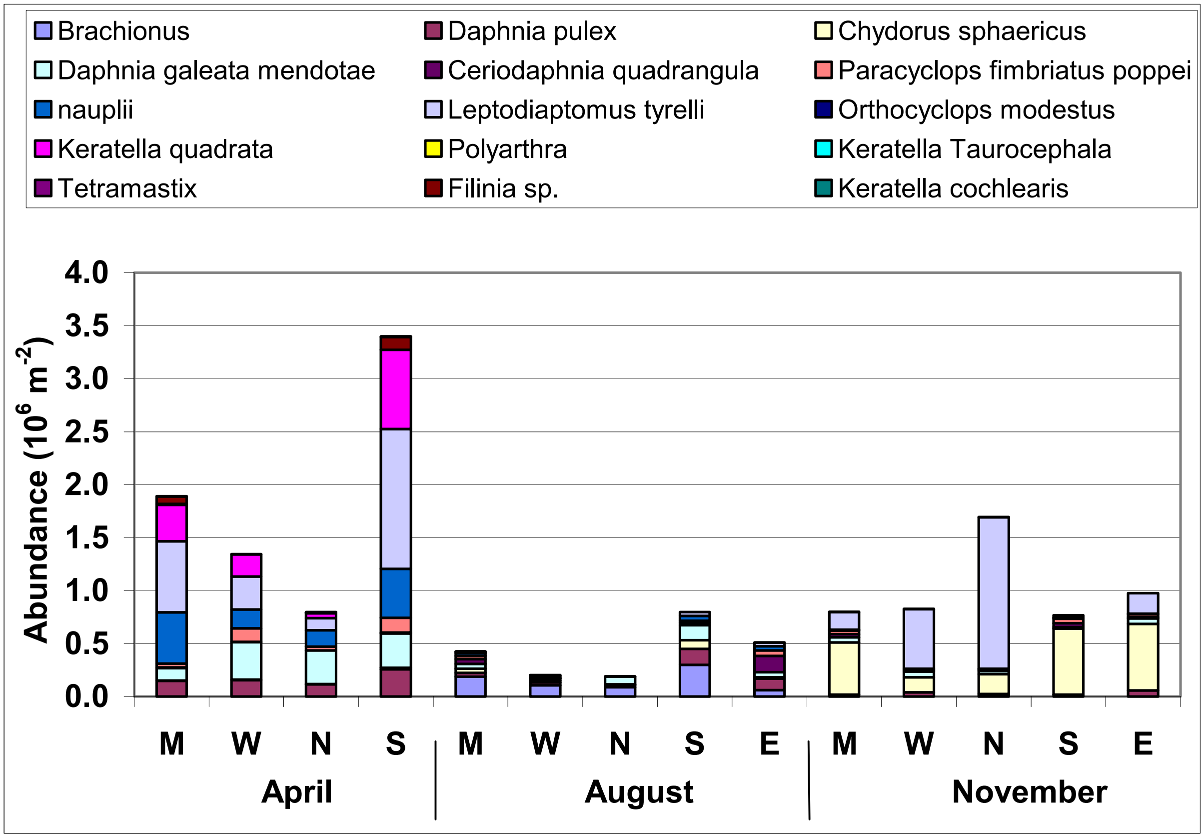
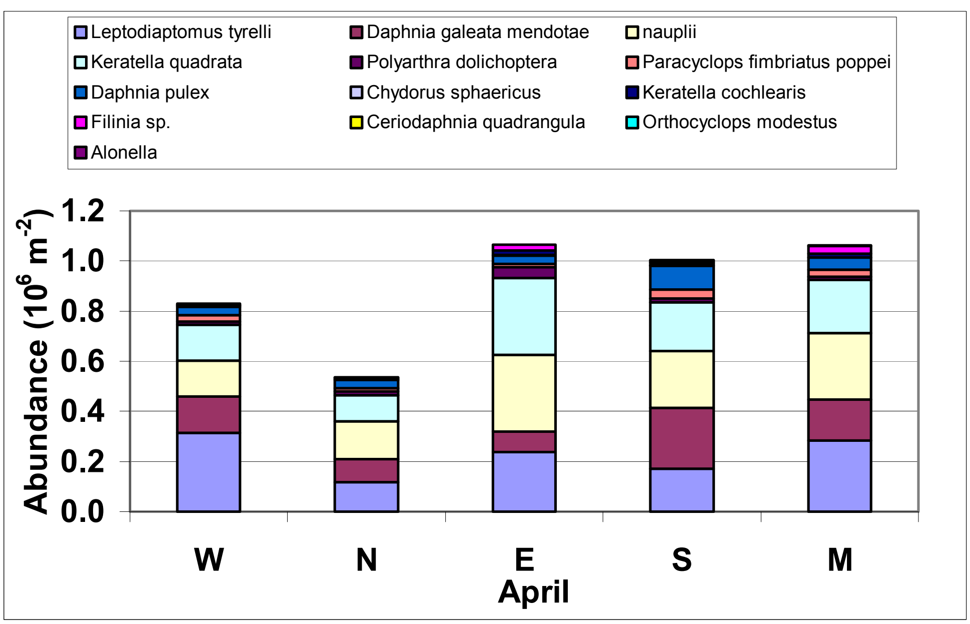


Fig. 5.42 Crowley Lake zooplankton abundance, 2002



Summary

Crowley Lake (Long Valley Reservoir) is located in southern Mono County in the Long Valley Caldera at an elevation of ~2062 m. Created in 1941 with construction of the Long Valley Dam, it is a moderately sized reservoir with an area of 15.6 km^2, volume of 0.135 km^3 and a mean depth of 8.6 m. The lake undergoes a regular seasonal pattern of thermal stratification typical of temperate, dimictic lakes. Ice cover disappears in late March – mid-April resulting in spring turnover and a brief period when the entire water column is well-mixed and near 4°C. Warming air temperatures and increasing insolation result in heating and the rapid onset of seasonal thermal stratification during April - early May. The epilimnion (upper mixed layer) warms rapidly during May through July, while the hypolimnion warms somewhat more slowly. With cooler air temperatures and decreased insolation, the epilimnion begins to cool in late August. Further cooling in autumn results in a period of mixing prior to becoming ice-covered in late December. Associated with this dimictic seasonal mixing regime are changes in the supply rates and availability of nutrients with consequent changes in phytoplankton community. The annual temperature regime was very similar during 2000 and 2001.

Eutrophic status

The concept of lake trophic status is multidimensional and includes measures of nutrient concentration and loading, transparency, chlorophyll, and floral and faunal composition. The most widely used trophic state indicators (TSI) are those developed by Carlson (1977) based on transparency, TP, and, chlorophyll. TSI values greater than 50 indicate eutrophic status. The mean June-October mixed-layer values for these three measures indicate the eutrophic state of Crowley Lake (Table 5.6).

Table 5.6 Mean mixed-layer trophic state indicators

Year	Transparency		TP		Chl a	
	Mean	TSI	Mean	TSI	Mean	TSI
2000	4.5	38	3.05 µM 94 µg l^{-1}	70	21.8	61
2001	3.6	42	3.24 µM 100 µg l^{-1}	71	21.7	61

In addition to these measures, the hypolimnion was anoxic below 12 m during August in both years and the phytoplankton community was dominated by cyanophytes including nitrogen-fixers. The transparency is greater than expected given the chlorophyll and TP concentrations; however, during both years transparency was reduced to near zero during occasional blooms.

Warner (1965) and EPA (1975) documented the eutrophic status of Crowley Lake based on chlorophyll and chlorophyll and phosphorus, respectively. The summer pattern and magnitude of chlorophyll *a* concentrations was remarkably similar to that observed at a deep water station in 1964 (Warner 1965). Cyanophyte blooms may be highly spatially and temporally variable and the three lakewide surveys conducted in 2000 and 2001 cannot be used to describe the relative frequency or magnitude of nuisance blooms. An assessment of this would likely require at least weekly sampling. Thus, while the seasonal chlorophyll concentration was similar to that described by Warner, we cannot assess whether Crowley Lake has become significantly more eutrophic in this period.

Given the low N:P ratios of inputs and the high overall rates of phosphorus loading to Crowley Lake, the sestonic (particulates lake) molar ratio of TN:TP was surprisingly high through much of the summer (range 9 – 36, mean 22.4) suggesting that nitrogen fixation or release of previously sequestered nitrogen from the sediments is making up the nitrogen deficit. In fact, N:P ratios greater than 23 are generally considered an indication of P-limited phytoplankton growth (Healy and Hendzel 1980). Molar carbon to nitrogen ratios of summer seston (planktonic particulates) in the upper 5 m ranged from 5.0 to 8.4 with a mean of 6.3, very close to the Redfield molar ration of 6.6 for balanced growth providing further evidence of nitrogen sufficiency (Wetzel, 2001).

