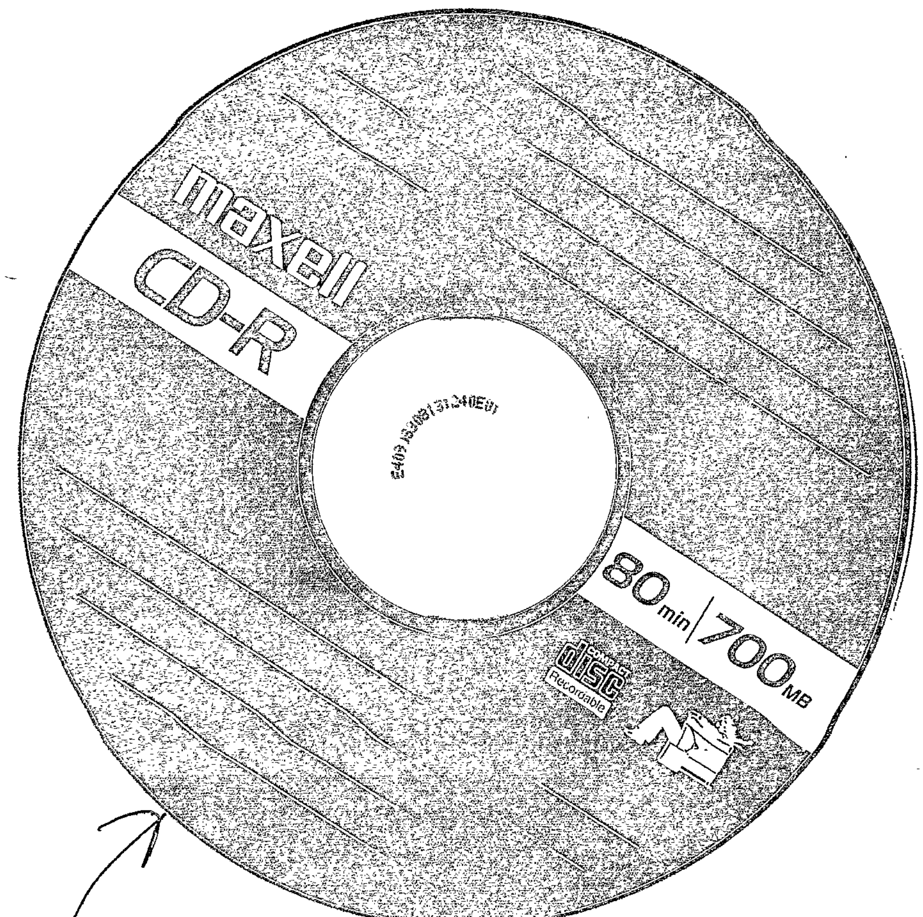


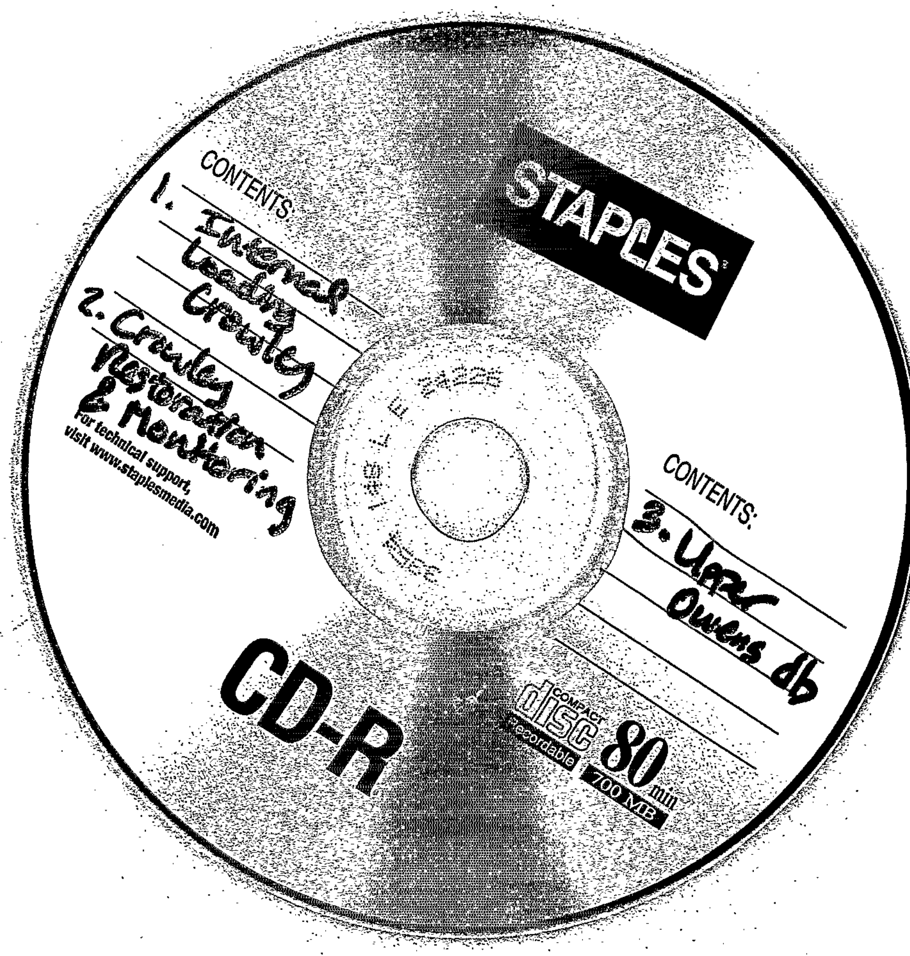
September 2005

TO: Jessie + Craig J

Fr: Tom Gavigan 530.542-5429

(1) Crowley Lake STAFF REPORT

(2) Crowley Lake FACT SHEET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State of California
The Resources Agency
Department of Fish and Game

THE TROUT FISHERY OF CROWLEY LAKE, MONO COUNTY, CALIFORNIA[1]

E. P. PISTER
Region 5, Inland Fisheries

SUMMARY

Crowley Lake is located in southern Mono County, California, at an elevation of 6,781 feet. It is an artificial impoundment approximately six miles long and three miles wide with a maximum surface acreage of 5,272. High total dissolved solids, combined with a relatively shallow mean depth, result in a high level of biological productivity.

Early management practices at Crowley Lake consisted primarily of planting fingerling brown and rainbow trout. As angling pressure increased, it became apparent that planting fingerling trout alone could not long maintain a satisfactory level of angling success. The value of planting larger trout was investigated and found feasible.

Present management practices are based around the annual planting of approximately 300,000 subcatchable rainbow trout averaging 10 per pound. Planting is usually done at, or near, the end of the Crowley Lake angling season on July 31.

Analysis of rainbow trout stomach contents revealed that the majority of their summertime food consisted of immature Tendipedidae and Cladocera. Later in the fall, rainbow trout consume chiefly small tui chubs (*Siphateles* sp.) and Cladocera.

The growth rates of Crowley Lake trout are exceptional. Rainbow trout planted in August at an average size of 10 per pound (about 5.8 inches, fork length) are taken by anglers at approximately one pound and 12 inches by the beginning of the following season about eight months later. This rapid growth continues into later years. Brown and cutthroat trout grow at a similar rate.

Crowley Lake rainbow trout were found to possess a higher mean condition factor than rainbow trout from nearby waters. However, condition factors for brown and cutthroat trout were only average.

The severity of winter conditions and the degree of reservoir fluctuation exert considerable influence on trout growth. Exceptional growth occurs during winters in which ice-cover is of short duration and the reservoir level is constant or rising.

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[1] Submitted July 1964. Issued May 1965.
Inland Fisheries Administrative Report No. 65-9.

An intensive study of the Crowley Lake fishery during the 1958 angling season revealed that nearly 25 percent of the seasonal angling pressure and 35 percent of the seasonal catch occurred on the opening weekend. Over 65 percent of the seasonal angling pressure and over 80 percent of the seasonal catch occurred during May. As the rainbow trout population was harvested, both angler use and success dropped significantly. It was estimated that 53 percent of the subcatchable rainbows planted in 1957 were eventually taken by anglers.

In several Mono County lakes stocked with catchable trout, the cost per pound of trout returned to the angler is about $0.90. The Crowley Lake management program produces a pound of trout in the angler's creel for approximately $0.15.

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INTRODUCTION

In May, 1947, the California Department of Fish and Game issued a news release indicating that on the opening weekend of the season at Crowley Lake 5,920 anglers caught nearly 9,000 trout weighing over 17,000 pounds. Fourteen years later, in May, 1961, the Department's release read as follows: "Opening weekend of trout season at Crowley Lake was another record breaker. The largest two-day crowd ever - nearly 19,000 anglers - took over 72,000 trout, a record number. The fish averaged one and one-eighths pounds. The total catch weighed 40 and one-half tons - another record. A check by Department of Fish and Game personnel showed that this year's (1961) opening weekend at Crowley drew nearly 5,000 more fishermen, over a thousand more boats, and almost 14,000 more trout were caught, weighing 11 and one-quarter more tons than on opening weekend last year."

It is difficult to believe, when observing the thousands of anglers at Crowley Lake on the opening of the season, that less than a century ago the Owens River drainage contained no game fish of any species and that less than a quarter of a century ago Crowley Lake itself did not exist.

This report tells the story of this remarkable reservoir and explains the fisheries management plan which provides a satisfactory level of angling success in the face of constantly increasing angling pressure.

DESCRIPTION OF CROWLEY LAKE

Crowley Lake is located on the eastern slope of the Sierra Nevada in southern Mono County, California, at an elevation of 6,781 feet. The lake was created in April, 1941, when the Long Valley Dam was placed in operation by the Department of Water and Power of the City of Los Angeles to impound the waters of the Owens River. Five years later, in the spring of 1946, the lake reached spillway level. At maximum storage, the lake is roughly six miles long and three miles wide. Maximum depth is 114.5 feet, and surface area is 5,272 acres. Volume at spill level is 183,743 acre-feet, and mean depth was calculated to be 34.85 feet (Pister, 1960). Fluctuations of the lake level are gradual; severe, short-term changes do not occur.

As the lake gradually filled, large areas of meadowland and sagebrush flats were inundated, and the resulting bottom material proved to be very productive of fish food organisms, chiefly midge larvae and pupae (Diptera, Tendipedidae). Pister (op. cit.), in a study of the lake's bottom fauna in 1953, found the mean standing crop to be 153 pounds per acre between May and August, with a total standing crop of over 400 tons.

Bottom types are chiefly mud and ooze, grading to gravel and sand in the shoal areas. The unusually high productivity of the lake has apparently become stabilized at a point somewhat lower than that which existed during the first few years after flooding, but is still probably above the "average" for lakes at this general elevation (Calhoun, 1944; Reimers, Maciolek and Pister, 1955). Although the bottom fauna productivity in Crowley Lake is not extraordinarily high per unit of area, so much of the lake is shallow that the overall food production in relation to the size of the trout population is quite substantial. Winter conditions in the Crowley Lake area are severe, and the lake almost invariably freezes over its entire surface. Ice-cover usually forms in late December and disappears in early April.

Crowley Lake is strongly bicarbonate in character, with relatively high concentrations of silica, sodium, chloride, and phosphate. Total dissolved solids (187 ppm. are quite high when compared with those of nearby lakes (Reimers, Maciolek and Pister, op. cit.). In addition, 83 percent of the total bottom area lies beneath less than 50 feet of water. These factors probably exert much influence in creating a high level of biological productivity (Northcote and Larkin, 1956; Rawson, 1952, 1953a and 1953b).

Midsummer surface temperatures reach the low 70's. During this time, blooms of both zooplankton (Cladocera) and phytoplankton (Volvox and Gloeotrichia) are commo This plankton material, chiefly Cladocera, is an important food source for rainbow trout. The heavy algae bloom, combined with extensive growths of rooted aquatic plants of various species in the shoal areas, creates a depreciation of the oxygen supply and other unstable biological conditions, especially at night, occasionally resulting in the mortality of considerable numbers of nongame fish and an occasiona trout. Nonegame fish generally inhabit the shoal areas, while trout occupy the deeper, cooler portions of the lake and are therefore not greatly affected by these adverse conditions.

FISH FAUNA OF CROWLEY LAKE

Trout are not native to the Owens River drainage. Native fishes in the upper portion of the drainage are reported as sucker, Catostomus sp.; chub, Siphateles sp.; and dace, Rhinichthys sp. (Hubbs and Miller, 1948; Kimsey and Fisk, 1960). Only suckers and chubs have been collected recently from Crowley Lake. Collecting operations, however, have not been extensive.

Prior to the creation of Crowley Lake, rainbow trout, Salmo gairdnerii; brown trout Salmo trutta; Lahontan cutthroat trout, Salmo clarkii henshawi; golden trout, Salmo aguabonita; and eastern brook trout, Salvelinus fontinalis had been introduced into the Owens River drainage above the present location of Crowley Lake. However, only rainbow and brown trout were present in the lake area in significant numbers.

GAME FISH-NONGAME FISH RELATIONSHIPS

The role of nongame fish in the ecology of Crowley Lake is not thoroughly understood. It is known that significant populations of suckers and chubs exist, apparently without detriment to the trout population. Food habit studies reveal that the young of these species are consumed in large numbers by trout, particularly during the late fall when aquatic insect populations reach a low level. The overwinter growth of trout is unusually good, and it seems probable that this may be due in large measure to the easy availability of these small fish.

Nongame fish control measures do not appear warranted at this time. As long as the trout growth rate in Crowley Lake approximates the growth rate attained in a good fish hatchery, any changes in the existing situation should be carefully considered.

EARLY MANAGEMENT PRACTICES

In the early 1940's, as Crowley Lake began to fill, fish planting consisted primarily of fingerling brown and rainbow trout supplemented by relatively small numbers of yearling rainbows (Table 1). The high initial productivity of the lake and small population of large, predatory fish permitted good growth and survival. Under light, wartime angling pressure, a good catch rate of large fish was maintained. However, as the lake became more popular and angling pressure increased, the planting of fingerling trout could not maintain a satisfactory level of angling success.

TABLE 1

Crowley Lake Fish Plantings

	Subcatchables	Fingerlings					
Year	Rainbow	Rainbow	Kamloops rainbow	Brown	Cutthroat	Eastern brook	Total
1941	1,000			95,890			96,890
1942	21,905			124,426			146,331
1943	82,979				8,298[1]		91,277
1944	125	210,538					210,663
1945	182,417	7,904					190,321
1946	13,510	185,600			718,782		917,892
1947	35,088	122,000					157,088
1948	28,340	54,793					83,133
1949	21,923	54,400			190,800		267,123
1950		128,800					128,800
1951	161,240						161,240
1952	156,890				100,000		256,890
1953	224,409			176,400	161,476		562,285
1954	175,224			114,895	194,035		484,154
1955	207,616		30,000[1]		100,000		337,616
1956	238,690				158,400		397,090
1957	235,943				173,728		409,671
1958	212,183	135,390	182,080		226,725		756,378
1959	315,265	14,500	245,430		229,890	100,000	890,585
1960	295,~~860~~ 802	14,500			183,760	66,000	560,120
1961	~~436,982~~ 411,542	52,640	~~110,310~~ 100,390		100,000		~~674,442~~ ~~699,932~~ 664,572
1962	298,350	111,740	104,000		122,128		636,218
1963	317,775	105,750	79,900		99,940		603,365
1964	306,595	485,300					791,895
1965	363,479	1,464,400					1,827,879
1966	429,718						429,718

Management measures in the 1940's were carried out on an experimental basis in an effort to arrive at a satisfactory overall plan. The planting of larger numbers of subcatchable rainbow trout (averaging 10 per pound) was successful, and the problem then became one of producing adequate numbers of trout of this size to carry on a sustained planting program. The opening of Fish Springs Hatchery in 1952 made this possible. Since that date, Crowley Lake has been planted on an annual basis with large numbers of subcatchable rainbows.

PRESENT MANAGEMENT PRACTICES

The primary reason for Crowley Lake's popularity is that people are able to catch big fish. The average trout taken weighs a pound or more, whereas at other roadside waters anglers must generally be satisfied with planted rainbow trout weighing three or four ounces.

Crowley Lake is managed as a trophy fishery. To make this possible, special angling regulations have been placed in effect. The season opens with the surrounding area on the Saturday nearest May 1. It closes on July 31, three months earlier than the general area closure.

Shortly after the close of the season, approximately 300,000 subcatchable rainbow trout of the Hot Creek fall spawning strain are planted. With the advantage of the long growing season and abundant food supply these fish grow rapidly. Subcatchables planted in August at an average size of 10 per pound (about 5.8 inches, fork length) are taken by anglers at approximately one pound and 12 inches by the beginning of the following season about eight months later. Although fingerling trout of various species are planted regularly in Crowley Lake, the management plan is based upon the subcatchable program.

The time at which Crowley Lake is planted exerts considerable influence on the size of fish taken during the following season. Marking experiments carried on in 1960-61 show this difference (Table 2). Because of crowded hatchery conditions resulting from the 1960 drought, it became necessary to plant a portion of the regular yearly allotment in mid-June rather than after the close of the season. The remainder of the allotment was planted on August 29. In order to provide comparative information concerning growth and survival of the two plants, 10,000 of each group were fin-clipped and lengths and weights of the marked fish were recorded as they entered the catch during the 1961 season.

The growth rate of the marked fish is especially noteworthy. The additional two and one-half months of growing time in Crowley Lake permitted the June plant to surpass the August plant, even though the June-planted fish were significantly smaller when stocked. In addition, a higher survival rate of the June plant is indicated. It is possible that the August plant may have been affected by toxic shoal-area water conditions which are at a maximum in late August. Another theory is that, since the plants were made from different hatcheries, preplanting conditions may have exerted some influence.

On the basis of the 1960-61 study it would appear advantageous to plant Crowley Lake as early as mid-June. However, anglers are quick to learn of the easy availability of newly planted fish. More recently, when early planting has been necessary, these small fish have constituted a significant portion of the late-season catch. Since the premature harvest of subcatchables in Crowley Lake violates the current management principle which allows newly planted fish to attain substantial growth before being subjected to angling, every effort is now

TABLE 2

Growth and Return of Marked Subcatchable Rainbow Trout
Planted in June and August, 1960

	June 15 plant	August 29 plant
Hatchery	Fish Springs	Hot Creek
Strain of rainbow trout	Hot Creek fall spawning	Hot Creek fall spawning
Time in lake prior to following season	10.5 months	8 months
Number of marked trout planted	10,000	10,000
Mean fork length at planting (inches)	5.03	5.82
Mean fork length on April 29-30, 1961 (inches)	12.97	11.89
Mean length gain (inches)	7.94	6.07
Mean weight at planting (ounces)	1.23	1.54
Mean weight on April 29-30 (ounces)	18.73	14.82
Mean weight gain (ounces)	17.50	13.28
Number of marked fish returned on April 29-30, 1961 1/	203	129
Total number of marked fish returned through July 31, 1961 1/	239	180
Total trout planted in 1960	183,402	112,458

1/ Indicates number of marked fish seen during creel censuses carried on during weekends.

being made to plant the lake as close to the end of the season as possible. Because the principal angling methods in use at Crowley Lake involve the use of bait, it is felt that an attempt to minimize the taking of newly planted fish by means of a size limit would result in a high degree of mortality among the fish returned to the water and would defeat the intended purpose.

During the winter of 1960-61, precipitation in the Sierra Nevada was only a fraction of normal, and hatchery water supplies were seriously depleted. Consequently, it became necessary to plant the majority of the 1961 subcatchable allotment in early May. These fish grew rapidly and large numbers were taken prior to the close of the 1961 season and therefore did not enter the catch in 1962.

The lack of precipitation during the 1960-61 winter had an indirect effect on trout survival. The area and volume of the lake was reduced to approximately 50 percent of maximum by November, 1961. Predation on the newly planted fish by the population of large brown trout was probably greater than usual. The smaller available population of rainbow trout at the beginning of the 1962 season is clearly indicated by early season catch data (Table 3).

When normal planting procedures were followed (planting of subcatchables during the latter portion of the season or post-season), a close correlation between the magnitude of the previous year's plant and opening weekend angling success was noted. Using data for seven years between 1953 and 1961 (census data are not available for 1955 and 1957), a correlation coefficient of 0.92 was calculated for the relationship between numbers of rainbow trout subcatchables planted during the previous year and mean catch per angler hour over the opening weekend of the following season (Figure 1). A similar relationship was noted for mean catch per angler hour for the entire season.