Freshwater lakes are generally limited by phosphorus, in part, because nitrogen fixation by cyanobacteria (blue-green algae) is often able to relieve nitrogen limitation. The presence of heterocystic cyanobacteria in Crowley Lake, the recurring algal blooms, and the low N:P loading ratios all suggest nitrogen fixation will be an important part of the overall nitrogen budget. However, nitrogen fixation rates measured in pelagic samples during summer 2002 were relatively low (see Contract SWRCB #00-196-160-0) and could only account for a fifth of the imbalance between inputs and outputs observed during 2000 and 2001. However, algal blooms are highly variable and episodic; measured fixation increased on the 2002 September sampling with the appearance of the nitrogen-fixer, *Aphanizomenon flos-aquae* and *Aphanizomenon* has been reported previously in the lake always appearing late in the season (Melack and Lesack 1982, Warner 1965, EPA 1978). Thus, nitrogen fixation rates measured in 2002 may not accurately represent those occurring during 2000-2001.

CHAPTER 6: DATA MANAGEMENT

Data management, storage, and public access are critical components of environmental assessment projects. This project included design and implementation of a relational database and a geographical information system (GIS) of the Crowley watershed. Both products are being provided on CD-ROM along with this report.

Relational database

All data and metadata collected as part of this project are included in a relational database designed and implemented in Microsoft Access2002. This database (CrowleyWatershed.mdb) is being provided as a separate product on CD-ROM. All data adhere to the first three normal forms (Fig. 6.1).

CrowleyWatershed.mdb contains the following types of data:

- Physical, chemical, and biological limnological data
- Descriptive metadata (e.g., type of data, raw and source files, processing instructions, units of measurement, and status/description of quality of data)
- Information about the sampling locations
- Information about equipment and their maintenance and calibration
- Information about field and laboratory methods employed
- Information about people and organizations associated with the data

The core of the database is built around a flexible search routine (Fig. 6.2) that allows various types of queries and collating of data to be performed. Also, menu-driven search routines are provided for querying all the associated metadata. Further documentation is provided with the CD-ROM.

Crowley Watershed GIS

The Crowley Watershed GIS was implemented in ArcView3.2 and contains the location of each sampling station as well as a series of thematic layers to aid in interpretation. An example view indicates the spatial extent (Fig. 6.3). Provided thematic layers include:

Hydrologic units (Cal Water coverage)	USGS 7.5' quads
Spot orthophotos	USGS 1:24k stream and lake coverage
Land ownership	Elevation
LADWP hydrologic monitoring stations	All sample locations
Fencing locations	Irrigation improvement locations
Pictures of sampling locations	Roads

Documention of each coverage is provided on the CD-ROM.

Fig. 6.1. Data relationships within Crowley Watershed relational database.

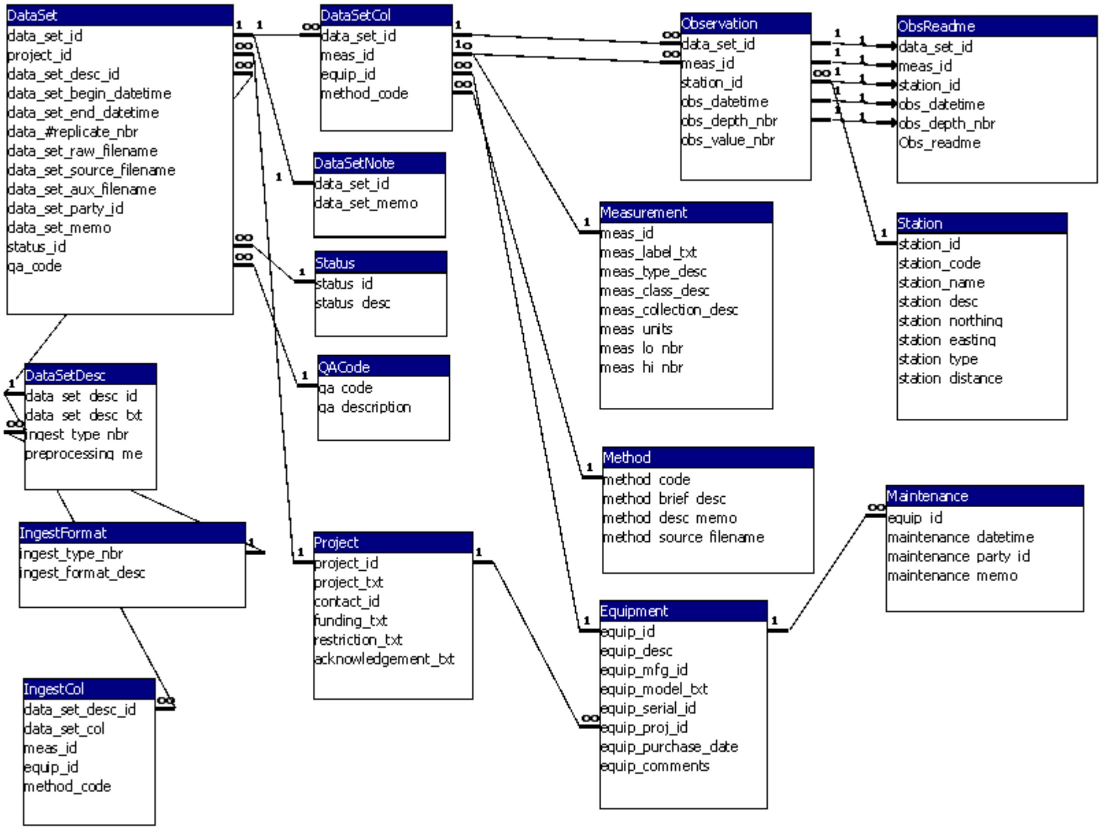


Fig. 6.2. Search routine in Crowley Watershed relational database.