Hot Creek fall spawning strain rainbow trout have been the predominant plants in Crowley Lake and its tributaries. Generally, the females retain their fall spawning characteristic, while the males quickly revert to spring spawning under natural conditions. Consequently, natural spawning by rainbow trout in recent years has not been extensive.

Beginning in 1958, both fingerling and subcatchable rainbows of the Mt. Whitney spring spawning strain were planted in increasing numbers as part of the overall allotment for Crowley Lake. Since that time, considerable spawning activity by these fish has been noted in the tributary streams, normally beginning in March and continuing into May. We may therefore expect more natural recruitment of rainbow trout than has been experienced in past years. This was indicated early in the 1963 season, when naturally produced fish about nine inches long were observed in the catch.

Fingerling trout of various species have also been planted regularly. Brown trout fingerlings were planted intermittently until 1954, when it became apparent that natural reproduction in the tributary streams was adequate to maintain an excellent population. Since that time, brown trout have entered the catch at approximately the same rate as during the period in which they were planted.

Several experimental plants of Kamloops rainbow trout have been made in Crowley Lake. This strain survives well when reared to yearling size and is very popular among anglers. In 1955, 30,000 yearling Kamloops were stocked and contributed significantly to the fishery during the next three years. Those fish remaining into the 1958 season exhibited strong migratory tendencies. Some were observed spawning in upper McGee Creek over five miles and 1,200 feet above Crowley Lake.

TABLE 3

Creel Census Data For Eight Angling Seasons at Crowley Lake[1]

	1953	1954	1956	1958	1959	1960	1961	1962
Mean catch per angler hour, opening weekend	0.46	0.56	0.52	0.70	0.57	0.94	0.85	0.39
Mean catch per angler hour, remainder of May	0.30	0.41	0.43	0.45	0.28	0.57	0.31	0.34
Mean catch per angler hour, June	0.23	1/ *	0.18	0.22	0.24	0.19	0.18	0.12
Mean catch per angler hour, July	0.20	0.19	0.11	0.22	0.28	0.19	0.19	0.17
Mean catch per angler hour, season	0.33	0.37	0.29	0.38	0.39	0.66	0.45	0.26
Mean catch per angler hour, opening weekend, rainbow trout	0.44	0.47	0.46	0.63	0.54	0.94	0.82	0.36
Mean catch per angler hour for season, rainbow trout	0.31	0.33	0.27	0.33	0.36	0.64	0.42	0.23
Percent rainbow trout in catch, May	94.86	87.00	90.85	90.82	92.02	98.34	95.02	90.03
Percent rainbow trout in catch, June	93.81	1/	86.59	76.38	82.09	87.57	75.23	81.36
Percent rainbow trout in catch, July	89.92	93.42	56.95	71.88	92.96	94.12	88.40	83.65
Percent rainbow trout in catch, season	94.11	88.26	87.97	87.97	90.69	97.77	92.92	88.30
Percent brown trout in catch, May	4.23	10.25	4.50	5.92	4.80	1.37	2.94	8.66
Percent brown trout in catch, June	5.56	1/	5.32	18.50	15.25	10.54	22.48	16.59
Percent brown trout in catch, July	9.45	5.00	28.70	15.34	5.98	5.63	9.51	15.04
Percent brown trout in catch, season	5.05	9.19	6.07	7.91	6.28	1.89	5.01	10.30
Percent cutthroat trout in catch, May	0.91	2.75	4.65	3.26	3.18	0.29	2.04	1.23
Percent cutthroat trout in catch, June	0.63	1/	8.09	5.12	2.66	1.89	2.29	2.05
Percent cutthroat trout in catch, July	0.63	1.58	14.35	12.78	1.06	0.25	2.09	0.38
Percent cutthroat trout in catch, season	0.84	2.55	5.96	4.11	3.03	0.35	2.07	1.24
Number of censuses conducted during season	15	11	17	56	15	15	16	15
Number of anglers interviewed during season	4,389	1,012	2,406	9,768	3,195	4,563	5,071	4,044

1/ Creel censuses were not conducted in 1955, 1957, and June, 1954.

* Angling occurred only on Sunday because of high winds.

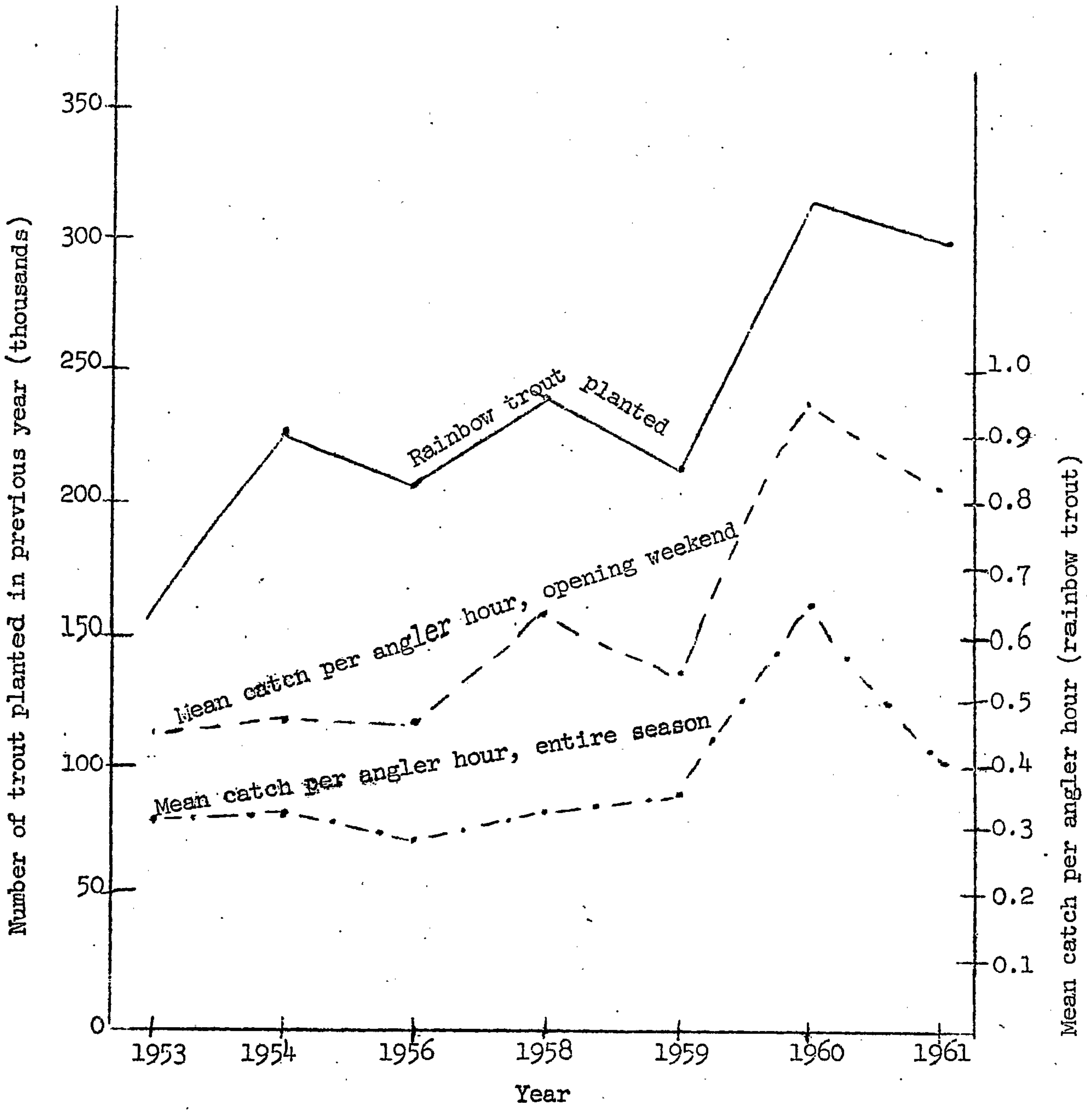

FIGURE 1. Relationship of numbers of subcatchable rainbow trout planted in previous year to angler success.

At this time they had attained lengths of approximately 20 inches. Probably because of the heavy angling pressure at Crowley Lake, and consequent rapid rate of harvest, Kamloops rainbow are seldom taken in excess of three pounds in weight. Fingerling plants of Kamloops rainbow to date have not been particularly successful, and this is also generally true of Lahontan cutthroat. Plants of eastern brook trout fingerlings have been totally unsuccessful.

The only fish taken at trophy size are brown trout. The Crowley Lake record for this species is 19 pounds 10 ounces. Brown trout in the 8- to 10-pound range are taken rather frequently.

An additional management measure in effect at Crowley Lake is a reduced limit. Only seven trout may be taken at Crowley. This tends to reduce the tremendous early season catch and provides better angling for fishermen visiting the lake later in the season.

FUTURE MANAGEMENT PLANS

The present management procedures in effect at Crowley Lake may be deemed satisfactory, but the question naturally arises as to what changes must be made to meet the greatly increased angling pressures expected in future years.

It is reasonable to assume that greater numbers of subcatchable rainbow trout will be planted, especially if additional rearing facilities become available. Since catch data make it apparent that an increase in planting would result in an even higher degree of early season angling success, with little benefit to the fishery in June and July, it will probably become necessary in future years to initiate a lower bag limit.

The exceptional fishery at Crowley Lake will in all likelihood result in an increase in angling pressure even greater than that anticipated for the remainder of the area. Consequently, additional means of providing a satisfactory fishery for as long a period during the season as possible will be investigated. Two possibilities would be opening the lake to fishing only on alternate weeks during the season, and restricting the methods of angling. An experiment was carried on during the fall of 1963 and 1964, when a portion of the shoreline was opened to angling with barbless flies only, with a minimum size limit of 12 inches. Although the angling pressure during these special seasons was comparatively light and the catch rate was low, some beautiful fish were taken, and anglers indicated a high degree of satisfaction.

Experimental management procedures will be continued. The planting of yearling Kamloops rainbow and cutthroat trout is planned.

METHODS OF EVALUATING THE FISHERY

With the exception of the 1958 season, when a more intensified study was made, the evaluation of management procedures in effect at Crowley Lake has been accomplished by means of a creel census program conducted primarily on weekends throughout the angling season. Anglers are inverviewed at random. It has been possible to contact as high as 65 percent of those on the lake on a given day. During the opening weekend of the angling season, when over 10,000 anglers are on the lake each day, a crew of 10 census clerks generally contacts about 15 percent of the anglers present. Only completed fishing efforts are recorded.

Total angler use has been calculated by boat counts at the lake and multiplying by the mean number of anglers per boat (ordinarily slightly in excess of 3). Boat counts on the opening weekend have been conducted by the Department of Fish and Game and later in the season by the Los Angeles Department of Recreation and Parks.

Each year, during a 48-hour period immediately preceding the opening of the angling season, the California Division of Highways conducts a count of vehicles and boats passing north through Bishop on Highway 395 on their way to the many waters of Mono County. It has been noted that a close correlation exists between the number of boats counted by the Division of Highways and the number of boats on Crowley Lake on the opening day. This ratio has ranged from 1:1.11 to 1:1.16, with a mean of 1:1.14. Likewise, counts of boats on the lake during the opening weekend have shown that boat use on Sunday has been a relatively constant percentage of that on Saturday. These figures have ranged from 87 to 88 percent, with a mean of 87.5.

This information will be used in estimating future opening weekend angler use and catch, with occasional counts being made to check the accuracy of the relationships. Use of these data greatly simplifies evaluation of the opening weekend fishery. After the opening weekend, angler use drops to a level where counting boats is a relatively simple matter.

The evaluation of established and experimental management procedures will be continued through the use of the creel census program.

THE FISHERY DURING THE 1958 SEASON

Creel censuses were conducted at Crowley Lake on 56 days of the 90-day 1958 season. With this level of sampling it was possible to estimate the magnitude of the catch with a reasonable degree of confidence.

Crowley Lake creel census data since 1953 (Table 3) reveals that catch data are quite similar from year to year and that the fishery during the 1958 season was typical of the usual pattern under the present management plan.

Observations over a period of years have indicated that shore anglers take relatively few fish. Consequently, only boat anglers were censused during the 1958 study. To minimize bias, all boat landing areas were censused, with major activity being devoted to the main boat launching area at the South Landing. Because all boats at Crowley Lake must dock in the immediate vicinity of the South Landing, it was possible to interview as high as 65 percent of the anglers on the lake during a given day.

The opening weekend of the angling season at Crowley Lake has gained fame throughout the west. Angler use and success are high during this period and throughout most of May (Tables 4 and 5). In 1958, nearly 25 percent of the seasonal angling pressure and nearly 35 percent of the seasonal catch occurred on the opening weekend. Over 65 percent of the seasonal angling pressure and over 80 percent of the seasonal catch occurred during May. Mean catch per angler hour for May was 0.70 on the opening weekend and 0.50 during the remainder of the month, with a monthly mean of 0.53. By far the greatest percentage of trout in the catch were rainbows planted at the close of the previous season. During the last two months of the season, as the more easily caught rainbows were removed from the fishery, brown and cutthroat trout constituted a much great percentage of the species composition. During May, the total catch was comprised of over 90 percent rainbow trout. During June, this figure was dropped to 76 percent and dropped again in

TABLE 4

Crowley Lake Angler Use Data, 1958 Season

	Angler days	Percent of seasonal total
Opening weekend use	12,243	23.89
May use, exclusive of opening weekend	21,204	41.38
Total May use, including opening weekend	33,447	65.27
Total June use	11,109	21.68
Total July use	6,690	13.05
Total seasonal use	51,246	100.00

TABLE 5

Crowley Lake Catch Data, 1958

	$\bar{X} - (t_{.05} s_{\bar{x}})$	$\bar{X}$	$\bar{X} + (t_{.05} s_{\bar{x}})$
Opening weekend[1]			
Rainbow trout		43,810	
Brown trout		3,723	
Cutthroat trout		1,397	
Total opening weekend catch		48,930	
May, exclusive of opening weekend			
Rainbow trout	56,754	62,613	68,472
Brown trout	2,430	3,213	3,996
Cutthroat trout	1,890	2,430	2,970
Total	61,074	68,256	75,438
Total estimated May catch[2]			
Rainbow trout		106,423	
Brown trout		6,936	
Cutthroat trout		3,827	
Total		117,186	221,105 hrs
June			
Rainbow trout	10,200	11,640	13,080
Brown trout	2,490	2,820	3,150
Cutthroat trout	630	780	930
Total	13,320	15,240	99273 17,160
July			
Rainbow trout	5,456	6,975	8.494
Brown trout	899	1,488	2,077
Cutthroat trout	961	1,240	44105 1,519
Total	7,316	9,703	12,090
Total estimated seasonal catch[3]			
Rainbow trout		125,038	
Brown trout		11,244	
Cutthroat trout		5,847	
Total		142,129	

[1] Because of extremely heavy use and exceptionally high level of angler success on the opening weekend, catch data for these two days were calculated separately and are absolute figures. Catch data for the remainder of the season were calculated to the 95 percent confidence interval.

[2] Total May catch figures equal sums of opening weekend catches and mean May catches.

[3] Total seasonal catch figures equal sums of opening weekend catches and means of May, June, and July catches.

July to 71 percent. For the season as a whole, the catch was comprised of approximately 88 percent rainbow, 8 percent brown, and 4 percent cutthroat.

While the catch per angler hour for rainbow trout dropped from a mean of 0.63 during the opening weekend to 0.15 during July, the mean catch per hour for brown and cutthroat trout remained relatively constant during the entire season. This indicates that the rainbow trout, being more easily caught, are quickly harvested, while the populations of brown and cutthroat trout remain relatively constant. This theory is given further substantiation through gill net sampling operations, which reveal that brown trout comprise nearly 35 percent of the trout population of Crowley Lake, even after heavy stocking of rainbows. It is obvious that the average Crowley Lake angler finds it most difficult to catch brown trout.

Studies of returns of marked rainbow subcatchables planted in 1957 revealed that natural recruitment of this species had been negligible. Five percent of the 1957 plant was marked by removal of the left ventral fin, and an identical percentage of the rainbow trout taken in 1958 bore this mark. An attempt to provide for natural recruitment is being made through the planting of the spring spawning Mt. Whitney strain.

It was estimated that 53 percent of the subcatchable rainbows planted in 1957 eventually entered anglers' catches. However, the 1958 study included only boat anglers. Since shore anglers are known to take predominantly rainbow trout, we must consider the 53 percent figure to be minimal.

COST OF MANAGING CROWLEY LAKE

Nearly 90 percent of the 1958 catch at Crowley were rainbow trout planted in 1957. These fish, reared at the Fish Springs, Hot Creek and Mt. Whitney-Black Rock installations, weighed 26,943 pounds at planting time and cost $19,297 based on average production costs during the fiscal years 1955-56 to 1957-58 and prorated according to the poundages planted from each installation (Macklin and Cordone, 1956, and Macklin and Tharratt, 1957 and 1958). Mean weight of rainbow trout taken in 1958 was approximately one pound. The season's take of rainbow trout, 125,038, therefore totaled approximately 125,000 pounds. Dividing this figure into the total cost figure of $19,297, we find that the average cost per pound of rainbow trout returned to the angler during the 1958 season was slightly over $0.15.

During the same years, production costs of catchable-sized rainbow trout, which provide the main form of management for roadside waters in the Inyo-Mono area, averaged $0.76 per pound for the three installations mentioned above. Assuming an average recovery rate of 85 percent (von Geldern, 1960, and Pister, 1961), the cost per pound of catchable trout returned to the creel in 1958 was $0.90. Despite the efficiency of the Inyo-Mono catchable program, it is possible to provide six pounds of trout to the creel at Crowley Lake for the same cost as each pound returned to the creel by the catchable program. Angler satisfaction is, needless to say, much higher at Crowley because of the larger fish.

With the exception of brown trout, it is impossible to estimate the management cost of the other species of trout planted in Crowley Lake in terms of pounds returned to the creel, since it is not known what percentage of the catch is supplied by naturally produced fish. Brown trout, however, are no longer stocked in Crowley, so it is safe to assume that the entire catch is provided through natural reproduction.

FOOD AND FEEDING HABITS OF TROUT

The great abundance of midges (Tendipedidae) in Crowley Lake is especially significant when one considers the value of these organisms as a food for trout, and the degree to which trout feed upon them. All of the rainbow trout stomachs examined contained tendipedids, with pupae comprising 89 percent of the total volume (Table 6).

Tendipedid larvae generally remain in or near the bottom of lakes and do not become readily available for consumption by trout until their journey to the surface as pupae to emerge as adult insects. This emergence occurs principally in the early morning hours, during one of the most active periods of trout feeding, and thus probably explains the large numbers of pupal and emerging forms found in the stomachs of the fish. Concerning the value of tendipedids (Tendipedidae-Chironomidae) as trout food, Johannsen (1937) states the following: "The ability of the chironomids to live on foodstuff that has a general distribution, their ability to build their own shelter and their consequent adaptability to a variety of conditions, their great reproductive capacity, and their brief life cycle, combine to make these insects so important a forage organism for fish."

Next in importance to tendipedid pupae was zooplankton. Cladocera made up over 10 percent of the total volume of organisms consumed and were present in 33 percent of the stomachs examined. Tendipedid larvae were taken only rarely, presumably because of their bottom dwelling habit. In addition to insects and plankton, small nongame fish, chiefly Siphateles sp., are consumed in large numbers by rainbow trout during the fall months. During this period the young Siphateles sp. are about two inches in length.

Insufficient numbers of brown and cutthroat trout stomachs were available to obtain a valid picture of the feeding habits of these species. Nine brown trout stomachs examined in 1958 contained approximately equal volumes of ramshorn snail (Helisoma sp.) and chironomid pupae.

GROWTH AND CONDITION

Growth

The growth of subcatchable rainbows in Crowley Lake has, through the years, followed a regular pattern. Fish planted in August at a mean fork length of 5.8 inches and 1.6 ounces (10 per pound) attain a mean fork length of approximately 10 inches and a weight of 9 ounces before ice-cover forms in December. By the beginning of the angling season near the first of May (about five months later), these fish reach a mean fork length of nearly 12 inches and a weight of about one pound. Since ice and snow generally cover the lake from late December through late March or early April, winter growth may be considered exceptionally good.

Growth continues at a good rate during the season and, by mid-June, the mean sizes are nearly 13 inches and 20 ounces. By the end of the season in late July, fish are approximately 14 inches in length and 26 ounces in weight.

Rainbow trout which go through their first angling season without being caught enter the catch as 2+ fish at the beginning of the following season when about 17 inches long and 37 ounces in weight. The few which remain into July are taken at a mean fork length of approximately 18 inches and a weight of approximately 46 ounces.