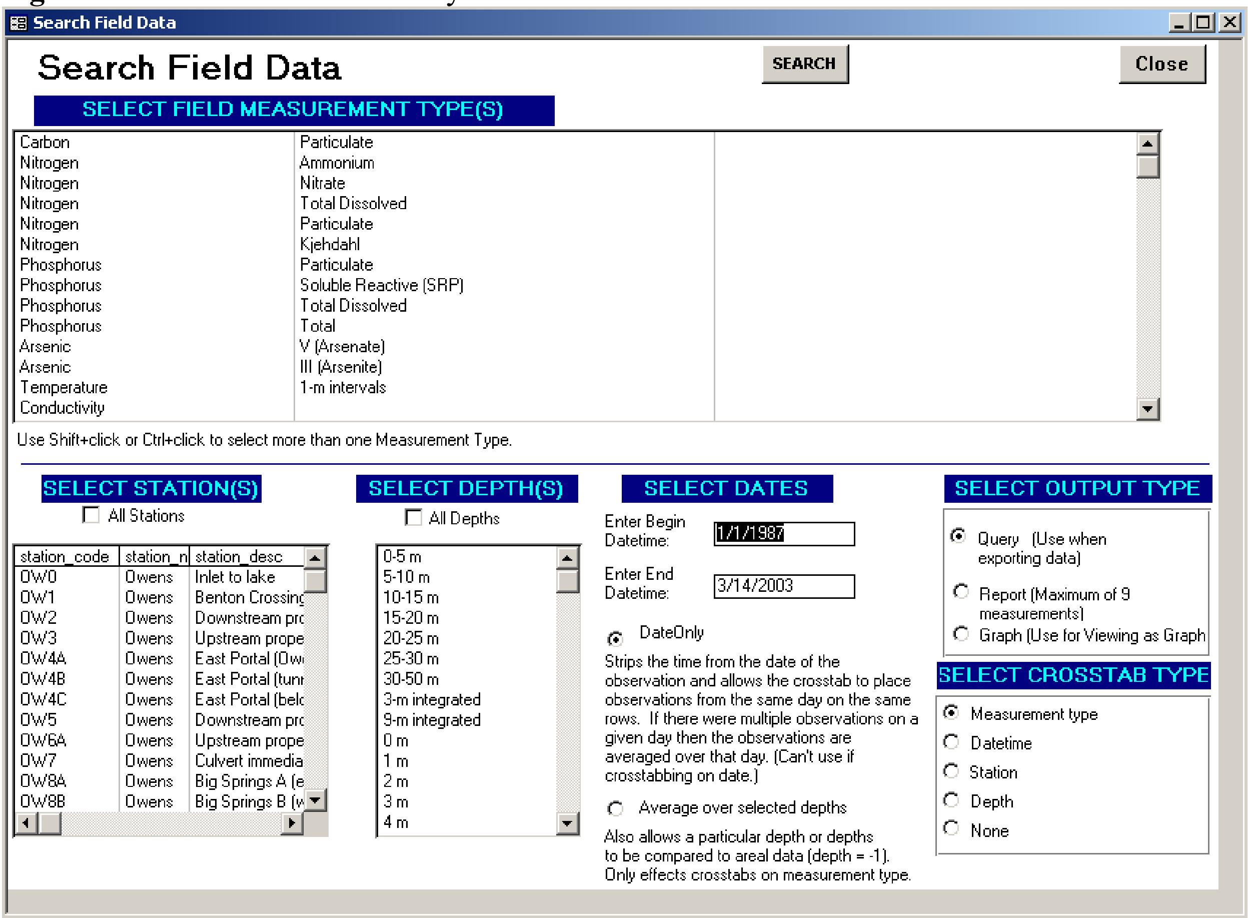
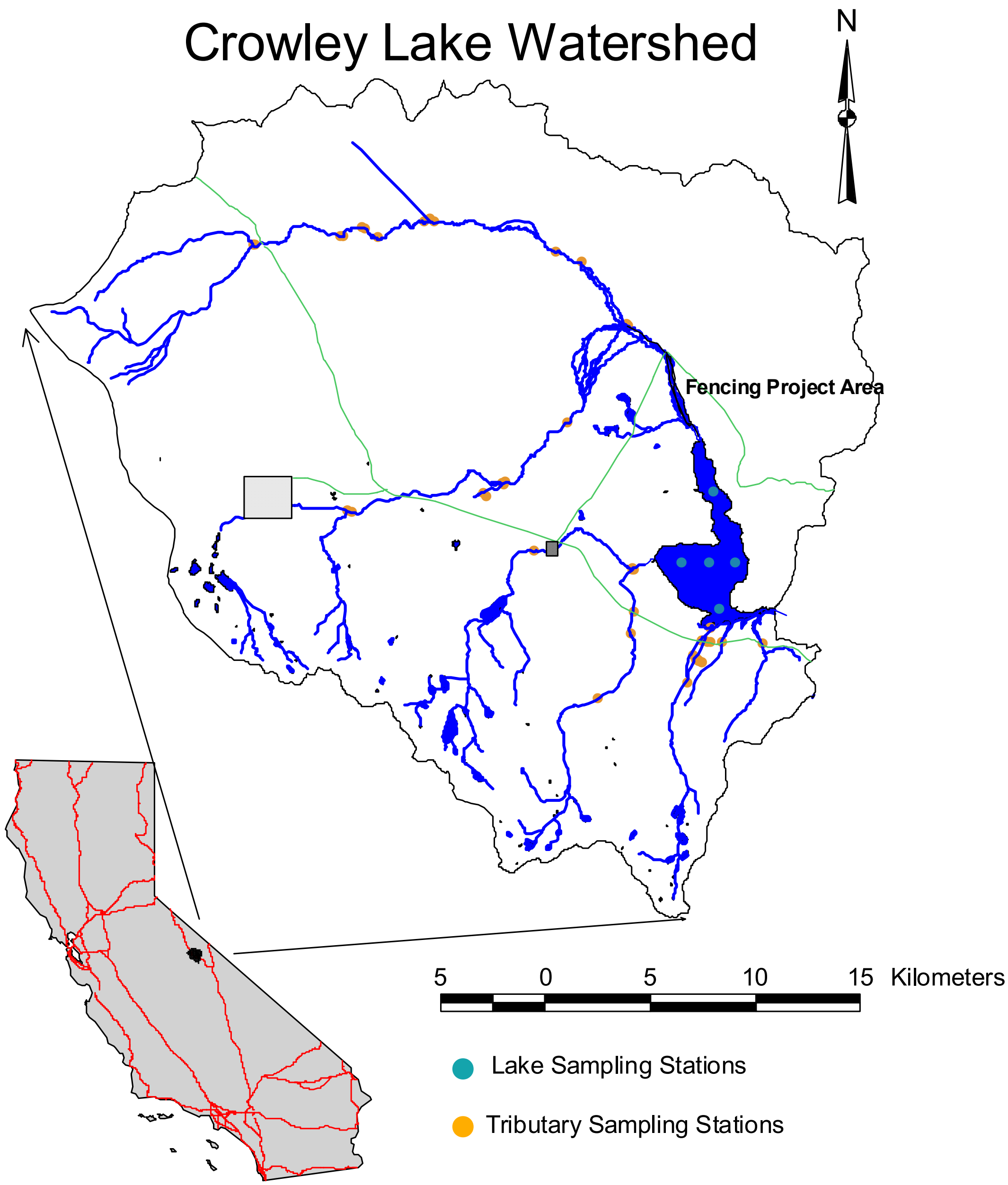


Fig. 6.3. View of Crowley Watershed GIS illustrating the spatial extent of the watershed.



APPENDIX A

TASK 3 PRODUCT for CONTRACT 9-175-256-0 ("CROWLEY WATERSHED RESTORATION")

R. Jellison and D. Dawson, University of CA, Santa Barbara – April 30, 2001

3. **TASK 3.** **Implementation of best management practices (BMPs) on the Owens River**

3.1 ***Construct riparian corridor fencing**:* Construct a fence along the Owens River riparian corridor from the Benton Crossing Road to the lake during the first year of the project (construction will be under subcontract to the City of Los Angeles). The fence will be constructed similar to existing fences above the Benton Crossing bridge and on Convict Creek. It will allow public access to all areas of the river through convenient access points.

3.2 ***Re-locate parking and provide controlled access points;*** Close roads within the project area and re-locate parking outside the area fenced in Task 3.1 above. This will reduce human impacts on the floodplain by controlling vehicle access in sensitive riparian areas.

3.3 ***Implement livestock management:*** Exclude livestock during the term of this contract. After the exclusion period, livestock will be allowed access in early summer, with use of 40% of the herbaceous vegetation. Then the livestock will be removed and excluded until the following year.

Task Products: "Before and after" photographs of 4.4-km riparian fenced area, access points, parking and irrigation improvements.

Tasks 3.1, 3.2, and 3.3 have been completed. Attached is the first part of the Task 3 Product, "before and after" photographs of the riparian fenced area. Photographs of the access points and parking will be in a following submittal.

The "before" photographs were taken in locations that we knew we could reproduce. At the time the photos were taken the exact location of the fencing had yet to be established. In fact, the exact location of the fencing was determined during installation. Consequently, the photo points may not be the most illustrative locations. However, they are more than adequate to demonstrate completion of the task.

Photo 1 is taken standing on the Benton Crossing abutment, looking downstream over the top section of the new fence.

Photo 2 is taken from the south end of Brown's Campground. The fence is visible along the left edge of the "after" photo.

Photo 3 is taken at a point midway along the fenced area, upstream of the lake-river divide, at a prominent fishing sign. The "after" photo is looking upstream over the corridor fence inside the fenced area.

Photo 4 is taken at the same general location as 3, just slightly upstream, looking downstream.

Photo 5 upstream of the lake-river divide near a prominent boulder. It is taken inside the fence. In the "after" photo the fence is visible along the opposite bank.

Photo 6 is taken approximately 200 yards downstream of the end of the fence. In the "after" photo the bottom end of the fence is barely visible in the upper right hand part of the picture.

All photo locations as well as the fence boundary have been located by GPS and will be reflected in the project GIS.

Owens River 1 From Bridge at Benton Crossing Road Downstream (OW1)

May 22, 2000

April 24, 2001

Owens River 2 From South Point of Brown's Campground

May 22, 2000

April 24, 2001 – Taken from inside the fence

Owens River 3 From River-Lake Divide Upstream (Upper Owens River Fishing Monument)

May 22, 2000

April 24, 2001

Owens River 4 From River-Lake Divide Downstream (Upper Owens River Fishing Monument)

May 22, 2000

April 24, 2001

Owens River 5 Just North of Mouth Upstream

May 22, 2000

April 24, 2001 – Taken from inside the fence

Owens River 6 Near Mouth Upstream (OW0)

May 22, 2000

April 24, 2001 – Approximately 200 yds. downstream from the end of the fence

Owens River 7 at Mouth Facing Downstream

May 22, 2000

April 24, 2001– Approximately 200 yds. downstream from the end of the fence

APPENDIX B

Quarterly Report Attachment A
Contract 9-175-256-0: "Restoration of Riparian Habitat and Assessment of Riparian Corridor Fencing and Other Watershed Best Management Practices on Nutrient Loading and Eutrophication of Crowley Lake, California"

Tasks 3.4 and 3.5 of the contract Scope of Work state:

3.4 ***Repair and/or adjust riparian fence. Install additional gates or parking*:** Make adjustments to fencing and parking areas as necessary within one year following construction of fencing and re-location of parking areas. These may include repair of fencing, moving sections of fence, constructing new gates for public access, or constructing new public parking areas. The need for such action will be based on results of Task 4 below.

3.5 ***Install irrigation and water measuring improvements to reduce return flows*:** Reduce irrigation return flows by improving existing, or constructing new, water diversion structures and measuring devices to allow more precise irrigation flows.