TABLE 6

Foods Consumed by Crowley Lake Rainbow Trout, 1953

Organism	Stomachs containing organism		Number organisms	Volume (cc.)	Percent total volume
	Number	Percent			
Tendipedidae pupae	18	100.0	9,763	113.5	89.3
Tendipedidae larvae	1	5.6	4	0.1	+
Cladocera	6	33.3	Not counted	13.2	10.4
Copepoda	1	5.6	Not counted	0.3	0.2

Dates of collection: May 9, 16; June 5, 21, 23; July 5

Size range of fish (pounds): 1.0 to 3.5

Number of stomachs examined: 18

Number of empty stomachs: 0

Survival into the third year by Crowley Lake rainbow trout is negligible, but an occasional fish of the 3+ age class is taken at about 20 inches and 4 pounds.

The season's catch of rainbow trout at Crowley Lake is comprised of approximately 95 percent 1+ and 5 percent 2+.

The virtual absence of 3+ and 4+ rainbow trout in the catch is difficult to explain. It is surmised that this is attributable to heavy angling pressure and harvest, an extraordinarily rapid growth rate, and the genetic characteristic of the strain itself.

Although the growth rates of cutthroat and brown trout have not been thoroughly investigated, examination of scales from these species indicates that their growth is also very rapid.

The rapid growth rate of Crowley Lake rainbow trout is particularly impressive when compared with growth rates of the same species from nearby lakes. In a study of the growth rates of rainbow trout in Convict Lake, located about five miles west of Crowley Lake, Reimers, Maciolek and Pister (op. cit.) reported calculated total lengths at formation of the first, second and third annuli of 3.8, 6.4 and 11.1 inches. Slower growth rates were exhibited by rainbow trout from lakes located at higher elevations in the same drainage (Table 7). Measurements of Crowley Lake rainbow trout taken during late fall gill net sampling reveal mean total lengths of 10.1, 15.8 and 19.9 inches at the end of the first, second and third years of life. It is difficult to make direct comparisons of growth because rainbows planted in Crowley Lake are held for nearly nine months in hatcheries prior to planting. However, the exceptional growth of fish in Crowley Lake is obvious.

Condition

The condition factor K was calculated for 138 Crowley Lake trout collected during the 1958 season (Table 8). This factor, which is in general use to indicate plumpness in relation to length, was calculated according to the formula:

$$K = \frac{\text{Weight in grams x 100,000}}{\text{Total length in millimeters}^3}$$

Rainbow trout collected during the early portion of the angling season had a mean condition factor of 1.30, whereas mean condition factors for brown and cutthroat trout were calculated to be 1.06 and 0.94, respectively. Reimers, Maciolek and Pister (op. cit.) reported average condition factors ranging between 0.88 and 1.15 for rainbow trout in three lakes of the Convict Creek Basin and an average condition factor of 1.05 for brown trout in Convict Lake.

Although the average condition factor for rainbow trout was significantly higher for Crowley Lake, the brown trout condition factors were nearly identical. This may be explained at least partially by the spawning habits of the species involved. Rainbow trout of the Hot Creek fall spawning strain have not been observed to spawn extensively under natural conditions and therefore do not undergo the rigors of the spawning process and the accompanying loss of body weight which ordinarily accompanies spawning. Brown trout, however, do not finish their spawning activities until early winter and apparently are unable to regain their normal condition during the period of ice-cover preceding the angling season. Cutthroat trout generally are in the midst of their spawning activities at the onset of the angling

TABLE 7

Trout Growth and Condition in Crowley Lake and Nearby Waters[1]

Lake and species of trout	Year of life 1	2	3	KTL
Crowley, rainbow	10.1	15.8	19.9	1.30
Convict, rainbow	3.8	6.4	11.1	1.02
Mildred, rainbow	3.6	5.7	7.7	1.15
Dorothy, rainbow	3.4	5.8	8.2	0.88
Crowley, brown	9.4	14.6	18.7	1.06
Convict, brown	3.9	8.5	12.5	1.05

[1] Average calculated lengths in inches at annuli formation for trout in various lakes of the Convict Creek Basin, Mono County (Reimers, Maciolek and Pister, 1955). Figures for Crowley Lake are mean actual lengths at the end of each year of life. Condition factors (KTL) were calculated from total lengths in millimeters.

TABLE 8

Average Coefficients of Condition (KTL) for Crowley Lake Trout

Species	Number of fish	Size range total length (inches)	Size range total length (mm.)	K total length (mm.)
Rainbow	50	11.3 to 18.7	287 to 475	1.30
Cutthroat	61	12.0 to 25.6	305 to 650	0.94
Brown	27	13.3 to 22.4	338 to 569	1.06

season, and their relatively poor condition is probably attributable to this factor. All trout species collected toward the end of July appear to be in better condition than in early May.

EFFECT OF RESERVOIR FLUCTUATIONS AND WINTER CONDITIONS ON TROUT GROWTH

The size of Crowley Lake may vary considerably from year to year, depending upon the amount of precipitation received in the drainage area. However, the lake has never been drawn down to a level where a reduction in food organisms has seriously reduced trout growth.

Ordinarily, Crowley Lake gradually decreases in surface acreage during the fall and winter months, reaches a low point in late winter or early spring, and then approaches its maximum acreage for the year during midsummer as runoff is stored. Under present management practices, the production of food organisms has been sufficient to maintain excellent trout growth.

Occasionally an unusually good growth year occurs. While the mean weight of rainbow trout taken during the opening weekend of the angling season is usually about one pound, instances have occurred in which the mean is considerably higher. This is well illustrated by growth data gathered from the groups of fish planted in 1959 and 1962 (Table 9). Although the growth rates of these two groups of fish were similar between August and November, the fish planted in 1962 grew much more rapidly in the period between November and the following May, reaching a mean weight of 18.9 ounces as compared to 15.3 ounces for the 1959 plant.

The most obvious explanation lies in the differences in the periods of ice-cover and the operation of the reservoir, which determines the amount of productive shoal area, during the two overwinter periods involved. During the winter of 1959-60, the lake had an ice-cover for 13 weeks, extending from December 15 through March 17, while the surface area decreased from 4,300 acres on November 1 to 3,600 acres on May 1. During the winter of 1962-63, conditions were very different. Ice was present for only seven weeks, extending from December 13 through February 2, and for only a short period was the lake completely covered. Surface acreage increased in this season from 3,950 on November 1 to 4,450 on May 1. It is reasonable to assume, therefore, that shoal area food production and conditions for trout growth were much better during the early portion of 1963 than during the same period in 1960.

FISH PRODUCTION OF CROWLEY LAKE

During the 1958 season a mean total catch of 142,149 trout was calculated. The mean weight of rainbow trout taken in 1958 was slightly over one pound each, whereas brown trout and cutthroat trout averaged approximately two pounds. The total estimated weight of trout taken in 1958 was 160,000 pounds. During the period August 1957, through July, 1958, the mean surface area of Crowley Lake was approximately 4,800 acres. Deducting the weight of trout planted during the previous season (26,943 pounds) from the total weight taken, we find that the lake yielded a net weight of 27.7 pounds per acre to the fishery.

Despite the fact that ever-increasing numbers of fish are planted in Crowley Lake, the point has not yet been reached where a decrease in the growth rate has occurred. In addition, the production of unharvested brown trout is difficult to estimate. Consequently, it is impossible at this time to calculate the maximum productive capacity of the lake. It may be in the neighborhood of 50 pounds per acre.

TABLE 9

Comparison of Growth Rates of Rainbow Trout Planted in 1959 and 1962

Date	1959 plant August 3	1962 plant August 1
Mean weight at planting (ounces)	2.6	2.7
Mean weight in early November (ounces)	9.0	8.5
Mean weight gain since planting (ounces)	6.4	5.8
Mean weight at opening of following season (early May) (ounces)	15.3	18.9
Mean weight gain since early November (ounces)	6.3	10.4
Mean fork length at planting (inches)	7.0	7.0
Mean fork length in early November (inches)	9.8	9.9
Mean length gain since planting (inches)	2.8	2.9
Mean length at opening of following season (early May) (inches)	12.2	12.8
Mean length gain since early November (inches)	2.4	2.9
Mean monthly weight gain, August to November (ounces)	2.1	1.9
Mean monthly weight gain, December to May (ounces)	1.1	1.7
Mean monthly length gain, August to November (inches)	0.9	1.0
Mean monthly length gain, December to May (inches)	0.4	0.5

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SOME LIMNOLOGICAL FACTORS INFLUENCING THE TROUT FISHERY OF CROWLEY LAKE, MONO COUNTY, CALIFORNIA[1]/

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INTRODUCTION

Of the many fishable waters in the Inyo-Mono area of eastern California, Crowley Lake is the largest and perhaps the most used. Each year anglers flock to Crowley Lake (over 60,000 in 1958) to vie for the "tacklebusters" for which the lake has become famous. Recreational facilities at Crowley are operated by the City of Los Angeles, with over 100 rental boats available. Launching areas for private boats are available also. Creel census figures for 1958 indicate that about 87 percent of the trout caught were rainbow trout (Salmo gairdnerii), the remainder being brown trout (Salmo trutta) and Lahontan cutthroat trout (Salmo clarkii henshawi).2/ The angling season at Crowley generally begins on the Saturday nearest May 1 and closes on July 31.

In order to maintain good catches, the Department of Fish and Game stocks over 200,000 subcatchable-sized rainbow trout (about 12 per pound) each fall. Occasional plants of kamloops rainbow (Salmo gairdnerii kamloops) and cutthroat fingerlings are made also. With the advantage of the long growing season and abundant food supply, these trout show considerable growth before the start of the next angling season. Rainbow trout planted in August at an average size of 12 per pound frequently attain weights in excess of a pound each by the beginning of the following season. Examination of scales from brown trout and cutthroat trout indicates that growth made by these species is also very rapid. Relatively rapid growth appears to continue during the winter; however, feeding habits, food abundance and growth in the winter have not been investigated.

During the spring of 1953, a series of investigations was started to gain more basic knowledge of Crowley Lake and its trout fishery to evaluate management practices. Trout stomachs were preserved and scale samples were taken; weights and length measurements were recorded regularly during creel census activities; measurements were made of temperature, dissolved oxygen, plankton abundance, and turbidity;and bottom samples were taken at four stations. Observations were carried out at irregular intervals throughout the spring, summer, and fall of 1953. Limitations of the sampling procedure are recognized (Reimers, Maciolek, and Pister, 1955). It is believed, however, that sufficient data have been gathered to afford a reasonable picture of the limnology of Crowley Lake and the effect of various limnological factors on the trout population.

It should be borne in mind that lake productivity studies involve consideration of a multitude of factors, any one of which may be of greater importance to the problem at hand than is currently recognized. The factors emphasized here are largely the author's personal opinion, based on field and laboratory observation and pertinent references to the literature. Unless stated otherwise, all dates listed in this report pertain to 1953.

1/ Submitted July 26, 1960. Inland Fisheries Administrative Report No. 60-11.
2/ A report concerning the 1958 Crowley Lake fishery is in preparation.

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DESCRIPTION OF CROWLEY LAKE

Crowley Lake is located on the eastern slope of the Sierra Nevada at an elevation of 6,781 feet. The lake was created in April, 1941, when the Long Valley Dam was placed in operation by the Los Angeles Department of Water and Power to impound the waters of the Owens River. ~~Four~~ Five years later, on ~~April~~ March 11, 1946, Crowley Lake reached its present size, and water began to flow over the dam's spillway. When filled to spill level, the lake is roughly six miles long and three miles wide. Maximum depth is 114.5 feet, and surface area is 5,272 acres. Volume at spill level is 183,743 acre feet, and mean depth was calculated to be 34.85 feet.

As the lake gradually filled, large areas of meadowland and sagebrush flats were inundated, and the resulting bottom material proved to be very productive of fish food organisms. Bottom types are chiefly mud and ooze, grading to gravel and sand in the shoal areas. The unusually high productivity of bottom food is apparently becoming stabilized at a point somewhat lower than that which existed during the first few years after flooding, but is still considerably above the "average" for lakes at this general elevation. Since Crowley Lake is located so high above sea level, winter conditions are severe, and the lake almost invariably freezes over its entire surface. Ice cover usually forms in December or January and disappears early in April.

METHODS

Four sampling stations were established at depths of 75, 35, 25, and 15 feet (Figure 1). Temperatures, Secchi disc readings, plankton hauls, bottom samples, and dissolved oxygen samples were taken at the 75-foot station. Bottom samples only were taken at the other three stations.

Temperatures taken at intervals from the surface to a point near the bottom were obtained from water samples immediately after they were brought to the surface in a standard Kemmerer water sampler.

Water transparency was measured near noon on calm, sunny days with a standard Secchi disc 20 centimeters in diameter. The mean of several disappearance and reappearance values measured in feet was used as the final figure.

Plankton samples were obtained by means of a Wisconsin-type net constructed of No. 20 silk bolting cloth with an opening of 11.6 centimeters. Hauls were made from a depth of 20 feet to the surface. Because of the unusually large numbers of plankton organisms present in the lake during plankton blooms, the net very likely was clogged to some extent and became inefficient to an unknown degree.

Table 1
Chemical Analysis of Crowley Lake Waters,
Compared with Analyses of Waters of Lakes in the Convict Creek Basin
(Reimers, Maciolek, and Pister, 1955)

	Crowley	Convict	Mildred	Dorothy	Genevieve	Edith	Clover-leaf	Bright Dot	Bighorn	Witsana-pah	Constance
Silica	29.0	11.0	8.0	3.6	7.1	7.0	5.5	8.7	7.6	5.4	4.7
Iron	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.02
Manganese	0.00	*∠.01	∠.01	∠.01	∠.01	∠.01	∠.01	∠.01	∠.01	∠.01	∠.01
Boron	0.72	0.01	0.04	∠.01	0.01	0.01	∠.01	0.06	0.01	∠.01	∠.01
Calcium	20.00	22.00	16.00	3.60	4.40	3.30	2.60	17.00	11.00	7.60	6.70
Magnesium	4.20	1.0	0.7	0.4	0.4	0.3	0.5	0.7	0.6	0.6	0.5
Sodium	34.0	1.1	0.7	0.4	1.1	0.9	1.3	0.4	0.4	0.7	0.6
Potassium	5.5	1.7	1.4	1.7	1.0	1.2	1.1	1.0	1.7	1.4	1.4
Bicarbonate	133.0	62.0	46.0	11.0	17.0	13.0	14.0	54.0	19.0	20.0	17.0
Sulfate	10.0	9.1	8.3	3.8	3.3	3.0	1.8	5.2	16.0	6.3	5.4
Chloride	17.0	0.1	0.2	0.1	0.3	0.4	0.6	0.1	0.4	0.7	0.4
Fluoride	0.6	∠.1	∠.1	∠.1	∠.1	∠.1	∠.1	∠.1	∠.1	∠.1	0.1
Nitrate	0.4	0.12	0.08	0.06	0.06	0.06	0.19	0.06	0.1	0.04	0.1
NH_3	.042	.017	.052	.016	.024	.024	.028	.02	.02	.03	.028
NO_2	.000	.003	.001	.002	.06	.001	.001	.001	.002	.001	.001
Copper	.00	.12	.08	.1	.08	.12	.08	.06	.10	.06	.08
PO_4	.30	.06	∠.01	∠.01	.07	∠.01	.04	∠.01	∠.01	∠.01	.02
T D S	187.	77.0	58.0	19.0	26.0	23.0	20.0	60.0	47.0	33.0	28.0
Hardness as $CACO_3$	67.	59.0	43.0	11.0	13.0	10.0	9.0	45.0	30.0	21.0	19.0
Non-carbonate	.0	8.0	5.0	.0	.0	.0	.0	1.0	14.0	5.0	.0
Specific Conductance	28.8	121.0	91.0	24.0	33.0	26.0	23.0	91.0	68.0	47.0	41.0
P H	7.3	7.9	8.0	7.2	7.2	7.0	7.1	7.9	7.3	7.3	7.2

*∠ - means less than

bottom fauna. The importance of morphometry on the production of organic matter in lakes has been noted by Thienemann (1927) and Rawson (1952, 1953a, and 1953b). Similarly, the significance of geology and dissolved nutrients are discussed by Naumann (1932), Deevey (1940), and Moyle (1946). The importance of the above factors are discussed further by Reimers, Maciolek, and Pister (op. cit.), who found the relationships among total dissolved solids, morphometry, and productivity to be generally true, although biological measurements between the 10 lakes examined were found to show little relationship to each other.

Temperatures

Surface temperatures in Crowley Lake reached a maximum on July 23, when 75 degrees F. was recorded, and were in the 70's from mid-July throughout August. Thermal stratification was evident throughout the summer, but at no time did it reach a degree sufficient for the establishment of a well-defined thermocline (Table 2). Spring overturn probably occurred in late April, shortly after the breakup of ice; fall overturn probably occurred in late September. Identical temperatures were recorded from bottom to surface on October 1.

Plankton

The long, warm period in mid-summer results in a heavy plankton bloom, the predominant organisms of which are blue-green and green algae (Gloeotrichia sp. and Volvox sp.). At the height of the bloom, measured on August 18, 1953, an average of over 100,000 colonies of Gloeotrichia sp. per cubic foot of water was measured in a plankton haul made from a depth of 20 feet to the surface of the lake. Cladocerans were also at a maximum on this date, when 2,250 organisms per cubic foot were measured. Copepods reached their maximum about six weeks earlier, when 1,495 organisms per cubic foot were collected on July 2 (Table 3).

The plankton bloom appeared to be strictly a "hot-weather" phenomenon, occurring when surface temperatures approached or exceeded 70 degrees F. Plankton volumes increased gradually from 1.59 cubic centimeters per cubic foot on May 13 (surface temperature 53 degrees F.) to 18.75 cubic centimeters per cubic foot on August 18 (surface temperature 71 degrees F.), and decreased rapidly thereafter. On November 12, the plankton sampled comprised only Aphanothece sp. and Cladocera, which were present in fairly large numbers (Table 3). Cladocerans maintained their numbers throughout the sampling period, while copepods diminished markedly during the falling water temperatures of late summer and fall. The apparent inverse relationship which existed between the two major phytoplankton species, Volvox sp. and Gloeotrichia sp., suggests that conditions are more favorable for Volvox sp. during spring and early summer, while Gloeotrichia sp. is more favored by conditions existing during mid-summer.

Transparency

As might be expected, the heavy concentration of algae had a decided effect on the transparency of the lake. During the height of the bloom on August 18, a standard 20-centimeter Secchi disc was visible to a depth of only five and one-half feet. A maximum Secchi disc reading of 20 feet occurred on May 13, when only 64 Volvox sp. colonies per cubic foot were collected. Other readings varied between these two values, depending upon the numbers of plankton organisms present at the time (Tables 2 & 3). In addition to Volvox sp. and Gloeotrichia sp., Stephanodiscus sp. and other diatoms were present in fairly large numbers, although no counts were made of these organisms.

Table 2

Temperatures, Dissolved Oxygen, Transparency, and Plankton Volumes of Crowley Lake, 1953

Date (1953)	Time	Temperature in Degrees Fahrenheit (Dissolved Oxygen Listed in Parentheses) Air	Surface	10ft.	20ft.	30ft.	40ft.	50ft.	60ft.	70ft.	80ft.	Secchi Disc (Feet)	Plankton cc/cubic ft.
May 13	11:00A.M.	55	53	52	50	50	50	51	50	50		20	1.59
May 19	10:30A.M.	60	55(7.8)		53(7.8)		52(6.8)		51(6.2)	51		17	1.81
May 29	11:00A.M.	64	56(7.4)		52(7.4)		51(7.4)		52(7.4)			17	.23
June 5	11:00A.M.	60	58(8.4)		55(7.6)		53(7.6)		52(6.4)			19	1.48
June 16	11:00A.M.	67	59(9.4)		58(8.8)		57(8.2)		55(7.6)			15.5	2.27
June 23	11:00A.M.	74	66(9.8)		61(9.0)		58(7.0)		57(5.8)			19	2.38
July 2	11:00A.M.	63	63(7.0)		62(6.4)		61(6.0)	59(4.4)	58(3.4)	57(2.8)		19	1.59
July 7	11:00A.M.	70	69(7.0)	68(7.2)	64(5.8)	64(5.2)	63(4.6)	61(3.8)	60(3.0)	59(2.2)		19.5	1.48
July 15	11:00A.M.	71	70(6.8)	69(6.8)	69(6.8)	67(4.6)	65(4.0)	63(2.8)	62(2.0)	61(1.4)		15	1.12
July 23	11:00A.M.	74	75(9.8)	74(9.0)	71(7.0)	68(5.0)	65(3.8)	64(2.8)	63(1.6)	63(0.9)		9	2.61
July 30	10:00A.M.	71	73(9.2)	73(8.4)	71(6.8)	70(4.2)	67(3.4)	64(2.4)	63(1.0)	62(0.7)		9.5	3.63
August 4	10:00A.M.	65	72(11.2)	71(10.4)	70(8.2)	68(7.2)	65(4.0)	64(1.8)	62(0.9)	61(0.8)		5.5	17.05
August 5	4:00A.M.	48	70(9.8)	68(9.4)	68(8.6)	65(4.6)	64(4.6)	62(1.1)	61(0.6)	60(0.6)			
August 18	2:00P.M.	80	71(12.6)	70(12.6)	69(8.0)	67(6.4)	66(3.0)	65(1.2)	63(0.8)	63(0.4)		5.5	18.75
Sept. 10	1:00P.M.	70	68(12.4)	67(12.4)	65(10.0)		64(7.4)		63(4.0)			8.0	3.55
October 1	1:00P.M.	63	62(12.0)		62(12.0)		62(9.2)		62(8.6)	62(6.8)		9.0	1.59
Nov. 12	3:00P.M.	60	48									9.0	1.02
August 5	5:00A.M.	At boat dock. Surface temp. 70°F, O_2 9.8 p.p.m. At 8 foot depth, temp. 69°F, O_2 4.0 p.p.m.											

Table 3

Summary of Plankton Productivity, Crowley Lake, 1953

Date (1953)	Surface Temperature	Time	Mean Volume in Cubic Centimeters in 1 Cubic Ft. of Water	Mean Number of Organisms Per Cubic Foot of Water: Cladocera	Copepoda	Volvox sp.	Gloeotrichia sp.	Aphanothece sp.
May 13	53	11:00A.M.	1.59	1,236	827	64	0	0
May 19	55	10:30A.M.	1.81	1,745	1,273	727	0	0
May 29	56	11:00A.M.	0.23	No Count Made				
June 5	58	11:00A.M.	1.48	591	295	10,636	0	266
June 16	59	11:00A.M.	2.27	727	1,091	40,545	0	0
June 23	66	11:00A.M.	2.38	525	668	16,705	0	0
July 2	63	11:00A.M.	1.59	1,082	1,495	trace	382	795
July 7	69	11:00A.M.	1.48	413	1,447	trace	473	591
July 15	70	11:00A.M.	1.12	682	932	250	2,682	45
July 23	75	11:00A.M.	2.61	732	418	1,000	13,427	2,300
July 30	73	10:00A.M.	3.63	727	800	150	12,654	2,327
August 4	72	10:00A.M.	17.05	681	681	0	65,227	10,909
August 5	70	4:00A.M.	8.29	663	332	500	22,295	10,452
August 18	71	2:00P.M.	18.75	2,250	375	0	104,636	18,000
September 10	68	1:00P.M.	3.55	894	215	0	720	52,000
October 1	62	1:00P.M.	1.59	509	191	125	300	74,454
November 12	48	3:00P.M.	1.02	859	0	0	0	4,170

Bottom Fauna

Bottom samples were taken at four stations located at various depths and locations around the lake (Figure 1). Station 1, located in silt at a depth of 90 feet, proved to be relatively unproductive. A few chironomid larvae (bloodworms) were taken from this depth; the only other organisms collected here were oligochaetes (Table 4).

Station 2, in coarse gravel at a depth of 35 feet, was fairly productive, yielding an average of 32 chironomid larvae per dredge haul. Some chironomid pupae were collected from this station, as were oligochaetes, and bivalve mollusks of the genus *Pisidium* (Table 5).

Station 3, located in clay and sand at a depth of 25 feet, was by far the most productive of the sampling stations. An average of 124 chironomid larvae per dredge was collected in 11 separate hauls, the maximum number of organisms being 283 and the minimum 37. In addition to the above, small numbers of chironomid pupae, mollusks, and oligochaetes were taken (Table 6).

Station 4 was located in a bed of algae, aquatic plants, and silt at a depth of 15 feet. This proved to be the second most productive area, yielding an average of 82 chironomid larvae per dredge haul. Small numbers of chironomid pupae, oligochaetes, and mollusks were also taken at this point (Table 7).

Thirty-two bottom samples were taken at the three shallower stations between the dates of May 13 and August 18 (Table 8). Of 3,094 organisms collected in these hauls, 2,551, or 82 percent, were chironomid larvae. The next most prevalent organisms were oligochaetes, which formed 10 percent of the total number. Chironomid pupae, water mites (Hydracarina), flatworms (Planariidae), and mollusks (*Pisidium* sp., *Planorbis* sp., *Physa* sp., *Lymnaea* sp., and *Helisoma* sp.), were collected also.

The average standing crop of bottom fauna lying beneath less than 50 feet of water during the period of sampling (May 13 to August 18) was calculated to be 185 pounds per acre, as determined by wet weights of the organisms collected. The bottom area of Crowley Lake lying beneath less than 50 feet of water is approximately 4,368 acres, or 83 percent of the total acreage, measured at level of spill. Even assuming the bottom area lying beneath more than 50 feet of water to be completely unproductive, which it obviously is not, the total standing crop of bottom fauna was estimated to be over 400 tons during the summer of 1953. The average standing crop of bottom fauna for the entire lake was calculated to be 153 pounds per acre.

Most limnological studies made in the western United States have been carried out in lakes of a strongly oligotrophic character. Since Crowley Lake is a man-made reservoir and is very young (approximately 12 years at the time of sampling), it perhaps should not be compared with natural, older lakes. Furthermore, various characteristics of Crowley Lake closely approach the criteria established by Welch (*op. cit.*) for a eutrophic lake (i.e., phytoplankton is chiefly of the cyanophyte-diatom type). However, since relatively little information is available on western waters similar to Crowley Lake, these older, oligotrophic lakes provide the only bases for comparison.

Table 4

Bottom Fauna, Crowley Lake, 1953: Station 1

Organism	Samples containing this Organism		Organisms	
	Number	Percent	Number	Percentage Total Number
Chironomid larvae	9	82	19	26.4
Oligochaeta	11	100	53	73.6

Depth: 75 feet
Number of Samples: 11
Number of bottom organisms per square foot: 26
Estimated weight of bottom fauna per acre (pounds): 12.36
Type of bottom: Silt and detritus (organic ooze)

Table 5

Bottom Fauna, Crowley Lake, 1953: Station 2

Organism	Samples containing this Organism: Number	Samples containing this Organism: Percent	Organisms: Number	Organisms: Percentage Total Number
Chironomid larvae	11	100.0	375	67.9
Chironomid pupae	7	63.6	20	3.6
Oligochaeta	10	90.9	94	17.0
Hydracarina	2	18.2	5	0.9
Pisidium sp.	11	100.0	50	9.1
Planorbis sp.	1	9.1	1	0.2
Physa sp.	1	9.1	3	0.5
Planariidae	2	18.2	4	0.7

Depth: 35 feet
Number of Samples: 11
Number of bottom organisms per square foot: 200
Estimated Weight of bottom fauna per acre (pounds): 95.4
Type of bottom: Coarse gravel

Table 6

Bottom Fauna, Crowley Lake, 1953: Station 3

Organism	Samples containing this Organism: Number	Samples containing this Organism: Percent	Organisms: Number	Organisms: Percentage Total Number
Chironomid larvae	11	100.0	1,359	87.7
Chironomid pupae	5	45.5	21	1.4
Oligochaeta	5	45.5	102	6.6
Hydracarina	1	9.1	1	0.1
Pisidium sp.	5	45.5	10	0.6
Planorbis sp.	6	54.5	31	2.0
Physa sp.	5	45.5	11	0.7
Planariidae	3	27.3	15	1.0

Depth: 25 feet
Number of Samples: 11
Number of organisms per square foot: 56.4
Estimated Weight of bottom fauna per acre (pounds): 269.1
Type of bottom: Clay and sand

Table 7

Bottom Fauna, Crowley Lake, 1953: Station 4

Organism	Samples containing this Organism		Organisms	
	Number	Percent	Number	Percentage Total Number
Chironomid larvae	10	100.0	817	82.4
Chironomid pupae	4	40.0	9	0.9
Oligochaeta	6	60.0	109	11.0
Hydracarina	1	10.0	12	1.2
Pisidium sp.	3	30.0	6	0.6
Planorbis sp.	4	40.0	10	1.0
Physa sp.	1	10.0	1	0.1
Planariidae	4	40.0	27	2.7

Depth: 15 feet
Number of Samples: 10
Number of organisms per square foot: 396.4
Estimated Weight of bottom fauna per acre (pounds): 189.0
Type of bottom: Algae, aquatic plants and silt

Table 8

Summary of Bottom Fauna Productivity, Crowley Lake, 1953

Organism	Samples containing this Organism		Organisms	
	Number	Percent	Number	Percentage Total Number
Chironomid larvae	32	100.0	2,551	82.0
Chronomid pupae	16	50.0	50	1.8
Oligochaeta	21	65.6	305	10.0
Hydracarina	4	12.5	18	0.6
Pisidium sp.	19	59.4	66	2.1
Planorbis sp.	11	33.3	42	1.5
Physa sp.	7	21.9	15	0.5
Planariidae	9	28.1	46	1.5

Stations 2, 3, and 4.
Number of Samples: 32
Dates of sampling: May 13 - August 18
Mean number of bottom organisms per square foot: 386.8
Mean weight of bottom fauna per acre of area less than 50 feet deep: 185 pounds

To give a comparison between Crowley Lake and Sierra Lakes lying at similar elevations, Calhoun (1944) reported a productivity of 134 pounds per acre for Upper Blue Lake, located at an elevation of 8,130 feet in Alpine County, California. Convict Lake, located not more than 10 miles from Crowley Lake at an elevation of 7,583 feet, was found to have a bottom productivity of 34.57 pounds per acre, as determined in September, 1951. Lakes Cloverleaf and Mildred, located in Convict Creek Basin at elevations above 9,000 feet, produced bottom fauna in excess of 200 pounds per acre (Reimers, Maciolek, and Pister, op. cit.). Although the productivity of bottom fauna in Crowley Lake is not extraordinarily high per unit area, so much of the lake is of a shallow character that the overall production of food organisms is quite substantial.

Effect of Dissolved Gases on the Fish Population

Dissolved oxygen in the upper stratum of Crowley Lake was plentiful, even reaching a state of supersaturation on numerous occasions (Table 9). However, dissolved oxygen decreased markedly at the lower depths as light penetration and photosynthetic activity diminished. This oxygen deficiency at lower depths may very possibly be one of the factors contributing to the mortality of considerable numbers of rough fish and an occasional trout during the mid-summer months. This die-off is not believed to be serious enough to cause any concern regarding the survival of the fishery, but is large enough to be offensive to anglers, when dead fish drift in to shore and decompose.

Prescott (1951) states that in summer Gloeotrichia sp. becomes so concentrated as to form a veritable puree in bays and near the shoreline (which it does in Crowley Lake), and follows with the statement that such superabundant growths are frequently followed by unbalanced biological conditions as a result of the death and decay of plant masses. To add to the depreciation of the oxygen supply by algae blooms, rooted aquatic plants of various species become so abundant during the time of fish mortality that trolling by anglers in the shoal areas becomes impossible. There is little doubt that oxygen concentrations drop even lower at night, when oxygen is utilized rather than released by plant life. A measurement made at 4:30 a.m. on August 5, at a point eight feet in depth near the shore, indicated a dissolved oxygen content of only 4.0 p.p.m., which, in this situation, is probably inadequate for the maintenance of fish life. The water temperature was 69 degrees F at this point.

Doudoroff (1957), in discussing minimum oxygen tolerances of fish, states that high temperatures, extremes in pH, and high concentrations of carbon dioxide and other toxic substances markedly increase the susceptibility of fish to a deficiency of dissolved oxygen.

Prescott (op. cit.) emphasizes the importance of carbon dioxide in the metabolism of a lake, and states that a rapid increase in carbon dioxide tension may either kill fish or seriously upset their physiology. Death, in this case, is brought about through failure to eliminate carbon dioxide from the body because of the high concentration of carbon dioxide in the water or, indirectly, through ionization forming injurious carbonic acid.

Although no direct measurements were made of the amount of carbon dioxide present in Crowley Lake during the sampling period, it may be assumed that this gas was present in rather large quantities, since it is basic to photosynthetic activity, which in turn is necessary for the maintenance of a heavy alga bloom. The role

Table 9

Dissolved Oxygen Present in Upper, Middle, and Lower Depth Strata of Crowley Lake with Saturation Values Corrected for Altitude

Date (1953)	20 ft. below surface				40 ft. below surface				60 ft. below surface			
	Temp. (Degrees F.)	O_2 p.p.m.		Per-cent Sat.	Temp. (Degrees F.)	O_2 p.p.m.		Per-cent Sat.	Temp. (Degrees F.)	O_2 p.p.m.		Per-cent Sat.
		Sat.	Act.			Sat.	Act.			Sat.	Act.	
May 19	53	8.4	7.8	93.0	52	8.5	6.8	80.0	51	8.6	6.2	72.0
May 29	52	8.5	7.4	87.0	51	8.6	7.4	86.0	52	8.5	7.4	87.0
June 5	55	8.2	7.6	93.0	53	8.4	7.6	91.0	52	8.5	6.4	75.0
June 16	58	7.9	8.8	111.0	57	8.0	8.2	102.0	55	8.2	7.6	93.0
June 23	61	7.6	9.0	118.0	58	7.9	7.0	89.0	57	8.0	5.8	73.0
July 2	62	7.6	6.4	84.0	61	7.6	6.0	79.0	58	7.9	3.4	43.0
July 7	64	7.4	5.8	78.0	63	7.5	4.6	61.0	60	7.7	3.0	39.0
July 15	69	7.1	6.8	96.0	65	7.3	4.0	55.0	62	7.6	2.0	26.0
July 25	71	6.9	7.0	101.0	65	7.3	3.8	52.0	63	7.5	1.6	21.0
July 30	71	6.9	6.8	99.0	67	7.2	3.4	47.0	63	7.5	1.0	13.0
August 4	70	7.1	8.2	115.0	65	7.3	4.0	55.0	62	7.6	0.9	12.0
August 5	68	7.2	8.6	120.0	64	5.3	4.6	87.0	61	8.6	0.6	7.0
August 18	69	7.1	8.0	113.0	66	7.3	3.0	41.0	63	7.5	0.8	11.0
September 10	65	7.3	10.0	137.0	64	7.4	7.4	100.0	63	7.5	4.0	53.0
October 1	62	7.6	12.0	147.0	62	7.6	9.2	121.0	62	7.6	8.6	113.0

of carbon dioxide in the die-off of Crowley Lake fish during mid-summer is advanced simply as a possible explanation of this phenomenon. No actual measurements were made of carbon dioxide content, since accurate field equipment was not available.

Other factors possibly entering into the aforementioned mortality are disease, and another theory, advanced by Prescott (op. cit.), that fish may be killed by poisonous substances, such as hydroxylamine, produced by the decay of proteins, which blue-green algae contains in large amounts.

Food and Feeding Habits of Trout

The great abundance of Chironomidae in Crowley Lake is especially significant when one considers the value of these organisms as a food for trout, and the degree to which trout feed upon them. All of the rainbow trout stomachs collected throughout the season contained Chironomidae, and the pupae comprised 89 percent of the total volume of natural foods found to be consumed by these fish (Table 10).

Chironomid larvae generally remain in or near the bottom of lakes and do not become readily available for consumption by trout until their journey to the surface as pupae to emerge as adult insects. This emergence was observed to occur principally in the early morning hours, during one of the most active periods of trout feeding, and thus probably explains the large numbers of pupal and emerging forms found in the stomachs of the fish. Concerning the value of chironomids as trout food, Johannsen (1937, part IV, page 3) states the following: "The ability of the chironomids to live on foodstuff that has a general distribution, their ability to build their own shelter and their consequent adaptability to a variety of conditions, their great reproductive capacity, and their brief life cycle, combine to make these insects so important a forage organism for fish."

Next to chironomid pupae, zooplankton was consumed in the largest volume. Cladocera comprised over 10 percent of the total volume of organisms consumed by rainbow trout and were present in 33 percent of the stomachs examined. Chironomid larvae were taken only rarely, presumably because of their bottom dwelling habit. In addition to the above, rainbow trout are known to consume large amounts of "chum" in the form of salmon eggs, mackerel, and cheese, and also to take considerable quantities of rough fish (Siphateles sp.), when these fish are of a readily consumed size. The use of chum to attract fish has since been outlawed.

Insufficient numbers of brown and cutthroat trout stomachs were available to obtain a valid picture of the feeding habits of these species. Nine brown trout stomachs examined in 1958 revealed approximately equal volumes of ramshorn snail (Helisoma sp.) and chironomid pupae.

SUMMARY AND CONCLUSIONS

Trout planted in Crowley Lake show exceptionally rapid growth. Because of the importance of this fishery, a study was started in 1953 to gain more basic knowledge of the lake and its fishery. Standard limnological procedures were used throughout the study.

The high productive capacity of Crowley Lake is probably attributable to a relatively high total dissolved solids content combined with favorable morphometric features.

Table 10

Natural Foods Consumed by Crowley Lake Rainbow Trout, 1953

Organism	Stomachs containing this organism: Number	Stomachs containing this organism: Percent	Organisms: Number	Organisms: Percent Total Number	Organisms: Volume (cc.)	Organisms: Percent total Volume
Chironomid pupae	18	100.0	9,763	100.0	113.5	89.3
Chironomid larvae	1	5.6	4	+	0.1	+
Cladocera	6	33.3	Not Counted	--	13.2	10.4
Copepoda	1	5.6	Not Counted	--	0.3	0.2

Dates of Collection: May 9, 16; June 5, 21, 23: July 5
Size range of fish (pounds): 1.0 to 3.5
Number of stomachs examined: 18
Number of empty stomachs: 0

The predominant food organisms present were immature chironomids, and these insects were consumed in large quantities by trout. Although productivity of bottom fauna in Crowley Lake is not extraordinarily high per unit area, so much of the lake is of a shallow character that the overall productivity of food organisms is quite substantial. The great area of the lake is also likely to be advantageous from the standpoint of the fish population, in that possible overcrowding by game species, with consequent reduction of food organisms and trout growth, appears unlikely.

Heavy plankton blooms occur during the warm summer months. While contributing to the productivity of the lake and furnishing some trout food, these plankton blooms create unstable biological conditions, which result in some fish mortality. Because of heavy plankton and rooted aquatic weed growth in late July, Crowley Lake becomes somewhat undesirable to the angler. Because of poor angling conditions, and to provide protection for small trout planted in the fall, Crowley Lake is closed to angling on July 31.

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Final Report

Assessment of internal nutrient loading to Crowley Lake, Mono County

(SWRCB # 00-196-160-0)

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recent data

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INTRODUCTION

The most common impairment of surface waters in the United States is eutrophication caused by excessive inputs of phosphorus (P) and nitrogen (N). 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 as impaired by nutrients by the CA Water Resources Control Board. The lake is eutrophic and is characterized by an ample supply of nutrients and significant summer algal blooms (EPA 1978, Melack and Lesack 1982). 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.

The California Regional Water Quality Control Board, Lahontan Region (RWQCB), is the State agency responsible for protection of water quality within the Lahontan Region of California. The jurisdiction of the RWQCB extends from the Oregon border to the northern Mojave Desert and includes all of California east of the Sierra crest. The RWQCB implements the goals of the federal Clean Water Act to restore and maintain the physical, chemical, and biological integrity of the nation's waters. This includes the development of Total Maximum Daily Loads (TMDLs) for water bodies that do not currently meet State standards. Crowley Lake (Long Valley Reservoir) is listed as impaired pursuant to Section 303(d) of the Clean Water Act, and the RWQCB plans to develop TMDLs for the reservoir. In order to develop TMDLs, the RWQCB will need information on nutrient inputs and dynamics.