These tasks were completed late in summer, 2002. The following shall document task completion. Irrigation improvements in the Upper Owens River watershed are within Chance Ranch along Mammoth Creek (Figure 1).

Figure 1, Irrigation Improvements

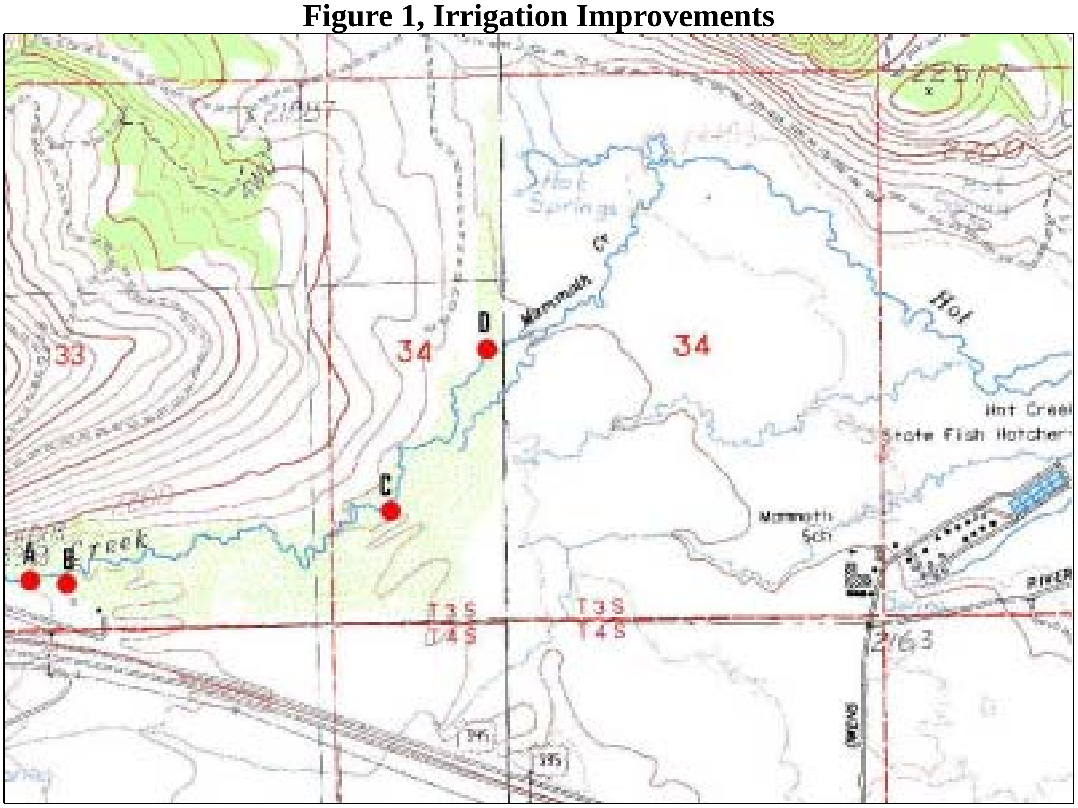


Figure 2: Location A

Location A (Figure 2) is at a point on Mammoth Creek at the upstream end of Chance Ranch. The main channel of the creek is heading off to the left (south) while a very old irrigation channel, which captures most of the flow is heading off to the right (north). Because of siltation in the main channel, down cutting in the irrigation channel, and the difficulty of getting to this location there is no good way to construct improvements here to allow more water to flow in the main channel. The solution to this problem was to build a new structure approximately 100 m downstream on the irrigation ditch at location B (Figure 3).

Figure 3: Location B

This structure allows water diversion out of the irrigation ditch into a new channel that returns it south to Mammoth Creek. Better control of the volume of flow in the irrigation ditch is critical to prevention of return flows to Mammoth Creek.

At location C (Figure 4) another irrigation improvement structure was constructed with contract funds. The concrete structure allows precise delivery of water from Mammoth Creek into an irrigation ditch. The new structure replaces a very old wooden structure that allowed excess water to pass into the ditch, even when closed.

Figure 4: Location C

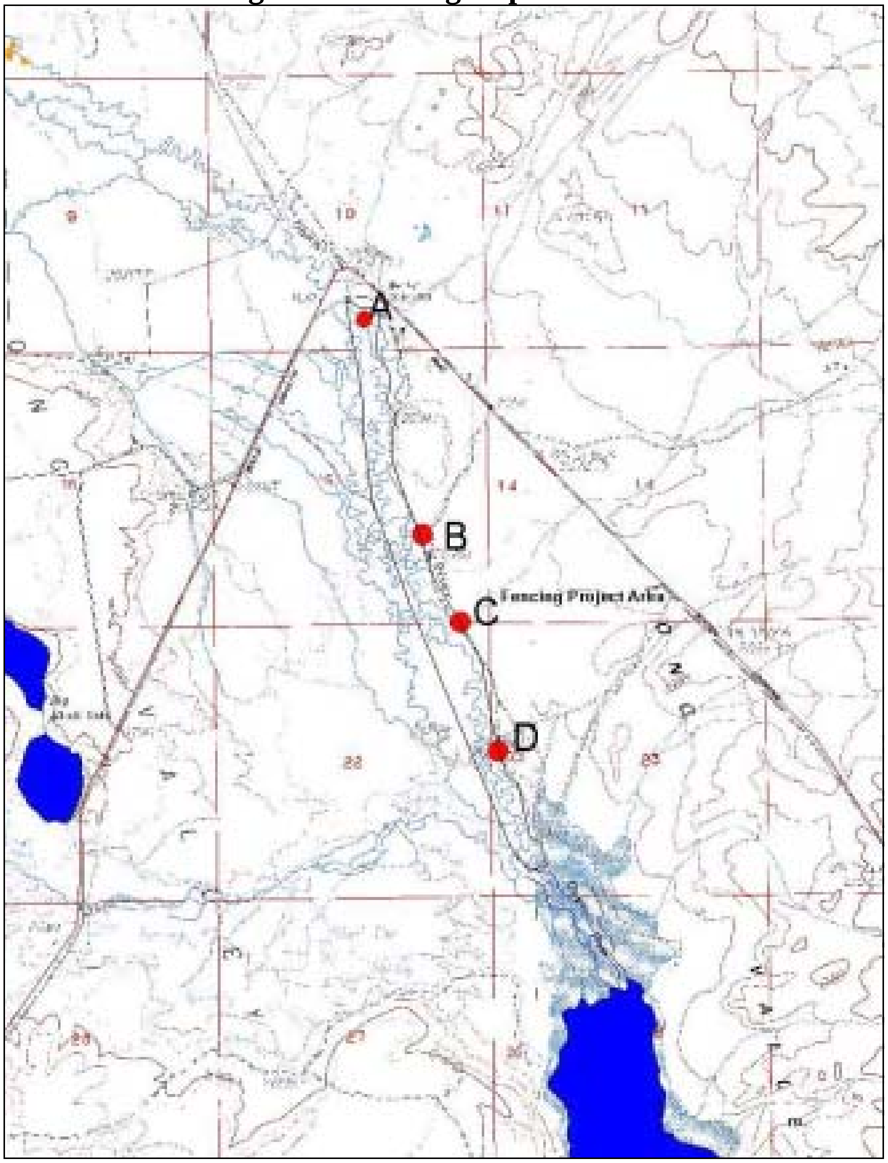
Location D (Figure 5) has a newly constructed wing wall and irrigation gate. At this location Mammoth Creek is making a sweeping turn to the right (from north to east). A very old wooden structure was replaced. The old structure allowed considerable water to pass into the ditch at all times.

Figure 5a: Location D

Figure 5b: Location D

Fencing changes and improvements were built in that portion of the Upper Owens River Watershed directly upstream from Crowley Lake (Figure 6).

Figure 6: Fencing Improvements



Location A (Figure 7) is a simple improvement to a pedestrian walk-through on the Owens River fence directly below Benton Crossing. The wooden fence rails were extended over the bank to prevent cattle from moving downstream into the fenced area. There is no photograph to document the change at location B. This was not a fence improvement but rather the original construction of the fence was rerouted to protect a population of *Astragalus johannis-howellii*, the Long Valley milkvetch (Figure 8). The fence was moved further from the river to move the plants inside. This required the relocation of a section of road and the ripping of the old road.

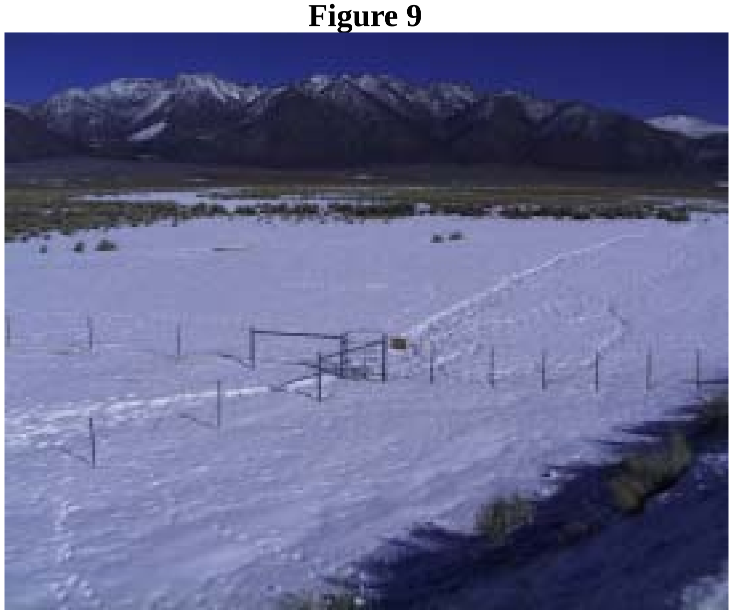
Figure 7: Location A

Figure 8: Long Valley Milkvetch

Location C on Figure 6 is the location of a walk-over ladder constructed over the fence. There is no photograph to document this improvement. This was at a location where people were parking and climbing over or through the fence to gain access to the river. It was far from any constructed corner or pull point so it was not practical to install a gate.

Figure 9 illustrates a typical improvement that was made throughout the newly fenced area. A typical location is indicated in Figure 6 as D. As fishermen were not properly closing gates a modification was made to all the gates to make them self closing. While you can't actually see the improvement itself in the photograph it was made consistently to all gates in the newly fenced area.

Figure 9



APPENDIX C – SCOPE OF WORK

SWRCB No. 9-175-256-0
The Regents of the University of California
University of California, Santa Barbara

EXHIBIT A-SCOPE OF WORK SWRCB

SWRCB-EXA (#/#/00)

1. PROJECT OFFICIALS:

The State Water Board's Contract Manager shall be Cindy Wise of the Lahontan (Region 6) Regional Water Quality Control Board staff. The Contract Manager shall be the day-to-day representative for administration of this agreement, and, except as otherwise specifically provided, shall have full authority to act on behalf of the State Water Board with respect to this agreement. The State Water Board's Executive Director, or designee, may perform any and all acts that could be performed by the Contract Manager under this agreement. Except as otherwise expressly provided, all communications relative to this agreement shall be given to the Contract Manager.

The Contractor's Project Director shall be Robert Jellison. The Project Director shall be the Contractors representative for the administration of the agreement and shall have full authority to act on behalf of the Contractor. All communications given to the Project Director shall be as binding as if given to the Contractor.

The parties may change their Contract Manager or Project Director upon providing ten (10) days written notice to the other party.

2. WORK TO BE PERFORMED:

A. Scope and Objectives:

Crowley Lake (Long Valley Reservoir), Mono County is a valuable aquatic resource whose management requires the balancing of competing economic, recreational, and ecological values. Crowley Lake is the premier trout fishery in the eastern Sierra Nevada as well as the largest reservoir in the Los Angeles aqueduct system. The lake is classified as eutrophic, meaning a lake with both an ample supply of nutrients and high rates of primary productivity. The watershed is subject to a wide array of uses including cattle grazing, fishing, snow skiing, camping, and urban development, all of which may be contributing to nonpoint source pollution and increased eutrophication of Crowley Lake. In addition, several large springs flowing into the lake's tributaries have high concentrations of phosphorus. Adverse impacts of increased eutrophication at Crowley Lake include de-oxygenation of bottom water, downstream fish kills, and decreased water quality as indicated by taste, odor, and large areas of floating algal mats.

The purpose of the work covered by this contract is to restore a substantial length of the main tributary (Owens River) immediately upstream of Crowley Lake by 1) implementing BMPs to reduce or prevent pollution from discharges associated with livestock grazing, irrigation, recreation, boating and physical habitat alteration; 2) determining the effectiveness of the restoration and BMPs by measuring a variety of recover parameters both upstream and downstream of the restoration site; 3) implementing a preliminary TMDL strategy for the watershed including monitoring and re-evaluation of the strategy; and 4) providing technology transfer, technical assistance and public education.

Crowley Lake is 'listed' for nutrients per Section 303(d) of the federal Clean Water Act, and is a TMDL priority for the Regional Water Quality Control Board. Although a TMDL is not yet in place, the preliminary TMDL strategy for the waterbodies listed in this watershed includes implementation of BMPs geared toward reducing nutrients from nonpoint sources. The restoration strategy in this project will serve this purpose, and thus implements the preliminary TMDL strategy. Another aspect of TMDL implementation included in this project is the step of monitoring and re-evaluation. Because the preliminary TMDL strategy for the CWA 303(d)-listed waterbodies in this watershed is based on implementing more of the same types of BMPs that are already in place and that are included as part of this project, an evaluation of the effectiveness of the various treatments is essential. There is evidence that some of these BMPs (e.g., fencing, revised grazing strategies) have made improvements in riparian habitat, but it is unknown if there have been similar improvements in water quality. One component of this project will use water quality monitoring to evaluate the effectiveness of the various treatments.

This project entails close cooperation between the principal private landowner in the Crowley watershed (City of Los Angeles) and the Valentine Eastern Sierra Reserve (University of California) also located in the watershed. The Los Angeles Department of Water and Power and University of California are providing 32.6% and 12.2% matching funds, respectively.

This project specifically addresses six priority activities identified by the Lahontan Regional Water Quality Control Board in its Watershed Management Initiative (WMI) Planning Chapter. It will provide critical information useful to the landowner and operator in evaluating their BMPs, and to the Lahonton Board in implementing its WMI.

B. Work to be Performed:

The Contractor shall be responsible for the performance of the work as set forth herein below and for the preparation and submittal of products and final reports as specified in this Exhibit. The Project Director shall promptly notify the Contract Manager of any events or proposed changes that could affect the scope, budget, or schedule of work performed under this agreement.

1. **TASK 1: <u>Project Management and Administration</u>**

1.1 Provide all technical and administrative services as needed for contract completion; monitor, supervise and review all work performed: and coordinate budgeting, scheduling, contract and subcontract administration to assure that the contract is completed within budget, on schedule, and in accordance with approved procedures, applicable laws and regulations.

1.2 Ensure that contract requirements are met through completion of quarterly progress reports submitted to the Contract Manager by the 10th of the month following the end of each calendar quarter (March, June, September and December) and through regular communication with the Contract Manager. The quarterly progress reports shall describe activities undertaken and accomplishments of each task during the quarter, milestones achieved, and any problems encountered in the performance of the work under this contract. The description of activities and accomplishments of each task during the quarter shall be in sufficient detail to provide a basis for payment of invoices and shall be translated into percent of task completed for the purpose of calculating invoice amounts.

1.3 Complete a one-page contract summary form (form to be provided by the State Water Board) within three months of the contract execution.

1.4 Document steps taken in soliciting and awarding the subcontract and submit them to the Contract Manager for review.

1.5 Secure all required permits for project work including but not necessarily limited to U.S. Corps of Engineers 404 permit and Department of Fish and Game Stream Alteration Agreement.

1.6 At the completion of this project and prior to final payment, the Project Director shall fill out and provide a project survey form to the Contract Manager.

<u>Task Products</u>: Quarterly Progress Reports, subcontract documentation, project survey form, contract summary, permits

2. **TASK 2: <u>Project Planning, Design, Meeting of Cooperating Agencies and Stakeholders</u>**

2.1 ***Conduct project planning****:* Hold a meeting with cooperating agencies (RWQCB, City of Los Angeles, Fish & Game, Mono County, Long Valley Hydrologic Advisory Committee, Mono

County Collaborative Planning Team, Inyo National Forest, Alpers Owens River Ranch, Wood Ranches). Stakeholders who are not participating as cooperating agencies will also be invited to attend this meeting. Note that the City of Los Angeles owns a major portion of the lands in the Crowley watershed.

At this meeting, inform all cooperating agencies of the timing and scope of work, solicit design input with regard to the exact location of monitoring sites, and initiate data sharing arrangements. The number and general locations of individual sampling stations are described below. While the number of sampling stations shall not be decreased, one to several additional stations may be considered if deemed necessary and appropriate by meeting participants. The exact location (within 5 m) of individual sampling stations will be based on site characteristics and input from meeting participants. These final sampling sites are subject to mutual agreement between the Project Director and the Contract Manager.

2.2 ***Prepare QA Plan*****:** Prepare and maintain a Quality Assurance Plan (QAP) in accordance with the EPA QAP Plans for Environmental Data Operations, QA/R5 Interim Final 5/94, where applicable. The QAP shall be approved by the Contract Manager <u>prior</u> to the implementation of any sampling or monitoring activities.

2.3 ***Compile existing data*****:** Compile existing water quality data for Crowley Lake watershed

<u>Task Products</u>: QA Plan, preliminary database, meeting minutes, list of selected sites.