A 2-yr study of nutrient loading to Crowley Lake found high nitrogen and phosphorus loading rates to Crowley Lake (California Water Control Board Award #9-175-256-0; Restoration to Riparian Habitat and Assessment of Riparian Corridor Fencing and Other Watershed Best Management Practices on Nutrient Load and Eutrophication of Crowley Lake, California). Measured phosphorus inputs were approximately equal to reservoir outflows suggesting very little retention by lake sediments. Nitrogen outflows from the reservoir were 3-4 times the measured inputs in precipitation and tributary inflows, suggesting the sediments or nitrogen fixation are significant sources of nitrogen. In preparation for designing and implementing TMDL's for Crowley Lake and its tributaries, the Lahontan RWQCB awarded this supplemental research grant to further assess nutrient budgets of Crowley Lake. The goals of this research were to measure summer changes in water quality and other ecological variables within Crowley Lake and to assess internal nutrient loading to the reservoir through measurements of pelagic nitrogen fixation and sediment-water fluxes. Here, we present the results of this study.

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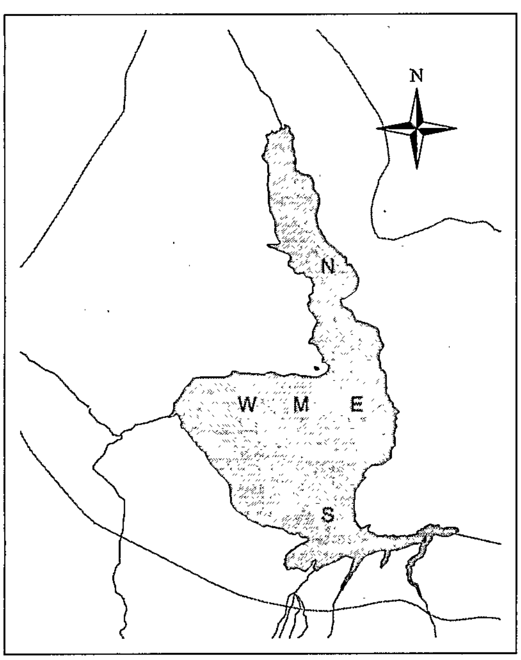
Aquatic Research Laboratory (SNARL) of the UC Natural Reserve System. Particulate carbon and nitrogen analyses were performed by the Marine Science Analytical Laboratory, UCSB. We thank the Los Angeles Department of Water and Power for providing access to the lake and Wayne Hopper (LADWP, Bishop) for providing Long Valley hydrological data.

METHODS

Field Sampling

Eight 2-day lakewide surveys were conducted at approximately biweekly intervals from 20 June 2002 to 25 September 2002 to assess limnological conditions and collect pelagic plankton samples for a variety of analyses including the measurement of nitrogen fixation rates. Five pelagic stations were chosen to represent the major sectors of the lake (Fig. 1). The N station is located midway up the long narrow portion of the lake, is relatively shallow (5-6 m), and is influenced by inflows from the Owens River, the dominant inflow and source of nutrients (see Jellison et al 2003, SWRCB #9-175-256-0). The W, M, and E stations lie along a west-east transect at the widest portion of the lake and are ~8, 15, and 18 m deep, respectively. The W station is located near the inflows from McGee Creek the second largest inflow and source of nutrients. The S station is in the central portion of the deep (23-24 m) southern portion of the lake. Although we had intended to begin the biweekly sampling immediately following our 3 April 2002 lakewide survey conducted as part of a cooperative nutrient loading study with the Los Angeles Department of Water and Power (SWRCB #9-175-256-0), they denied permission to continue sampling until review of the supplemental research included in this contract. Thus we were not able to sample again until mid-June. However, to assess the changes from several weeks after ice-off to the first sampling in mid-June we include the results of the 3 April survey in this report.

Fig. 1 Pelagic sampling stations on Crowley Lake



On the first day of the survey, temperature, dissolved oxygen, and nutrient profiles were determined to assess hypolimnetic nutrient accumulation and vertical mixing. Temperature was collected with a high-precision, conductivity-temperature-depth profiler (CTD) (Seabird Electronics, Model Seacat 19) at the two deep stations (S and E)(Fig. 1) and at two additional deep stations (one near the dam and one approximately 2 km west of station E. The two additional stations were included to lessen errors in estimating changes in the lakewide heat budget. Dissolved oxygen concentration was measured at the S and E stations at 1-m intervals 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. At the E and S stations, samples for the determination of ammonia (NH_4) and soluble reactive phosphorus (SRP) were collected with a Van Dorn water sampler at 1-m intervals from 11 m to near the bottom. Water samples were immediately filtered and kept cool and in the dark during transport to the laboratory.

For the purposes of this project, DIW is 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 $\mu S\ cm^{-1}$. For reagent and standard preparation this water is further polished by ion exchange to a specific conductance of approximately 0.5 $\mu S\ cm^{-1}$. All bottles used in water sampling were soaked in deionized water 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 which were rinsed with at least 150 ml of DIW or sample water.

On the second day of each survey a suite of physical, chemical, and biological characteristics were measured at each of the five pelagic stations (Fig. 1) and water samples collected for determination of nitrogen fixation rates. Temperature profiles were taken with a high-precision, conductivity-temperature-depth profiler (CTD) (Seabird Electronics, Model Seacat 19) equipped with a cosine-corrected photosynthetically available radiation (PAR) sensor (LiCor 191S). Both CTD and LiCor sensors are calibrated annually by the manufacturer. The CTD records at 0.5 s intervals and was deployed by hand-lowering at ~0.2 $m\ s^{-1}$. On two dates when the CTD was not available (20 June and 1 July) temperature was measured at 1-m intervals with a Yellow Springs Instruments temperature-oxygen meter (YSI, model 58) and probe (YSI, model 5739). Transparency was measured at all five stations with a 20-cm white Secchi disk.

A 5-m integrated sample was collected at all five stations for analysis of water quality, phytoplankton, and nitrogen fixation. Samples were collected with a one-inch (inner diameter) Tygon tube (#R3603) lowered into the water and retrieved by raising the lower end to the surface before draining the tube. Duplicate 60-ml subsamples for the determination of ammonia (NH_4), nitrate (NO_3) and soluble reactive phosphorus (SRP) were immediately filtered. Duplicate 60-ml subsamples for total nitrogen (TN) and total phosphorus (TP) were determined from unfiltered samples. Particulate nitrogen (PN), particulate carbon (PC), particulate phosphorus (PP) and chlorophyll a (Chl a) were determined from samples filtered in the laboratory (25 mm, ashed Whatman glass microfiber filters for PN, PC and PP; 47 mm Whatman glass microfiber filters for Chl a). Additional, duplicate 60-ml subsamples were preserved with formalin for phytoplankton identification and quantification. The remaining portion (1-2 liter) was used to assess nitrogenase activity via acetylene reduction rates during incubations conducted immediately on return to the laboratory.

Sediments were collected during autumn 2001 for use in laboratory benthic chamber experiments. Grab samples were obtained with an Ekman dredge. Gravity corers were also tried, but sediments could not be collected in the corers' tubes because of their high water content.

Four additional freeze cores were collected in September 2002 to provide information on sediment ammonia flux and historical changes in burial of carbon, nitrogen, and phosphorus. A single core was collected at the E and M stations and two cores were collected at the S station. Cores were collected with a 2 m, rectangular freeze-corer (see Crusius and Anderson 1991 for detailed description of method). The corer was quickly lowered to just above the sediment surface and then lowered gently into the sediments. The coring device was held vertical with the retrieval line during the first several minutes of freezing to assure it remained upright and then line tension relaxed to prevent sideways pressure due to boat movements during the remaining 12 minutes of freezing. The 15-min freezing period resulted in a flat frozen slab approximately 20 cm wide and 2.5 cm thick. Length varied depending on the sediment characteristics at the site.

Analytical Procedures and Analysis

Water quality and plankton enumeration

Samples for the determination of NH_4 and SRP were analyzed 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. Filtrations for Chla, PP, PC, and PN were performed in the laboratory on the same day as collection. Chla filters were frozen until analysis within two weeks. PP, PC, and PN were dried at 50°C for 48 h in a Fisher Scientific Isotemp oven and stored in a desiccator until shipped to the Marine Science Institute Analytical Laboratory, UCSB. Analytical methods and detection limits are listed in Table 1. With the exception of PC and PN above analyses were performed at the SNARL.

The plankton 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 16X magnification. To ensure capture of rare species, the entire sample was scanned and each organism identified to genus. For a more accurate estimate of the larger species, 60 ml was analyzed under a Wild Heerbrugg dissecting scope at 12X magnification. A portion of the total settling area was counted and extrapolated to the total surface area (Wetzel and Likens 1979). Biovolume was calculated using the methods of Hillebrand et al. (1999). Identification keys included Prescott, 1978; Dillard, 1999; and Canter-Lund and Lund (1995).

Table 1 Analytical chemistry methods

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/PP	Valderrama (oxidation/phospho-molybdate)	Valderrama, 1981	0.4
TN	Valderrama (oxidation/Cd reduction/azo dye)	Valderrama, 1981	0.4
PC, PN	Automated Organic Elemental Analyzer (Model CEC440HA), Dumas combustion method.	Marine Science Analytical Laboratory UCSB	
As	As(V)□As(III) reduction/phospho-molybdate	Johnson, 1971	0.02

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. 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.

Sediment Chambers

Two types of sediment chambers were used in laboratory experiments designed to measure sediment-water exchange.

Bench-top chambers consisted of 3 inch diameter, 15 inch long gray PVC pipes threaded on one end. The end without threads was covered by a black rubber cap. The threaded end had a PVC cap with 3 holes that allowed for sampling, venting, and bubbler tubing to be inserted. Nitrogen or air was bubbled into the chambers to create anoxic or oxic conditions.

Sediments collected by Ekman dredge were transported to the laboratory in a 5 gallon bucket, homogenized and then settled, which separated the sediment into a heavier portion and a suspended portion. To each chamber, 400 ml of heavier sediment, 400 ml of suspended sediment, and 400 ml of bottom water were added. All six chambers were placed in a cold room at 15° C, which was approximately the temperature of the bottom water at the time of the experiments. Samples for nutrient chemistry were taken each day for the next 4 days. 50 ml of water from 2 cm above the sediment surface was obtained using a 100 ml plastic syringe, fitted with a glass fiber filter and Tygon tubing which was threaded through the chamber caps. Samples were placed directly into acid washed plastic test tubes to be used for analysis. Ammonia and SRP determinations were done immediately. Nitrate samples were immediately frozen for analysis later.

Benthic chambers are clear Plexiglas chambers approximately 20 cm high and 50 cm in diameter. They are equipped with pumps that circulate water within the chambers. The chambers were mounted to plywood to permit their use in the laboratory. About 3 cm sediment and a half and half mixture of lake water and deionized water were placed in the chambers. The sediments were homogenized by circulating the water at sufficienly high speed and then settled for two days. Samples for ammonium, SRP and nitrate were collected every hour for eight hours using the technique described above.

Laboratory experiments designed to determine sediment exchange rates indicated that the sediments were a sink over the course of several days, but a very small source over several hours to one day. Although the bench-top chambers had a range of dissolved oxygen concentrations (Table 2), the changes over the experiments were similar in all six chambers. Nitrate concentrations varied little over time (0.02 mg l^{-1} to 0.18 mg l^{-1}), and decreased after an initial increase on day one (Fig. 2). Ammonium decreased slightly from about 1.6 mg l^{-1} to about 1.4 mg l^{-1} (Fig. 3). Phosphate decreased to low concentrations after a very slight increase (Fig. 4).

In the benthic chambers, nitrate levels rose from about 0.1 mg l^{-1} to approximately 0.15 mg l^{-1} between hours four and five, indicating some release of nitrate from the sediment (Fig. 5). Ammonium remained constant over the eight hour experiments. A very small increase in phosphate concentration was detected in the benthic chamber waters over eight hours (Fig. 6).

Table 2 Concentration of dissolved oxygen (DO) in bench-top chambers

Chamber		DO reading (mg/L)
1	N_2 bubbles	0.25
2	N_2 bubbles	0.25
3	No bubbles	0.26
4	No bubbles	3.03
5	Air bubbles	5.84
6	Air bubbles	6.15

Following these preliminary analyses, we decided further experiments were not warranted given the high porosity of the sediment and difficulty in interpreting these types of measurements. Therefore we focused our efforts on collecting and analyzing several freeze cores.

Fig. 2 Nitrate changes in bench-top chambers.

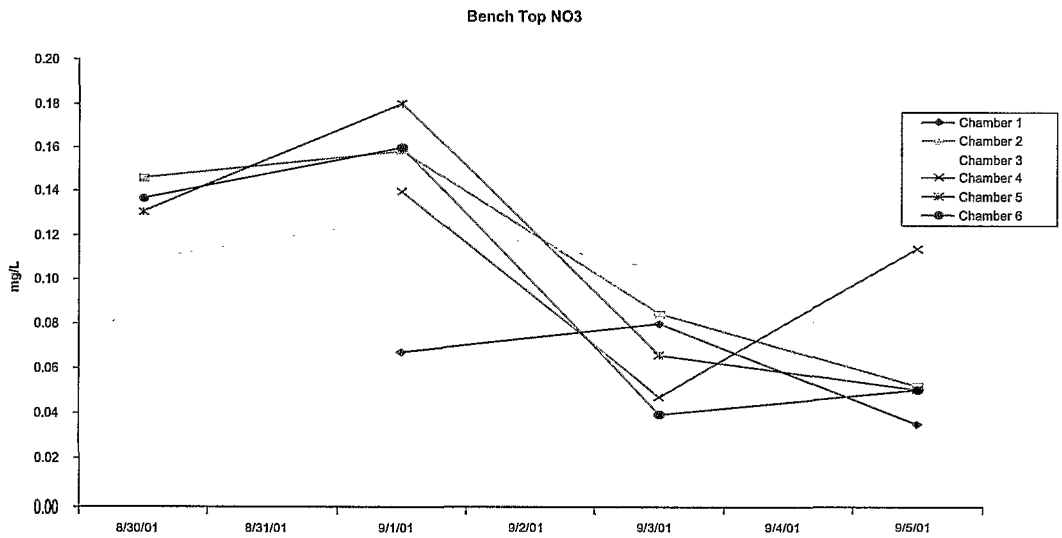


Fig. 3 Ammonia changes in bench-top chambers.

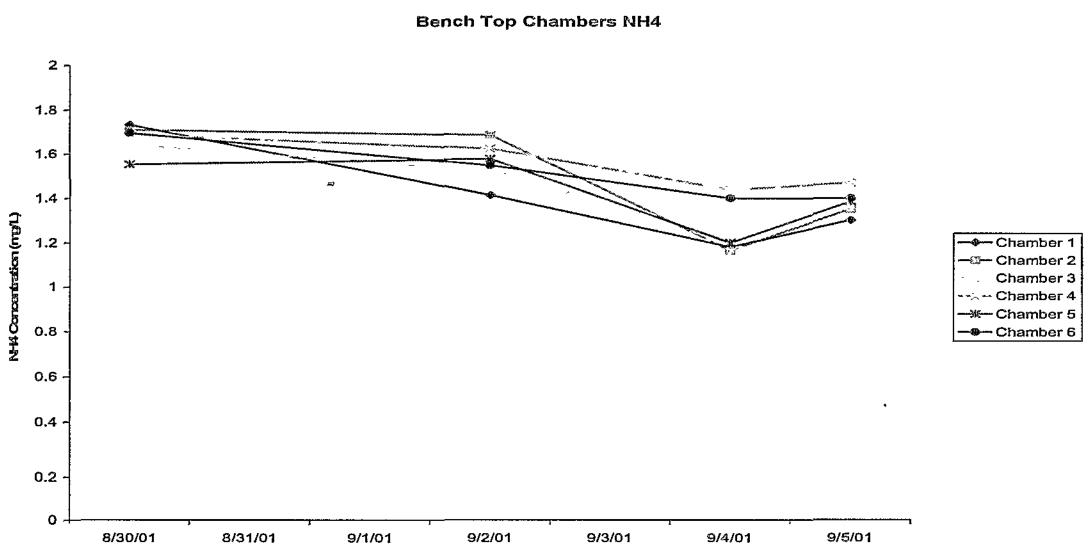


Fig. 4 Phosphate changes in bench-top chambers.

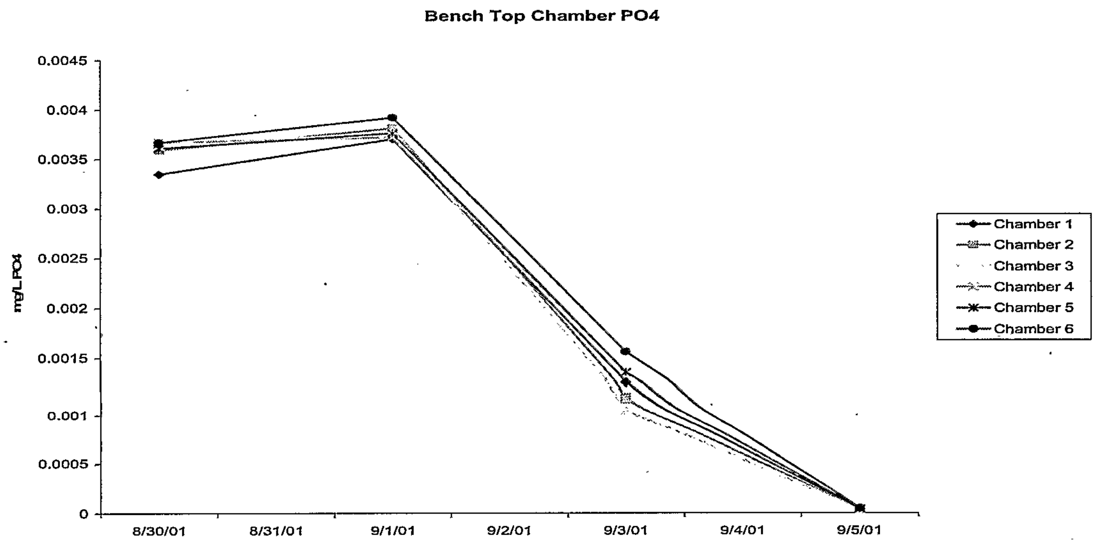


Fig. 5 Changes in nitrate in benthic chamber with slow circulation.

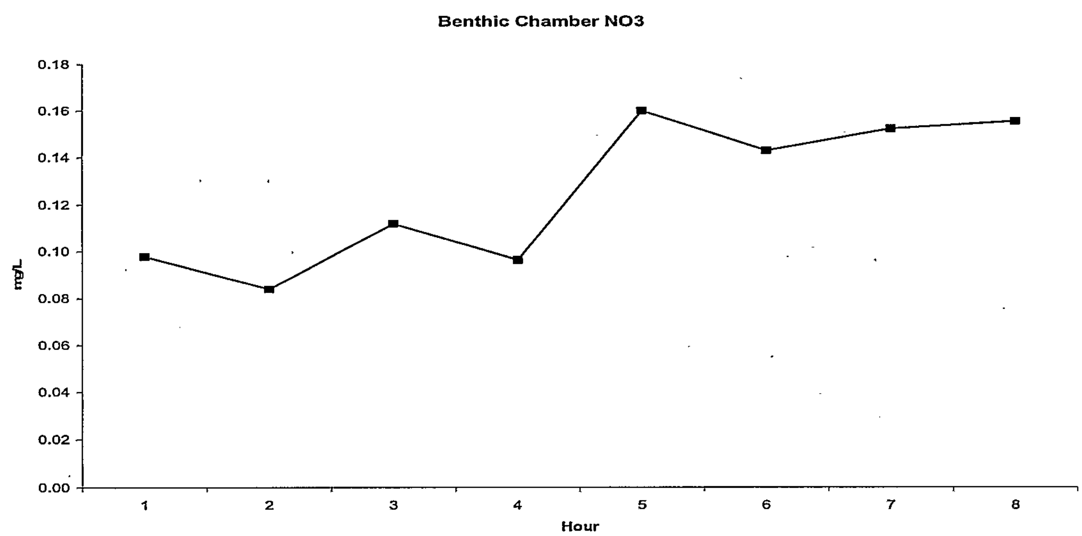
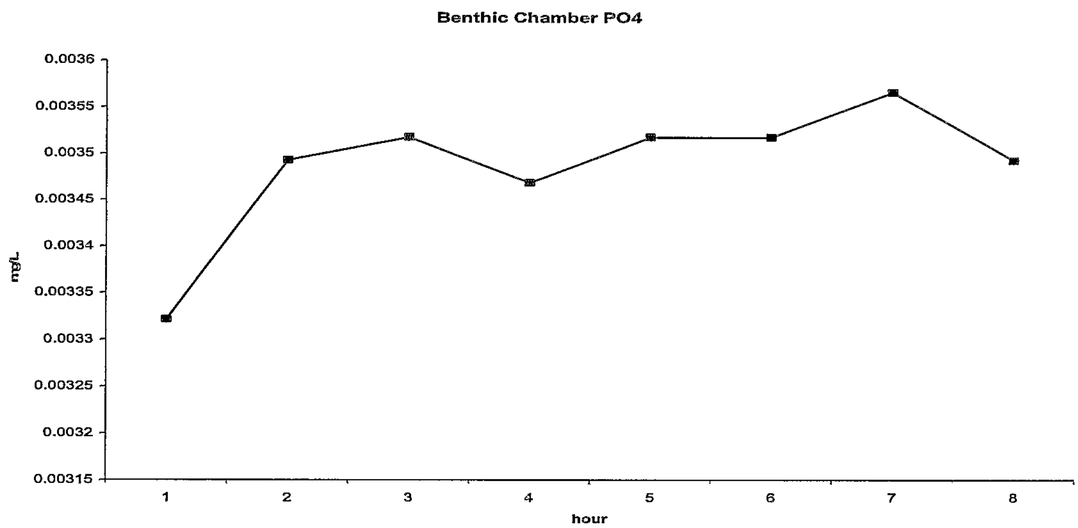


Fig. 6 Phosphate changes in benthic chambers.



Sediment freeze cores

Preparation of the cores took place in the SNARL cold room at a temperature of 5°C. The cores were allowed to warm enough to facilitate sectioning without losing their integrity. Each core was sectioned lengthwise and one half archived. The remaining section was subsampled each centimeter for the first upper 10 cm of the core and every 2nd cm to the bottom end. Each subsample consisted of four replicate 1-cm^2 sections of one cm depth.

Two subsamples were analyzed for porewater NH_4. Samples were centrifuged and supernatant removed, diluted 50X, and analyzed with the phenol-hypochlorite colorimetric method. An 800 µm standard was prepared and diluted as a quality control measure of dilution accuracy.

The remaining two subsamples were placed in acid-washed, rinsed, dried, and pre-weighed glass scintillation vials and used for determination of porosity, non-apatite inorganic phosphorus (NAI-P) dried, TP, TC, and TN. They were weighed immediately (wet weight) and then dried at approximately 50°C to a constant weight. Porosity was calculated as

$$\varphi = \frac{W_{wet}}{\left(W_{wet} + W_{dry} \times D\right)_w}$$

, where D, the bulk density, was assumed to be 2.2 g cm^{-3}.

Note that while bulk densities for various sediment constituents range from 1.4 for humus to 5.0 for various heavy minerals average bulk densities are typically 2.2 – 2.8 and even assuming bulk densities as low or high as 1.4 or 3.0 would have little effect on our calculations due to the high porosity of these sediments.

The dried sediment in each vial was then ground by hand using a small metal spatula and portioned for NAI-P, TP, PC, and PN analysis.

NAI-P was measured using the method of Schelske and Hodell (1995). Sediment was weighed and leached with 5.0 ml of 0.1 N NaOH for a 17 h period. The tubes were centrifuged and the supernatant analyzed for SRP using the ammonium molybdate method corrected for As interference with the sodium metabisulfite and sodium thiosulfate method. Internal standards of 5 and 10 μm PO_4 were prepared on three random samples during each analysis.

A second portion of dry sediment was weighed, diluted with 25 ml DDW and digested with persulfate solution at 250 ^{0}F for 30 minutes in an electric pressure steam sterilizer. Samples and standards were then analyzed for TP using the ammonium molybdate method as above.

The remaining dry sediment was reweighed and acidified using 1N HCl. The samples were re-dried and weighed prior to shipping to the Marine Science Institute Analytical Laboratory, UCSB, for PC and PN analysis.

Pore-water concentration profiles of ammonia were modeled after Klump and Martens (1981) to determine concentration gradients at the sediment-water interface. Exponential equations were fit by least-squares minimization from the bottom of the core to the sediment-water interface (bottom water concentrations) with

$$C_z = (C_\infty - C_0)(-e^{-az}) + C_\infty$$

where C_z, C_∞, and C_0 are the concentrations at depth z, infinity, and the sediment-water interface. C_∞ and a were calculated; C_0 was fixed at the bottom-water concentration. The gradients were calculated at z = 0. The flux of ammonia out of the sediment was then calculated from the best-fit concentration gradient with Fick's first law of diffusion:

$$Flux = -\varphi D \frac{\partial C}{\partial z}\Big|_z$$

where φ is porosity at the interface, D is the sediment diffusion coefficient corrected for tortuosity, θ, where

$$D = \frac{D_f}{\theta^2} \text{ and } \theta^2 \approx 1 - 2\ln(\varphi) \text{ (Boudreau 1996).}$$

Nitrogen fixation

Nitrogen fixation was measured by the acetylene reduction method (Flett et al. 1976). Experiments consisted of four light treatments for 5-meter integrated samples from each of the five Crowley Lake sampling stations. Light treatments consisted of two placed in direct sunlight in Convict Creek on the property of the Sierra Nevada Aquatic

Research Laboratory, one wrapped in a neutral density gray screen, and two in a laboratory water bath, one under artificial fluorescent lights (90-100 $\mu E\ m^{-2}\ s^{-1}$) and one placed in dark bag. Temperature was recorded in both the stream and water bath. Photosynthetic available radiation (PAR) was recorded daily by sensors located on the SNARL property. Hourly values were averaged over the incubation period. PAR measurements were also taken in the stream and water bath during each experiment using a Licor 185 Light meter.

Incubations consisted of 50 ml of lake water in a 60 ml serum bottle. Five ml of air was replaced with 5 ml of acetylene gas. Bottles were shaken for 30 seconds and incubated for a 4 h period. After the incubation period, 1 ml of gas was removed and injected into a Shimadzu GC-8A gas chromatograph. A set of ethylene gas standards (prepared from Scott Specialty Gases (Scotty mix 849 – 1% (by mole) ethylene in nitrogen) were run at the beginning of each experiment to provide a standard curve. A ratio of 3 moles of acetylene reduction (ethylene produced) to one mole of N_2 fixed was assumed (Flett et al. 1976). Note rates are reported in units of moles of N (not N_2) fixed for comparison with loading fluxes.

Lakewide estimates of planktonic nitrogen fixation were made using a numerical interpolative model which combines hourly insolation, in situ PAR attenuation, and nitrogen fixation versus light rates. We assumed the fixation versus light intensity rates measured in the 5-m integrated samples were representative of the euphotic zone. As no significant persistent differences in nitrogen fixation rates were noted among the five lakewide stations, a lakewide average for each day was used. The fixation versus light intensity relationship was represented as an initial slope and a maximum rate. Further refinement was not warranted based on the variability of the rate measurements. Hourly insolation values from SNARL 7 km west of the center of the lake and a lakewide average of in situ PAR attenuation was used.

<u>Hypolimnetic Nutrient Accumulation and Eddy Diffusivity</u>

Lakewide hypolimnetic nutrient (SRP and NH_4) accumulation was calculated by averaging data from the two deep stations and then linearly interpolating to 0.25 m from 11 m to the bottom. The deepest sample at the shallower E station often was elevated relative to the S station most likely reflecting close proximity to the sediments and was not used. A volume-weighted sum was then calculated based on hypsographic data provided by the Los Angeles Dept. of Water and Power.

Eddy conductivities were calculated using the flux-gradient heat method modified for solar heating (Jassby and Powell 1975).

$$K_z = -\frac{1}{\frac{\delta\theta}{\delta z}}\left[\frac{1}{A_z}\frac{d}{dt}\int_z^{z_m} A_u\theta_u du - \frac{1}{\rho c}R_z\right]$$

where K_z is the coefficient of vertical eddy conductivity at depth z, z_m is the maximum depth of the lake, A_z is area at depth z, u and z are depths positive downwards, R_z is irradiance at depth z, θ is temperature, ρ is density, c is thermal capacity, and t is time. The temperature gradients were estimated as 1 m central differences. Depths, areas, and volumes were changed to correspond to changes in the lake level. The heat integral was evaluated at 1 m intervals using lakewide mean temperatures and area-capacity curves. Eddy diffusivities were assumed equal to eddy conductivities after being corrected for molecular conductivity (0.13×10^{-6} m^{-2} s^{-1}; Chemistry and physics handbook 1977, Table E-11).

Solar heating was estimated from continuous measurements of incident PAR, calculated albedoes, and light attenuation within the water column. Comparison of measurements with an Eppley pyranometer (285–2,800 nm) and PAR (400–700 nm) collected at SNARL, indicated PAR comprised 44.6% of the total solar irradiance assuming a conversion of 4.57 µEinst = 1 joule (McCree 1972). This is close to findings in other studies (45%, Gates 1966; 41%, Jassby and Powell 1975). The PAR data were converted to total solar input using this ratio. Albedoes were calculated assuming all radiation was direct; this assumption introduces only a small error (Jassby and Powell 1975). Attenuation within the water column was divided into seven wavelength bands. Visible light attenuation was measured as PAR attenuation. The attenuation of infra-red light for five intervals was obtained from Hale and Querry (1973): 1.1 m-1, 700–800 nm; 3.4 m-1, 825–900 nm; 26 m-1, 925–1,000 nm; 870 m-1, 1,200–1,800 nm; and 7,800 m-1 from 2,000–2,400 nm. The effect of solar heating at the chosen depth of 12 m was insignificant (<1%) throughout the period.

Results

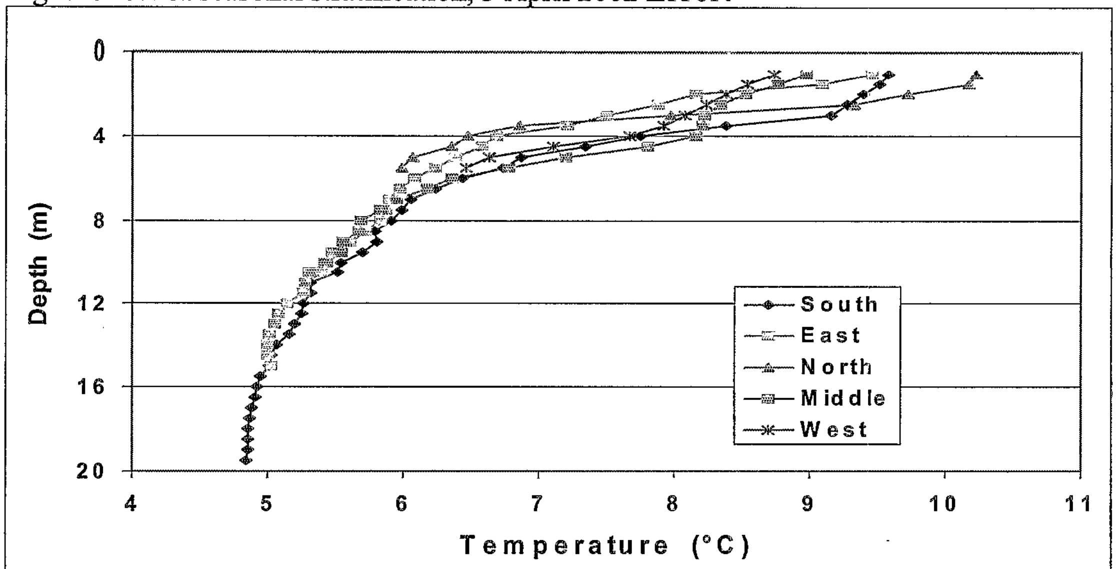
Eight 2-day lakewide surveys were conducted at approximately biweekly intervals from 20 June 2002 to 25 September 2002 to assess limnological conditions and collect pelagic plankton samples for a variety of analyses and the measurement of nitrogen fixation rates. On the first day of each survey, temperature, dissolved oxygen, and nutrient profiles were determined to assess hypolimnetic nutrient accumulation and vertical mixing. On the second day of each survey a suite of physical, chemical, and biological characteristics were measured at each of the five pelagic stations and water samples collected for determination of nitrogenase activity via the acetylene reduction measurements in laboratory incubations. To view the seasonal development, we include the results of a survey conducted 3 April 2002 a couple weeks after ice-off. Also, four sediment cores were collected in September 2002 to provide information on sediment ammonia flux and historical changes in burial of carbon, nitrogen, and phosphorus.

Physical, chemical, and phytoplankton conditions in Crowley Lake during 2002

Seasonal Thermal stratification

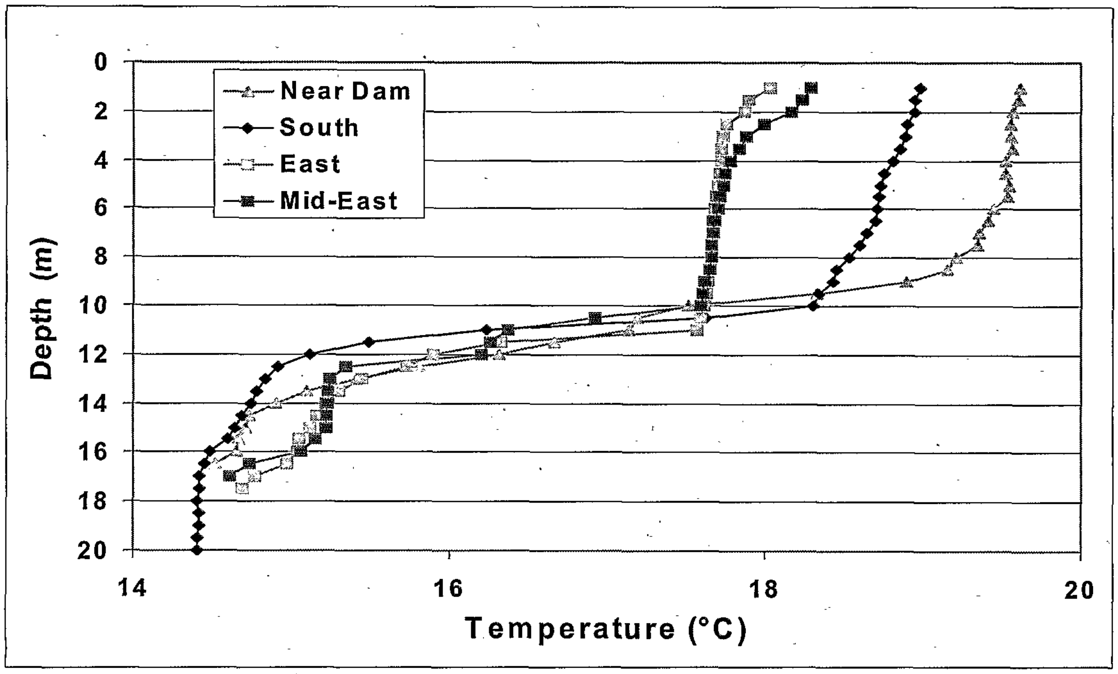
A lakewide survey was conducted on 3 April 2002 following ice-off in mid-March as part of a separate cooperative study of nutrient loading with the City of Los Angeles (SWRCB #9-175-256-0). Seasonal thermal stratification had already been initiated with temperatures nearly isothermal below 12 m at near 5°C, increasing gradually to 6°C between 12 and 8 m and then more rapidly to 8-10°C in the upper water column (<4 m) (Fig. 7). Near surface waters were slightly warmer at the N station which is influenced by the Owens River, and slightly cooler at the W and M stations which are more strongly influenced by McGee Creek inflows.

Fig. 7 Onset of seasonal stratification, 3 April 2002 **Error!**



By 19 June, the epilimnion (upper mixed layer) had warmed to 17.5-20°C while the hypolimnion had increased to 14-15°C (Fig. 8). There was a significant longitudinal gradient in which epilimnetic waters warmed from north to south. Epilimnetic temperatures were ~18.0°C at the E and Mideast station, ~18.9°C at the S station, and ~19.6°C at the Dam station. There was a pronounced thermocline between 10 and 12 m at all four stations.

Fig. 8 Early summer thermal stratification in Crowley Lake.



Epilimnetic temperatures continued to increase, reaching their annual maximum of 21-22°C in mid-August. The pronounced thermocline observed at 10-12 m was mixed downward through the summer and by mid-August only a gradual thermal gradient from 21-22°C near the surface to 18-19°C near the bottom existed indicating active mixing through this period (Fig. 9). Further mixing and seasonal cooling of the upper water column resulted in less than 1°C gradient between upper and lower water temperatures during September when the field sampling ended.

Seasonal and lakewide variation in dissolved oxygen

Dissolved oxygen concentrations showed marked seasonal variation typical of eutrophic temperate lakes (Fig. 10). During the 3 April 2002 survey the entire water column was well-oxygenated at the S station with values only ranging from 9.5 to 10.5 mg O_2 l^{-1}. By the next sampling on 19 June, the hypolimnion was anoxic (<1 mg O_2 l^{-1}). The hypolimnion remained anoxic until late August and was not fully oxygenated until the 10 September survey.

Fig. 9 Annual thermal stratification in Crowley Lake, 2002 (S Station). Tic marks show sample dates and isotherms in °C.