3. **TASK 3. <u>Implementation of best management practices (BMPs) on the Owens River</u>**

3.1 ***Construct riparian corridor fencing****:* Construct a fence along the Owens River riparian corridor from the Benton Crossing Road to the lake during the first year of the project (construction will be under subcontract to the City of Los Angeles). The fence will be constructed similar to existing fences above the Benton Crossing bridge and on Convict Creek. It will allow public access to all areas of the river through convenient access points.

3.2 ***Re-locate parking and provide controlled access points;*** Close roads within the project area and re-locate parking outside the area fenced in Task 3.1 above. This will reduce human impacts on the floodplain by controlling vehicle access in sensitive riparian areas.

3.3 ***Implement livestock management:*** Exclude livestock during the term of this contract. After the exclusion period, livestock will be allowed access in early summer, with use of 40% of the herbaceous vegetation. Then the livestock will be removed and excluded until the following year.

3.4 ***Repair and/or adjust*** r***iparian fence. Install additional gates or parking*****:** Make adjustments to fencing and parking areas as necessary within one year following construction of fencing and re-location of parking areas. These may include repair of fencing, moving sections of fence, constructing new gates for public access, or constructing new public parking areas. The need for such action will be based on results of Task 4 below.

3.5 ***Install irrigation and water measuring improvements to reduce return flows*****:** Reduce irrigation return flows by improving existing, or constructing new, water diversion structures and measuring devices to allow more precise irrigation flows.

<u>Task Products</u>: “Before and after” photographs of 4.4-km riparian fenced area, access points, parking and irrigation improvements.

4. **TASK 4. <u>Determining the effectiveness of best management practices (BMPs)</u>**

4.1 ***Establish baseline conditions of riparian corridor****:* Conduct riparian monitoring immediately following installation of riparian fencing along the Owens River from Benton Crossing to Crowley Lake (see Task 3 above). Establish three monitoring sites to characterize baseline using vegetation transects, physical and micro-habitat measurements, fish censusing via snorkeling, and photo-monitoring plots.

4.2 ***Monitor effectiveness of riparian fencing****:* Conduct riparian monitoring along the Owens River from Benton Crossing to Crowley Lake during the second year of the project. At the three monitoring sites in Task 4.1, conduct the same set of measurements used to establish baseline conditions.

4.3 ***Establish the sources and magnitude of nutrient inputs to Crowley Lake:*** Determine annual nutrient loading to Crowley Lake through biweekly sampling of tributary inflows during the spring-summer period (May-September) and monthly the rest of the year. Tributaries include the Owens River, and McGee, Convict, Hilton, Whiskey, and Crooked Creeks.

Sample at the following tentative sampling stations: **Owens River** where it enters the lake; near entry to the lake of the **combined McGee and Convict Creeks** (The two merge 1.6 km west of the lake); **Hilton Creek** (The creek divides into multiple channels for irrigation that then merge into two channels that flow into the lake. Both of these channels will be sampled at the lakeshore); **Whiskey Creek** at the lakeshore; **Crooked Creek** at the lakeshore; and the **lake outflow.**

Analyze samples from each of the seven sites for ammonia-ammonium (NH_3 plus NH_4^+), nitrate, dissolved inorganic phosphate, total nitrogen, and total phosphorus. Measure water temperature, pH, and dissolved oxygen during sample collection.

Calculate watershed nutrient loading to the lake. In the calculation, use sample analyses results and the extensive streamflow monitoring regularly conducted by the City of Los Angeles DWP along the major tributaries to the lake. Use measurements of atmospheric deposition (wet and dry fall) taken at the U.C. Sierra Nevada Aquatic Research Laboratory to include in the watershed nutrient loading determination.

4.4 ***Assess the contribution of various land use practices to the nutrient loading of Crowley Lake***:, Conduct three longitudinal surveys during each year of the project to determine whether there are measurable effects of different land-use practices on in-stream nutrient concentrations. At 22 additional sampling stations (tentative locations described below) which were selected based on different land-use patterns, conduct the same sample analyses and measurements described in Task 4.3 above.

The following are tentative sampling stations:

Six sampling sites along the **Upper Owens River** -- these are **Deadman Creek at Highway 395** (the creek drains the most northern watershed of the Owens River, lies within Inyo National Forest, and runs through both logged and un-logged parcels of mixed coniferous and Jeffrey Pine forests); just **above and below the inflow of Big Springs** into Deadman Creek (about 4.2 km downstream from the highway, the Owens River originates where Big Springs flow into Deadman Creek); at the **private/public land border and at Benton Crossing** [From Big Springs to Benton Crossing (effectively the Owens River inlet to Crowley Lake), the dominant land-use is grazing first on private lands and then within the National Forest. Samples]; and at the **Mono Craters tunnel outflow** to the river (Approximately 1.2 km below Big Springs, the Mono Craters tunnel delivers water from the Mono Basin as part of the Los Angeles Aqueduct system. While this flow has been recently reduced to allow restoration in the Mono Basin, flows will increase once Mono Lake reaches its target elevation) [Note: Sampling may occur at several additional stations along the Upper Owens River. These stations will be selected prior to commencement of the sampling portion of the project following consultation with private landowners and land management agencies.] **Mammoth Creek above and below the Town** of Mammoth Lakes (Below Big Springs the next major tributary is Hot Creek which originates from springs at the Hot Creek State Fish Hatchery. Mammoth Creek flows into Hot Creek below the hatchery. The headwaters of Mammoth Creek originate in the Mammoth Lakes basin just west of the Town of Mammoth Lakes. Mammoth Creek will be sampled above and below the town to isolate its contribution to the nutrient load); **Mammoth Creek just upstream from its confluence with Hot Creek** (Between the city of Mammoth Lakes and Crowley Lake, the predominant land-use adjacent to the Hot Creek is grazing. However, the Hot Creek fish hatchery and a series of large thermal springs are located in this reach. Samples are collected from Hot Creek hatchery under an NPDES permit. This data will be incorporated into the nutrient budget. Samples will be taken in Mammoth Creek just upstream from its confluence with Hot Creek and in Hot Creek downstream of the thermal area); **Convict Creek at Convict Lake outflow, above and below the University of California's Sierra Nevada Aquatic Research Laboratory (SNARL), and just above the confluence with McGee Creek**

(Convict, McGee, and Hilton Creeks all originate in steep basins of the Sierra Nevada immediately west of Crowley Lake. Land-uses along these creeks include recreational campgrounds, commercial pack stations, residential development, and horse and cattle grazing pastures. Sampling sites along Convict Creek will include Convict Lake outflow, above and below the University of California's Sierra Nevada Aquatic Research Laboratory (SNARL), and just above the confluence with McGee Creek. This will delineate any effects of the campground on Convict Creek, and grazing below SNARL); **McGee Creek above and below the campground, below the residential development (at Highway 395), and above and below the confluence with Convict Creek**. (McGee Creek has a pack station and campground above an area of residential development before entering irrigated pasture in Long Valley. Samples will be taken above and below the campground, below the residential development (at Highway 395), and above and below the confluence with Convict Creek.) **Hilton Creek above the residential development, at two sites below, and where the two distributaries enter the lake** [Of the three tributaries, Hilton Creek has the largest area of residential development. Samples will be taken above the residential development, at two sites below (the creek is split into two distributaries), and where the two distributaries enter the lake]

The exact location of final sampling sites shall be selected based on mutual agreement between the Project Director and the Contract Manager.

4.5 ***Conduct event-oriented sampling***: Conduct approximately 10-15% event-oriented sampling in addition to the sampling described above. Include sampling during initial snowmelt at Mammoth Lakes, immediately after any precipitation events, and at irrigation returns during periods of changing flow regime.

Task Products: Report from subcontractor on baseline conditions of riparian corridor (first year) and effectiveness of restoration (second year), summary tables of data.

5. TASK 5: Monitoring and re-evaluation as part of implementation of preliminary TMDL for Crowley Lake and its tributaries

5.1 ***Monitor ongoing eutrophication of Crowley Lake***: Assess the trophic status and overall nutrient content of Crowley lake at three times (ice-off, midsummer, and October) during the year by vertical profiles taken in each major sector of the lake. The main sectors consist of the north arm (30-ft depth), the western basin (25-ft depth), the central portion (50-ft depth), the eastern deep portion (60-ft depth) and the southern arm (75-ft depth). Collect an integrated sample from the upper mixed layer (5 m) at each station and at 5-m intervals to the bottom. In addition to the nutrient fractions determined on the tributary inflows, determine particulate phosphorus, nitrogen, and carbon; total dissolved phosphorus and nitrogen; chlorophyll *a*; and temperature, oxygen, and light profiles. Preserve a portion of the integrated samples for phytoplankton identification. Preserve a vertical net tow collected at each station for zooplankton identification and enumeration. Use these sampling results to provide an estimate of major changes in the nutrient status of the lake through the year and to indicate the relative magnitude of external nutrient loading to in-lake nutrient pools. Use the sampling results to provide a measure of eutrophication of the lake for comparison to past and future data. Use the sampling results to estimate effectiveness of preliminary TMDL strategy.