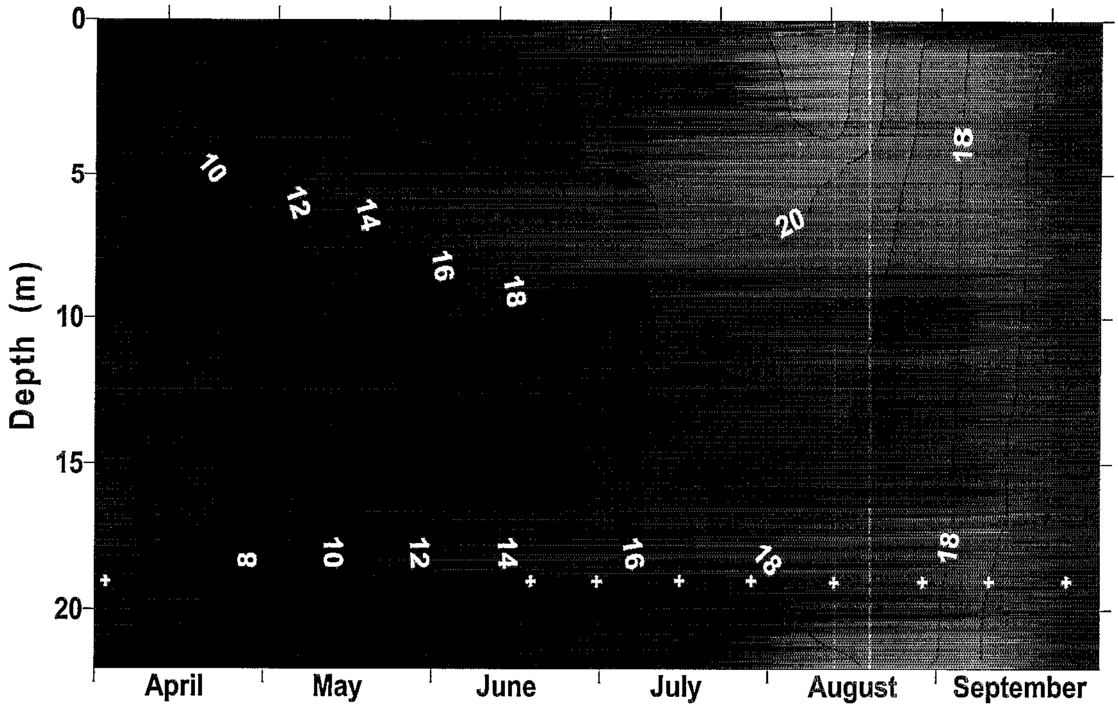
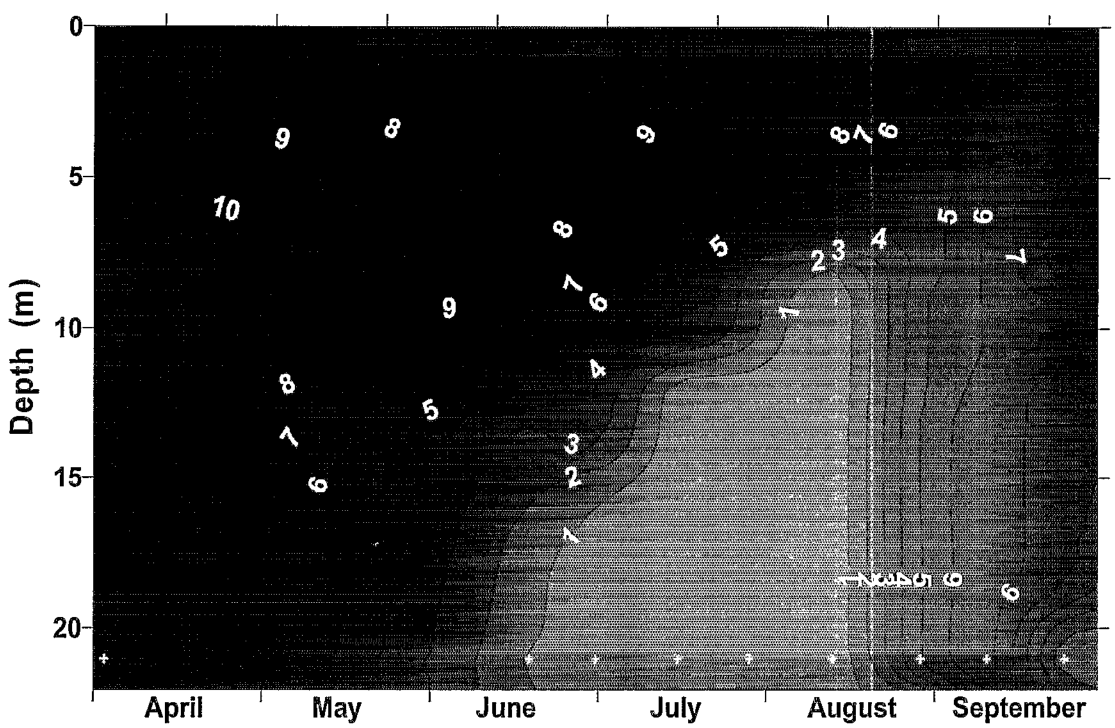
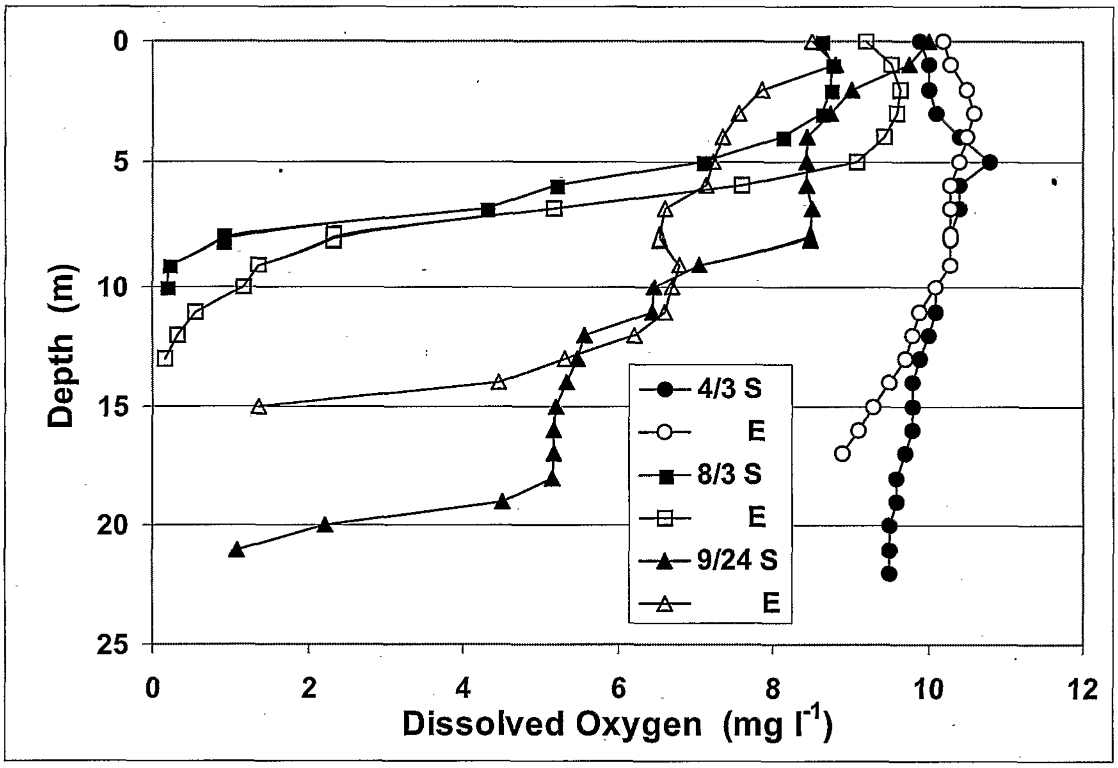


Fig. 10 Annual variation in dissolved oxygen (mg l^{-1}) in Crowley Lake, 2002 (S Station). Tic marks show sample dates.



Dissolved oxygen profiles were generally similar between the two deep stations, S and E (Fig. 11) except late in the year. On these dates, the decline in dissolved oxygen concentrations higher in the water column is most likely due to proximity with the bottom at 15 m. The E station is significantly shallower than the S station and the reservoir was significantly drawn down in autumn. Above 15 m, the dissolved oxygen profiles at the two stations were roughly similar.

Fig. 11 Comparison of dissolved oxygen at S and E stations during 2002.



Seasonal and lakewide variation in transparency

Secchi depth provides a readily collected and widely used measure of transparency (Fig. 12). On 3 April 2002, Secchi depth was 3.7-4.2 at N, W, M, and E stations. At the S station it was 6.0 m. By the next sampling on 19 June, the transparency at the S station had decreased to 4.0 m and the other 4 stations ranged from 3.2-3.8 m. Transparencies decreased further to 1.5-2.6 through July before increasing to near 4 m at all but the N station in mid-August. Transparencies then declined to 1.8-2.3 during September during an autumn bloom. Thus, the general trend in transparency reflects the presence of spring and autumn algal blooms. The overall mean transparency from 19 June through 24 September was 2.7 m (1 SE, 0.1; n, 56).

Photosynthetically available radiation (400-700nm) was also collected at all five stations. The euphotic zone depth as defined by the mean lakewide 1% light level varied from 4.5 to 9.5 m through the season (Fig. 13). On 3 April 2002, the 1% light level was between 8.5-9.5 m and depth attenuation was fairly uniform at the five stations (Fig. 14).

The euphotic zone decreased to 4.2-4.7 m by 2 July 2002 and was still nearly uniform at all five stations (Fig. 15). During the autumn algal bloom (25 September), the euphotic zone varied from 3-6 m and showed marked variation from north to south with the depth of the euphotic zone being less at the southern station (Fig. 16).

Fig. 12 Seasonal and lakewide variation in Secchi depth during summer 2002.

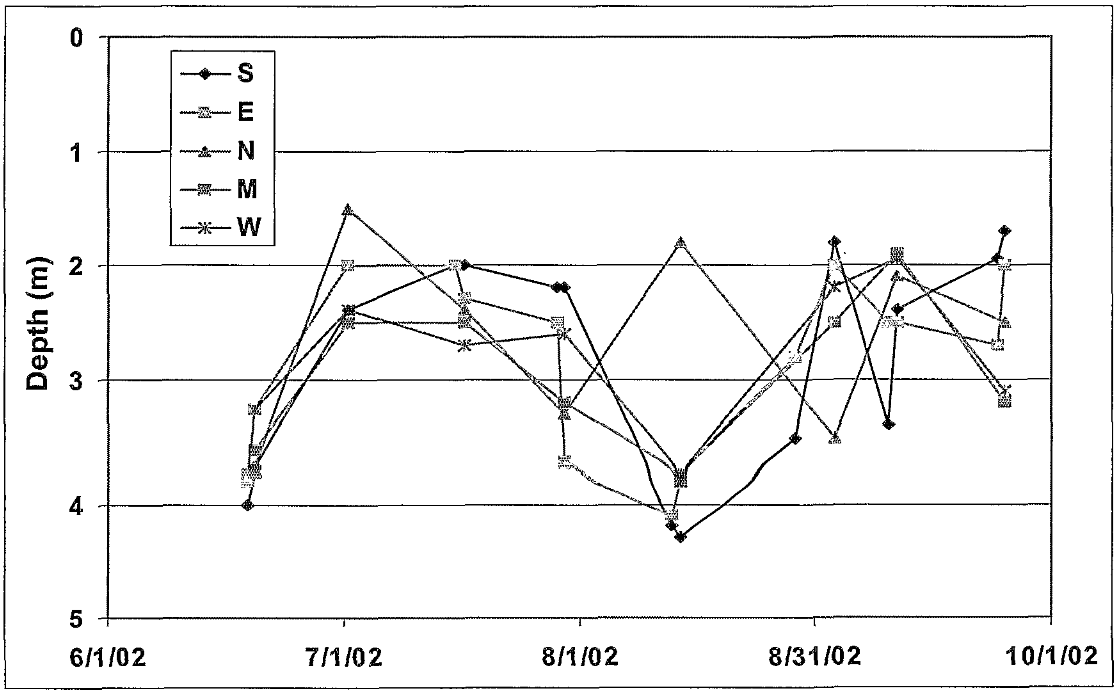


Fig. 13 Attenuation of PAR (fraction of surface) during 2002 (S station)

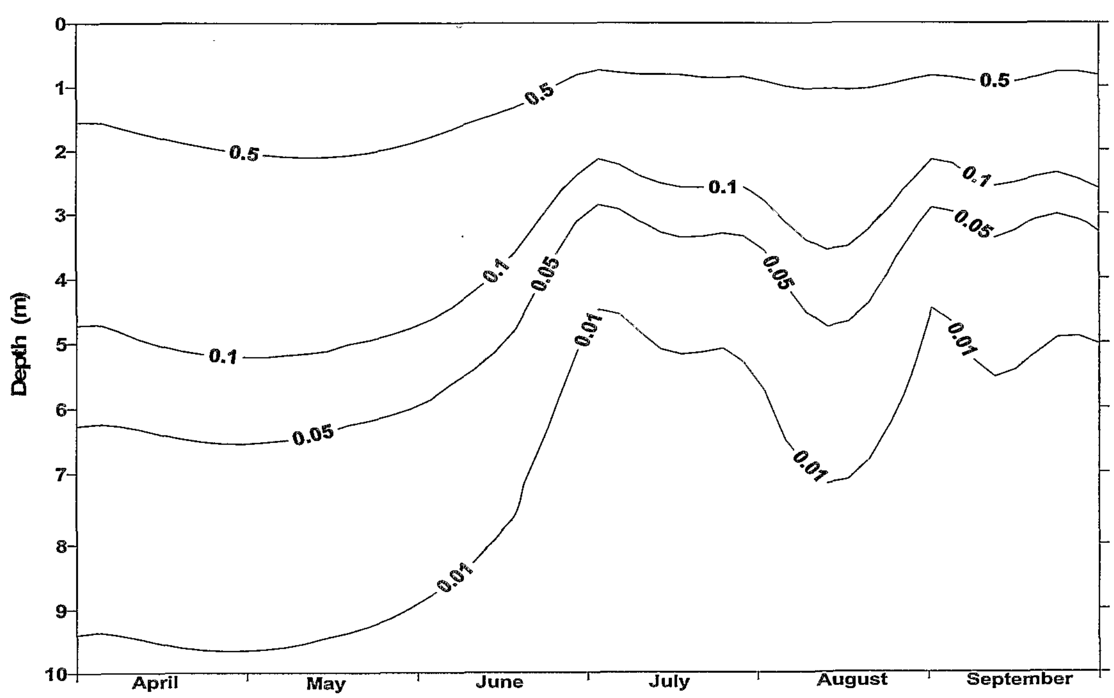


Fig. 14 Spring lakewide comparison of PAR attenuation

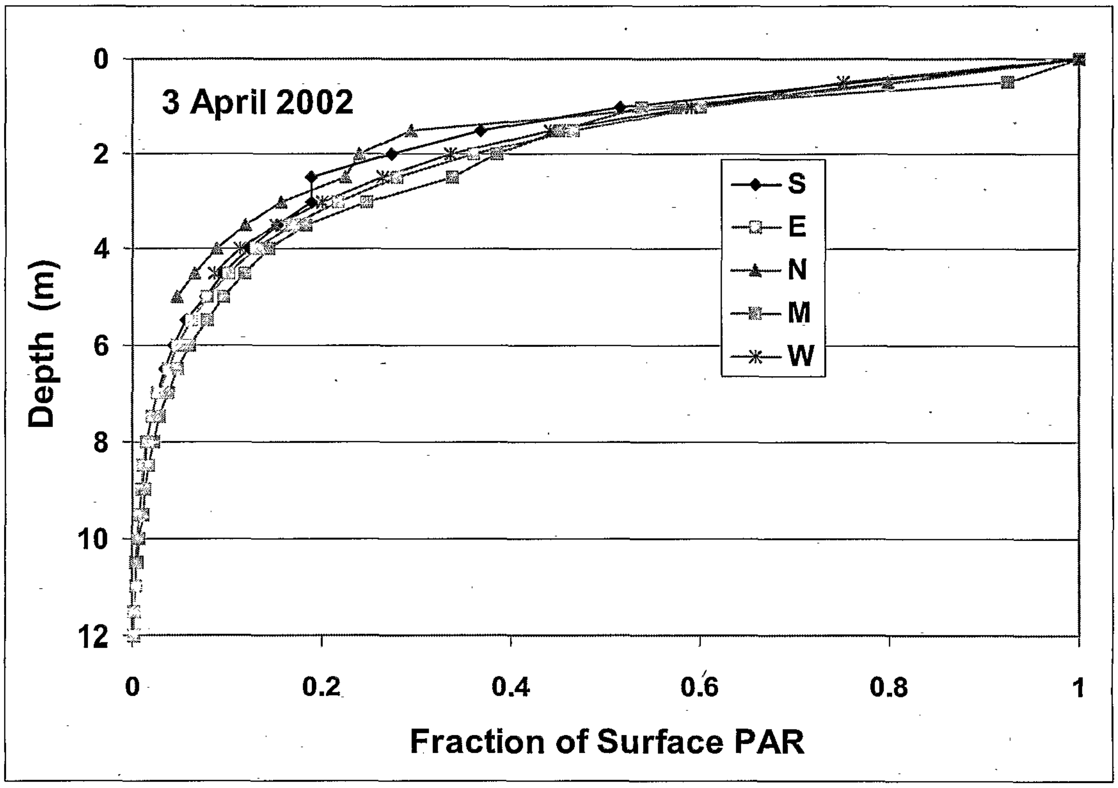


Fig. 15 Summer lakewide comparison of PAR attenuation

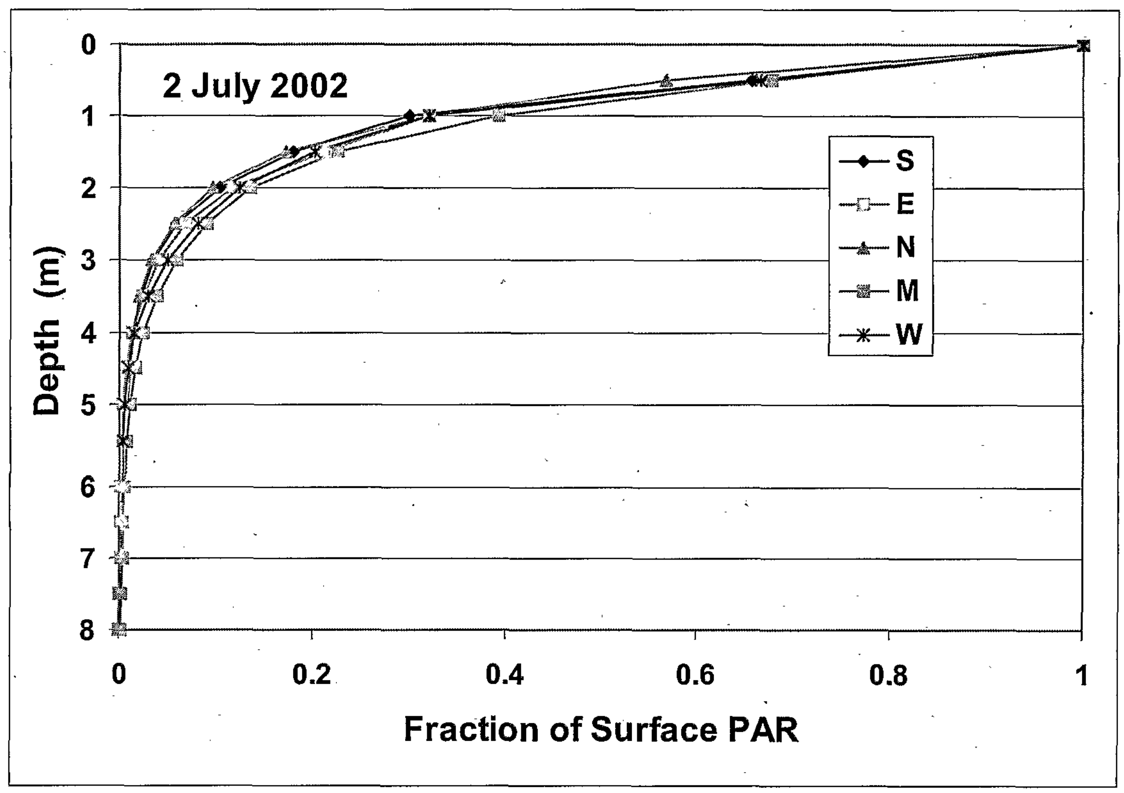
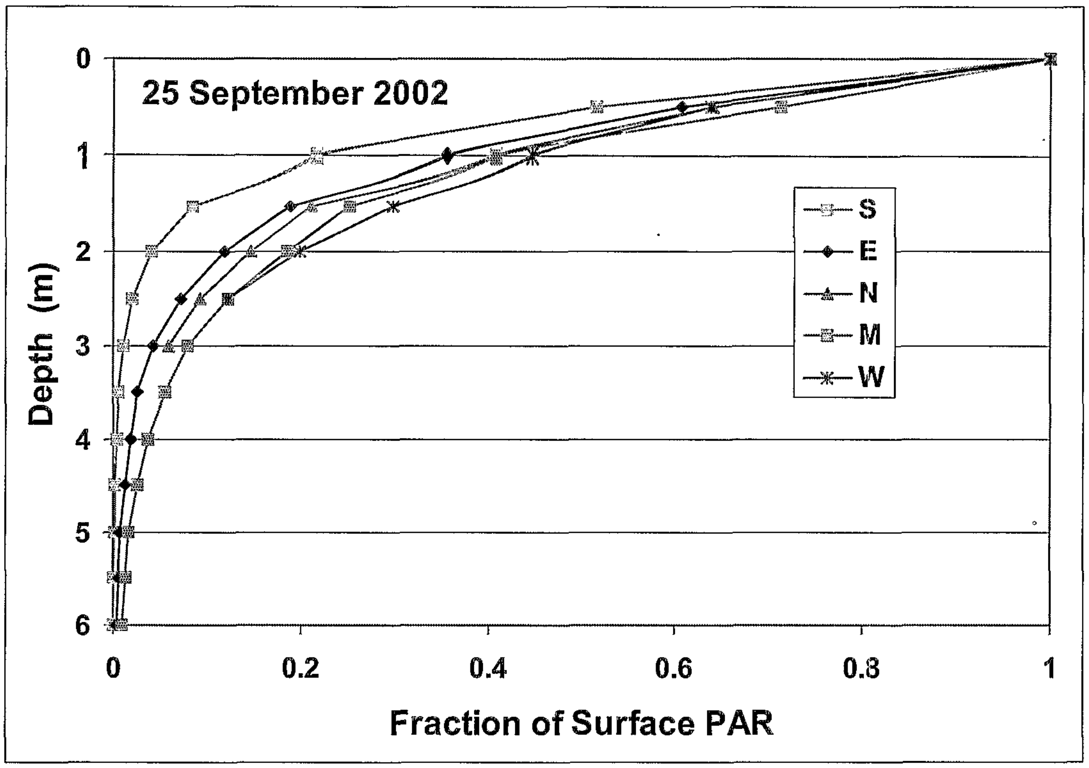


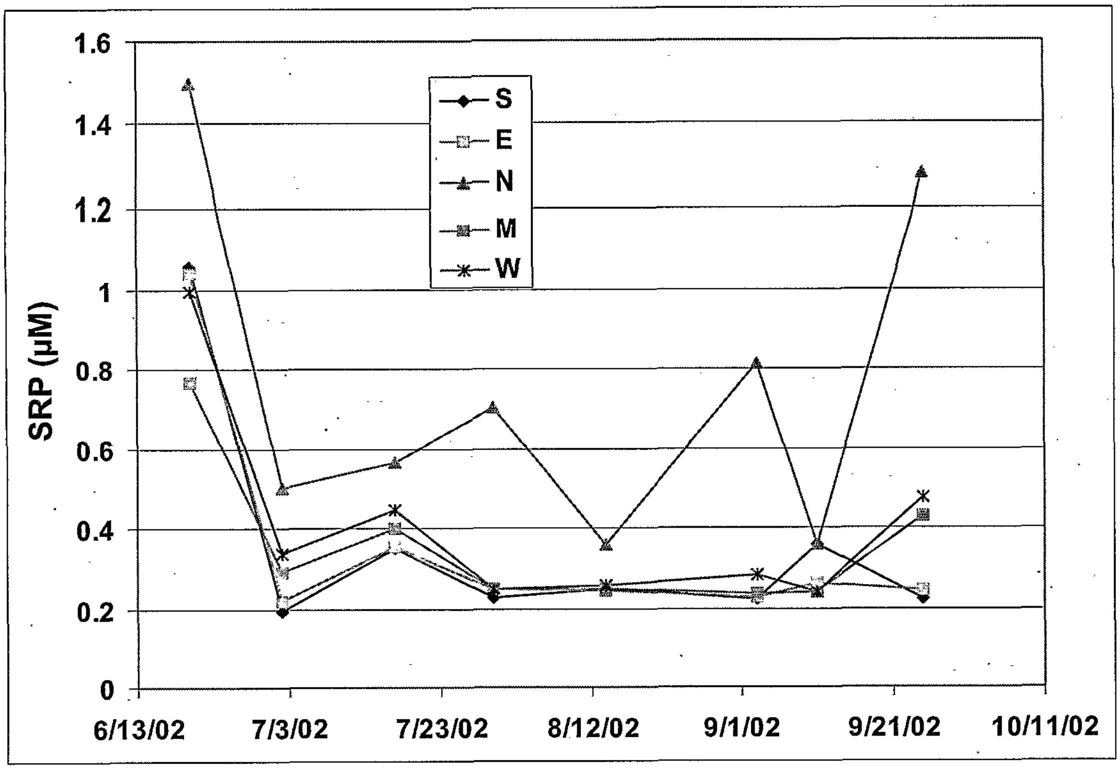
Fig. 16 Autumn lakewide comparison of PAR attenuation



Epilimnetic SRP and dissolved inorganic nitrogen (NH_4, NO_3)

Epilimnetic SRP concentrations in the upper 5-m integrated samples of the water column ranged from 0.2 to 1.5 μM (Fig. 17). On all but one date, the northern station was significantly higher than any of the other four stations. The northern station is in the center of the long narrow northern portion of the lake which receives inflows of the Owens River. The other four stations had concentrations below 0.5 μM throughout the summer except for on the first date, 19 June, when they were 0.8–1.1 μM.