5.2 ***Evaluate the contribution of various land management practices and the effectiveness of various BMPs on reducing nutrient loading from these land uses.*** Use the results of Task 4 (BMP effectiveness determination) in conjunction with the results of Task 5.1 (eutrophication monitoring) to evaluate the contribution of various land management practices and to evaluate the effectiveness of various BMPs on reducing nutrient loading from these land uses.

5.3 ***Determine MTBE concentrations in Crowley Lake***: Measure ambient MTBE (methyl tertiary butyl ether) concentrations in Crowley Lake. Collect a sample (2 replicates) from the surface at 5 stations during each sampling trip per year. Send samples to a commercial laboratory for analysis.

Task Products: Summary tables of data. Written evaluation of contribution of land management practices and the effectiveness of various BMPs on reducing nutrient loading from these land uses.

6. **TASK 6: Technology transfer, technical assistance, and public education**

6.1 ***Incorporate all project data and sampling locations into existing GIS***: Incorporate all data and sampling locations generated as part of the project into an existing Crowley watershed GIS maintained by the UC Reserve System and located at the Sierra Nevada Aquatic Research Laboratory (SNARL.) Incorporate existing relevant themes (data layers) provided by various agencies including Mono County, the City of Los Angeles, Inyo National Forest, and BLM into the Crowley watershed GIS. Coordinate this activity through the Eastern Sierra Land Information System Network of which SNARL is an active member.

6.2 ***Present a lecture as part of a public seminar:*** Present a public lecture on the results of the project following acceptance of the final project report by the Contract Manager. Include the lecture as part of an annual public seminar consisting of a series of evening lectures on active research conducted at SNARL.

6.3 ***Ensure public access to all project data****:* Following data review by the RWQCB, ensure that all data collected as part of this project is available upon request to public agencies and private landowners.

6.4 ***Include project information in brochures and tours****: Include* project information in City of Los Angeles' brochures and tours related to the Crowley Lake watershed.

Task Products: Geographic information system files, lecture notes

7. TASK 7: Reports.

7.1 ***Prepare draft report****:* Prepare a draft report documenting Tasks 2, 3, 4 and 5. The draft report shall document the project planning (including public input), present the water quality and other project data, and provide interpretations regarding success of riparian restoration, nutrient sources, nutrient loading, and effectiveness of BMPs used in the preliminary TMDL strategy. The Project Director shall submit one reproducible copy of the draft report for review and approval by the Contract Manager.

7.2 ***Prepare final report****:* Prepare a final report that addresses, to the extent feasible, comments made on the draft report by the Contract Manager. The Project Director shall submit one reproducible copy of the final report to the Contract Manager for review and acceptance.

Task products: Draft and final project reports.

C. Schedule of Completion Dates:

1. Project Management/Administration

1.1 *Technical and administrative services*:	Ongoing
1.2 *Quarterly Progress Reports* 10/10/2000)	Quarterly (starting
1.3 *One-page Summary*	08/2002
1.4 *Award Subcontract*:	Ongoing
1.5 *Permits*	08/2002
1.6 *Project Survey Form*	07/2002

2. Project Planning, Design and Meetings

2.1 *Project Planning*	05/2000
2.2 *Prepare QA Plan*	05/2000
2.3 *Compile existing data*	11/2000

3. Implementation of best management practices (BMPs)

3.1 *Riparian corridor fencing*	09/2000

3.2	*Access points and parking*	09/2000
3.3	*Livestock management*	ongoing (starting 06/00)
3.4	*Riparian fence repair and adjustment, and installation of additional gates or parking*:	09/2001
3.5	*Installation of irrigation and water measuring improvements to reduce return flows*:	09/2001

4. <u>Determining the effectiveness of best management practices (BMPs)</u>

4.1	*Establish baseline conditions of riparian corridor:*	09/2000
4.2	*Monitor effectiveness of riparian fencing:*	09/2001
4.3	*Establish the sources and magnitude of nutrient inputs to Crowley Lake:*	07/2002
4.4	*Assess the contribution of various land use practices to the nutrient loading of Crowley Lake:*	07/2002
4.5	*Event-oriented sampling:*	07/2002

5. <u>Monitoring and re-evaluation as part of implementation of preliminary TMDL for Crowley Lake and its tributaries</u>

5.1	*Monitor ongoing eutrophication of Crowley Lake:*	07/2002
5.2	*Assess the contribution of various land management practices and effectiveness of various BMPs on reducing nutrient loading from these land uses*	07/2002
5.3	*Determination of MTBE concentrations in Crowley Lake:*	07/2002

6. <u>Technology transfer, technical assistance, and public eduction</u>

6.1	*Project data and sample locations into GIS*	07/2002
6.2	*Public lecture as part of seminar series*	06/2003
6.3	*Data access and availability:*	ongoing
6.4	*Brochures and tours:*	ongoing

7. <u>Reports.</u>

7.1	*Draft*	12/2002
7.2	*Final*	02/2003

D. Reports

1. Not later than October 10, 2000, and quarterly thereafter, during the life of this agreement, the Project Director shall provide a written progress report to the Contract Manager describing activities undertaken, accomplishment of milestones, and any problems encountered in the performance of the work under this agreement, and delivery of intermediate products, if any.

2. The Project Director shall submit to the Contract Manager for approval the reports containing the results of the work performed in accordance with the schedule in this Exhibit.

3. Not later than December 31, 2002, the Project Director shall submit to the Contract Manager for review and comment one (1) copy of a draft report as described in Section B, Task 7.1 of this Exhibit.

4. Within four (4) weeks of receipt of the draft report, the Contract Manager shall submit final comments to the Project Director.

5. Not later than February 1, 2003, the Project Director shall submit to the Contract Manager for approval one (1) reproducible master and three (3) copies of the final report described in Section B, Task 7.2 of this Exhibit.

6. The report shall not be considered final until accepted and approved by the Contract Manager.

E. Task Budget

Task	State	Match	Total
TASK 1: Project Management and Administration	$6,021	$4,346	$10,367
TASK 2: Proj. Plan., Design, Mtg. of Cooperating Agencies/Stakeholders	12,250	10,707	22,957
TASK 3. Implementation of best management practices (BMPs)	26,500	142,700	169,200
TASK 4. Determining the effectiveness of BMPs	93,961	15,210	109,171
TASK 5: Implementation of TMDL for Crowley Lake and its tributaries	80,071	13,037	93,108
TASK 6: Technology transfer, technical assistance, and public education	8,778	2,173	10,951
TASK 7: Reports	17,360	10,701	28,061
TOTAL	$244,941	$198,874	$443,815

APPENDIX D

Quality Assurance Project Plan (QAPP)

For

Restoration of Riparian Habitat and Assessment of Riparian Corridor Fencing and Other Watershed Best Management Practices on Nutrient Loading and Eutrophication of Crowley Lake, California

Hereinafter referred to as "Crowley Watershed Restoration QAPP"

Project Director & co-PI	________________________________ Dr. Robert S. Jellison, Research Biologist Marine Science Institute, Univ. Calif., Santa Barbara, CA, 93106
Project QA Officer & co-PI	________________________________ Daniel D. Dawson, Director Sierra Nevada Aquatic Research Laboratory HCR 79, Box 198, Mammoth Lakes, CA,
Co-PI	________________________________ Dr. John M. Melack, Professor Donald Bren School of Environmental Science & Management Univ. Calif., Santa Barbara, CA, 93106
California RWQCB Contract Manager	________________________________ Cindy Wise Lahontan Regional Water Quality Control Board ……….

Crowley Watershed Restoration QAPP
Revision 2.0
5/7/2000

QUALITY ASSURANCE AND CONTROL PROCEDURES

An investigation of surface water chemistry requires a strong quality assurance (QA) plan for sampling and analysis. Our QA plan is comprised of rigorous field and laboratory quality control (QC) procedures. We implement a QA program to ensure the integrity of precipitation and surface water samples collected in the field and to produce reliable analytical data for samples analyzed in the laboratory.

Our QA procedures include the following components: Identical instruments are used and adherence to standardized data collection procedures and field protocols are emphasized with the field staff at all sites. Procedural variability in the field is assessed by replicate samples and by means of field blanks. In the laboratory, blanks include deionized water processed through plastic bottles, filters, and buckets, which assess contamination.

FIELD METHODS

Tributary Sampling

All apparatus and bottles used in surface water sampling are soaked in deionized water (DIW) for several days and then rinsed 4 times with DIW. Our experience has shown that acid washing does little to clean the bottles and increases the risk of sample contamination. Filtered samples are filtered in the field with plastic syringes fitted with Gelman A/E filters (1 micron) which are rinsed with at least 150 ml of sample water. For the biweekly sampling all samples with the exception of Benton Crossing are "grab" samples taken at a well-mixed location in the stream such as the outlet of a culvert. Samples at Benton Crossing will be integrated across the river with a DH-48 sampler. During longitudinal sampling a decision will be made at each field location as to the uniformity of samples collected. If there is any consideration of mixing problems, such as immediately downstream of Big Springs, the integrating sampler will be used. Two field blanks are also prepared each sampling trip. These consist of DIW carried into the field and filtered and treated exactly like a sample. Samples are kept cool and in the dark during transport. For long-term storage, samples are frozen.

Dissolved oxygen (DO) and temperature will be measured at each sampling location using a YSI Model 57 meter with combination DO and temperature probe

Lake Sampling

The approximate locations of five sampling locations have been identified in the Scope of Work. Stations are located in each major section of the lake and vary in depth between 8 and 25 m. On the first lake sampling date, final locations will be selected and locations recorded by GPS. GPS will be used on subsequent sampling trips to relocate sampling locations within 25 m.

In situ profiles of water temperature, conductivity, dissolved oxygen, and photosynthetically available light will be determined at each station at 1-m intervals. Temperature and conductivity will be measured with a high-precision, conductivity-temperature-depth profiler (CTD) (Sea-Bird Electronics, model Seacat SBE 19). The CTD is deployed with a free-fall rate of ~0.25–0.35 m s^{-1} and records temperature and conductivity every 0.5 seconds. The CTD sensors are very stable and are calibrated once per year by Sea-Bird Electronics. In situ light will be measured with a LI-COR light meter (model LI-250) equipped with a submersible PAR light sensor (LI-COR, model LI-192S). Dissolved oxygen concentration will be measured with a Yellow Springs Instrument temperature-oxygen meter (YSI, model 58) and probe (YSI, model 5739). The LI-COR meter and sensor are calibrated annually by LI-COR Inc and while a saturated air calibration is conducted prior to each use in the field the oxygen electrode will also be calibrated annually against Miller titrations of Crowley Lake water (Walker *et al.* 1970). In addition to the in-situ light profiles, water transparency will also be assessed using a 20-cm Secchi disk.

Samples collected for the analysis of nutrient fractions will be treated identically to those collected from the tributaries (see above). Samples for chlorophyll *a* analysis will be filtered through a 120-micron net filter to remove macrozooplankton and kept cool and in the dark during transport to the laboratory. Zooplankton samples will be collected with a plankton net (1 m x 0.30 m diameter, 120 μm Nitex mesh) towed vertically through the water column and immediately preserved with 5% formalin in lake water.

MTBE

Babcock Laboratories of Riverside, California will perform MTBE analyses. Prior to each lake sampling date, for each sampling location on the lake, Babcock will provide two 40-ml sample tubes containing small amounts of HCl, and a 40-ml field blank tube containing acidified DIW. At each sampling location the tube is held under the surface of the lake by hand and the cap is removed underwater allowing the tube to fill. The tube is recapped immediately with no airspace. The field blank is carried along on the sampling trip but otherwise not uncapped or handled. All sample tubes will be shipped the same day or the next day to Babcock. All analyses will be performed within 9 days of sampling. Babcock will employ EPA Method 8260A for analysis with a reporting limit of 1 ppb of MTBE. As MTBE use in California is being discontinued it is not anticipated that these results will be used for regulatory action. Therefore, no chain-of-custody will be required.

Atmospheric Sampling

Precipitation is measured at SNARL using a tipping-bucket rain gauge (Qualimetrics model 6011-B) connected to a solid-state data logger. The Los Angeles Department of Water and Power also measure precipitation at the Crowley Lake Dam. Precipitation samples are collected in polyethylene buckets using an Aerochemetrics wet/dry collector. Dry fall atmospheric inputs will be measured biweekly during the summer and monthly during the winter. Dry fall sampling buckets will be rinsed with 60 ml of DIW and analyzed for ammonium, SRP, nitrate, pH, and conductivity.

Stream Gauging

For the nutrient budget we will be relying on stream gauging data provided by the Los Angeles Department of Water and Power. All of the major tributaries have been gauged for upwards of 60 years with permanent flumes and stage recorders. For Hilton Creek, where the biweekly sampling is taking place at a location where the stream is divided, staff gauges will be installed below the highway in the 4 major channels. Rating curves for the staff gauges will be developed using a velocity-area method (Gore, 1996) employing a Marsh McBurney stream velocity meter.

For the longitudinal surveys stream gauging will take place at each sampling location to allow discrimination of dilution effects. Gauging will be done using a velocity-area method employing a Marsh McBurney stream velocity meter.

LABORATORY METHODS

For the purposes of this project DIW will be used to refer to filtered, deionized, reverse osmosis treated water. This is our primary washing and rinse water with a specific conductance of approximately 5 μS cm^{-1}. For reagent and standard preparation this water is further polished by ion exchange to a specific conductance of approximately 0.5 μS cm^{-1}.

Immediately following sample collection samples will be transported cold and in the dark to the Sierra Nevada Aquatic Research Laboratory for processing and analysis. pH measurements are done on unfiltered subsamples immediately upon return to the laboratory using a Fisher Acumet digital pH meter and Ross (Orion) combination electrode. The meter is calibrated in a two-point calibration with NRS-traceable buffers near room temperature. After calibration the accuracy of the calibration is checked using dilute solutions of HCl (10^{-4} and 10^{-5} N). The electrode is then rinsed with stirred DIW for several minutes before the pH of the quiescent sample is measured. Specific conductance of unfiltered subsamples are measured on a YSI Model 32 digital conductance meter (cell constant=1.0) corrected to 25°C. A 10^{-4} M KCl conductivity standard, which has a theoretical specific conductance of 14.7 μS cm^{-1} at 25°C is measured at the beginning of each laboratory session.

NH_4, SRP, and As will be analyzed on each duplicate field sample on the same day as collection. Remaining filtered field samples will be frozen and analyzed for NO_3 within two months of collection. Unfiltered samples for TN, TP , TDN, TDP, particulate P, and particulate C,H,N will be frozen upon return to the laboratory and kept frozen until analysis within two months of collection. TN, TP, TDN, and TDP may be analyzed in our laboratory at UCSB. If this is the case, frozen samples will be transported by car to UCSB and analyzed by one of our project staff who will transport them. The samples will never be out of our control and no chain-of-custody will be required. Table 1 shows the method employed and the detection limit for each nutrient analysis. Detection limits are reported as two times the standard deviation of replicate analyses. Detection limits for total and total dissolved fractions are more variable because of the digestion step.

Table 1 –Methods for Nutrient Analysis

Species	Method	Reference:	Detection Limit (μM)
NH_3+NH_4^+	phenol-hypochlorite colorimetric	Wetzel and Likens, 1991	0.30
SRP	phospho-molybdate colorimetric	Wetzel and Likens, 1991	0.06
NO_3	Cd reduction followed by azo dye colorimetric	Wetzel and Likens, 1991	0.20
TP	Valderrama (oxidation/phospho-molybdate)	Valderrama, 1981	0.4
TN	Valderrama (oxidation/Cd reduction/azo dye)	Valderrama, 1981	0.4
TDN	Valderrama (oxidation/Cd reduction/azo dye)	Valderrama, 1981	0.4
TDP	Valderrama (oxidation/phospho-molybdate)	Valderrama, 1981	0.4
As	As(V)$\rightarrow$As(III) reduction/phospho-molybdate	Johnson, 1971	0.02
MTBE	EPA Method 8260A	EPA Manual SW846	1 ppb

We also employ independent (external) checks on the accuracy of our chemical analyses. Routine analyses of standard reference materials (SRM) from the National Bureau of Standards (NBS) and the U.S. Environmental Protection Agency (EPA) are performed. The SRM was synthetic rain-water with certified concentrations for major cations and anions. Another independent check on our chemical data involves participation in the U.S. Geological Survey's Analytical Evaluation Program and Environment Canada's LTRAP Audit. These are regular audits that test the quality and accuracy of the analytical procedures used in laboratories throughout the U.S. and Canada. These agencies distribute water samples to participating laboratories and participants submit their results to these agencies and are assigned a score based on how close their results come to the mean value obtained from all participants. Our laboratories have always scored well (good to excellent ratings) in these audits.

Upon return to the laboratory, chlorophyll samples will be filtered onto 47 mm Gelman A/E filters and kept frozen until the pigments are analyzed. Chlorophyll *a* concentrations will then be determined by acetone extraction and spectrophotometric absorption (Wetzel and Likens 1991).

Phytoplankton and zooplankton identification and relative composition will be determined by standard microscopy methods (Wetzel and Likens 1991) employing inverted and dissecting scopes and appropriate keys, respectively.

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