Fig. 17 Epilimnetic (0-5 m integrated) SRP concentrations



Epilimnetic ammonium concentrations were low (<1.2 µM) throughout the summer except for a single sample on 3 September at the N station and on the last sample date (Fig. 18). The 5.5 µM reading at the N station appears to be an outlier and may have resulted from the integrated sampler coming into contact or disturbing the sediments. The reservoir had been drawn down significantly in late summer and the N station was just over 5 m deep. The increase at M, N, and W stations on 25 September likely resulted from deepening of the mixed layer and entrainment just prior to autumn overturn.

Epilimnetic nitrate was even lower than ammonium through most of the summer when it ranged from 0.1 to 0.3 µM (Fig. 19). As with ammonium, NO_3 was slightly higher on the first and last sample dates, 19 June and 25 August. A significantly higher value at the N station on 3 September also occurs and may be due to disturbing sediments (see above).

Fig. 18 Epilimnetic (0-5 m integrated) NH_4 concentrations

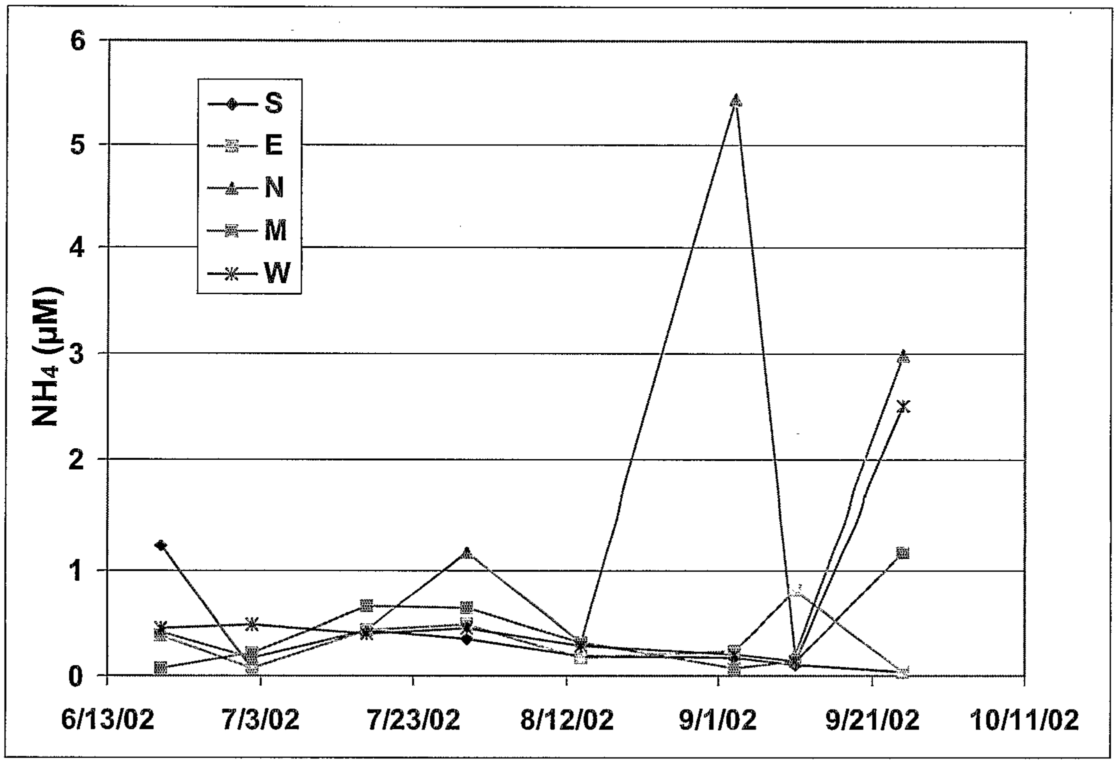
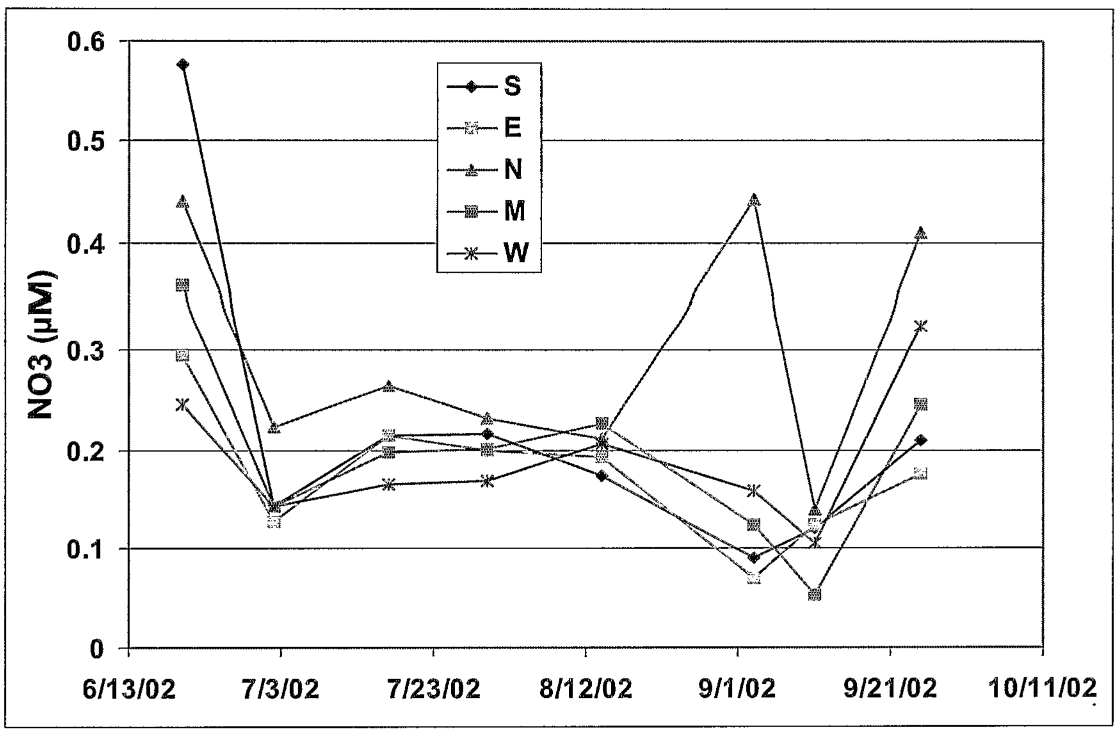


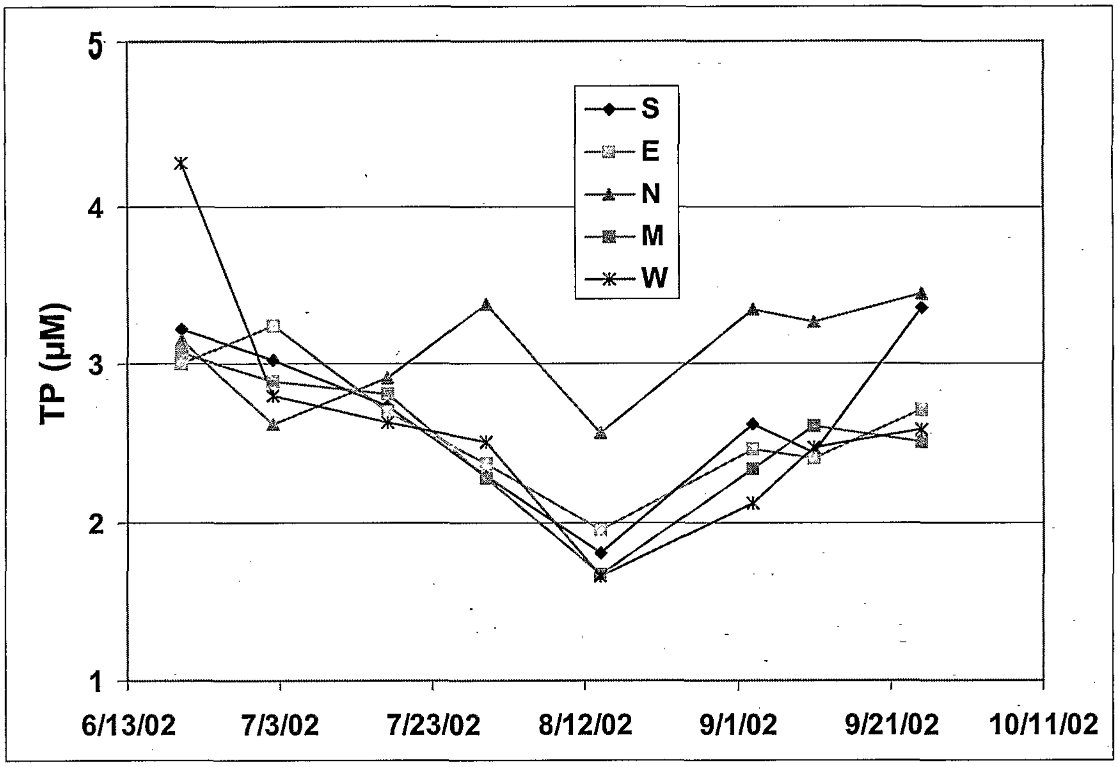
Fig. 19 Epilimnetic (0-5 m integrated) NO_3 concentrations



Epilimnetic total phosphorus (TP) and total nitrogen (TN)

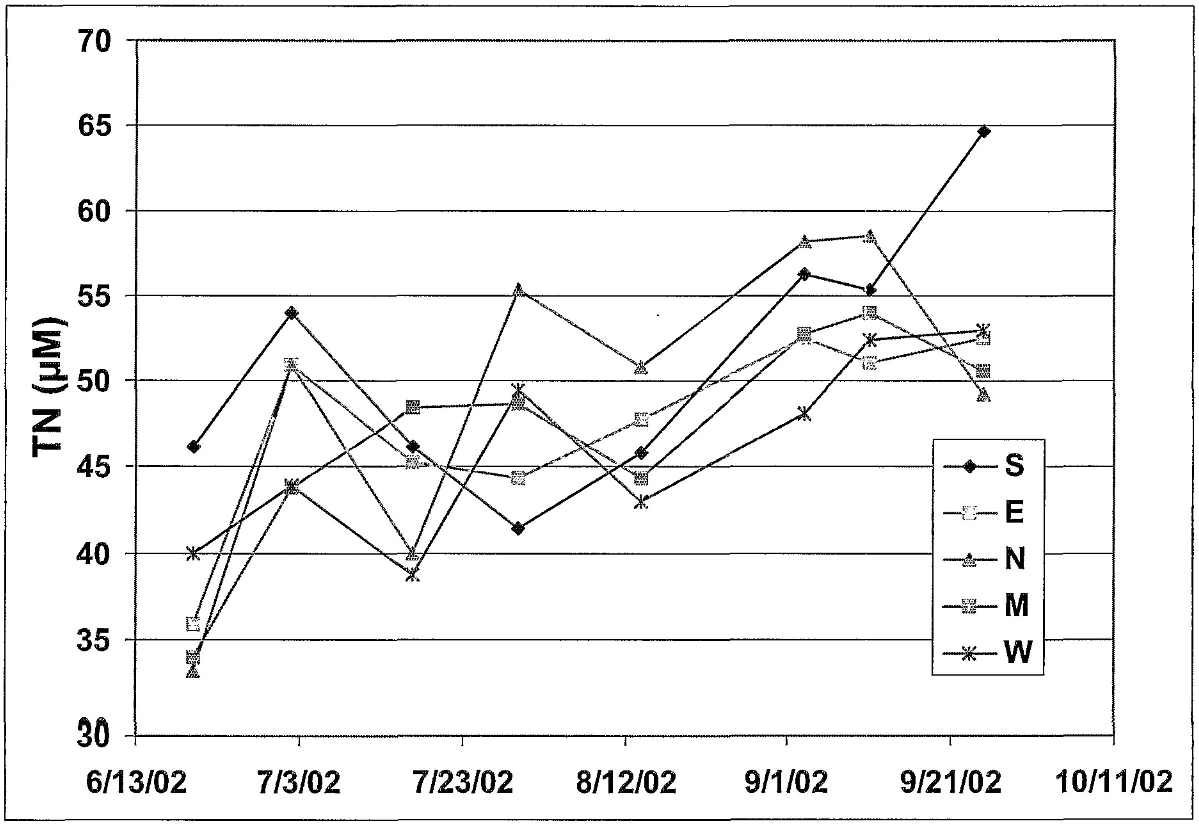
Summer epiliminetic total phosphorus (TP) concentrations ranged from 1.5 to 3.5 μM, except for a slightly higher value (4.3 μM) at the W station on 19 June 2002 (Fig. 20). The TP concentrations were very similar among W, M, E, and S stations through the entire period, while TP at the N station was 0.5-1.0 μM higher beginning on 30 July. The N station lies midway up the long, narrow portion of the lake which receives inputs from the Owens River. The slightly higher concentrations of TP, undoubtedly reflect the influence of the Owens River from which most of the TP loading to the lake comes. The general seasonal trend was peak average lakewide concentrations (3.3 μM) at the beginning of summer (19 June) declining to a minimum (1.9 μM) in mid-August, followed by a gradual rise to higher values (2.9 μM) by the end of September.

Fig. 20 Epilimnetic (0-5 m integrated) TP concentrations



Summer epilimnetic total nitrogen (TN) concentrations ranged from 33 to 65 μM (Fig. 21). There was a clear seasonal trend of gradually increasing concentrations through the period from a lakewide mean of 37.8 μM on 19 June to 54.0 μM on 25 September. On 25 September, the S station value (64.7) was 13 μM higher than the mean of the other four stations (51.8 μM). However, even without this value, the consistent seasonal increase is still present. As with TP, the N station was consistently higher beginning on 30 July and continuing through 11 September. However, N station values were only 5-10μM higher than the average of the other 4 stations and thus on a relative basis less pronounced than the TP values. The overall summer mean concentration was 48.3 μM (±1.1, 1 SE).

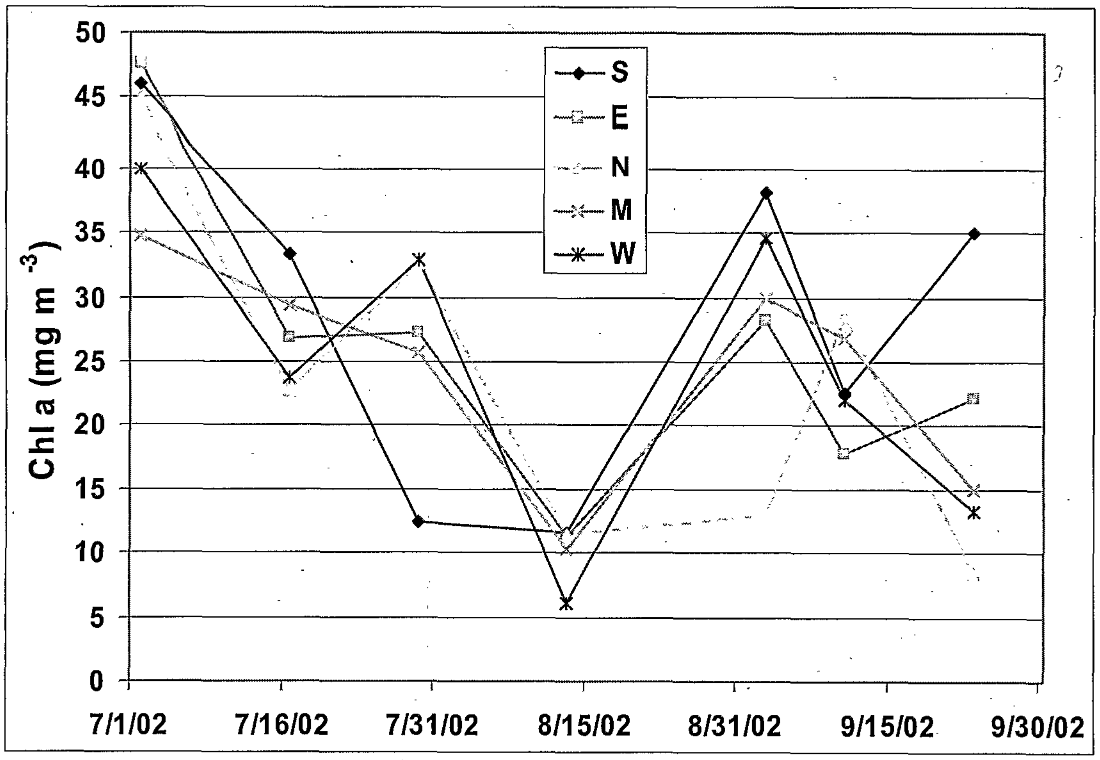
Fig. 21 Epilimnetic (0-5 m integrated) TN concentrations



Chlorophyll concentration and phytoplankton community

Summer epilimnetic chlorophyll *a* concentration ranged from 6 to 48 µg Chl *a* l^{-1} with the highest observed 3 July (mean, 43 µg Chl *a* l^{-1}) (Fig. 22). Following the peak concentrations observed during the spring algal bloom, chlorophyll *a* decreased to 10 µg Chl *a* l^{-1} in mid-August and was followed by a second smaller (mean, 29 µg Chl *a* l^{-1}) autumn bloom. Concentrations decreased slightly by mid-September and then at stations N, M, and W decreased further by the last sampling on 25 September. There was a slight increase at E and S stations between the last two sample dates. As these are the two deepest stations, this likely resulted from entrainment of nutrients during deep autumnal mixing.

Fig. 22 Epilimnetic (0-5 m integrated) Chl *a* concentrations



Phytoplankton samples for species enumeration were collected from all stations on each sample date to determine the species composition. General trends can be described using the South station as a typical representation of other stations in the lake. On 20 June, the cyanophytes dominate throughout the lake (Fig. 23) and continue to dominate through the summer (Fig. 24). The phyrrhophyte *Ceratium* was abundant at all stations, June through August when the biovolume of all phytoplankton decreased. At this time, we start seeing an increase in the relative biovolume of Bacillariophyceae (Fig 24). N station typically had a higher Bacillariophyceae (diatom) population than the other stations, increasing to 70% relative abundance on the 25 September sampling date. As the cyanophytes are the important nitrogen fixers in the lake, they will be discussed in more detail under the heading Nitrogen Fixation.

Fig. 23. Relative abundance of phytoplankton at each station on 20 June, 2002.

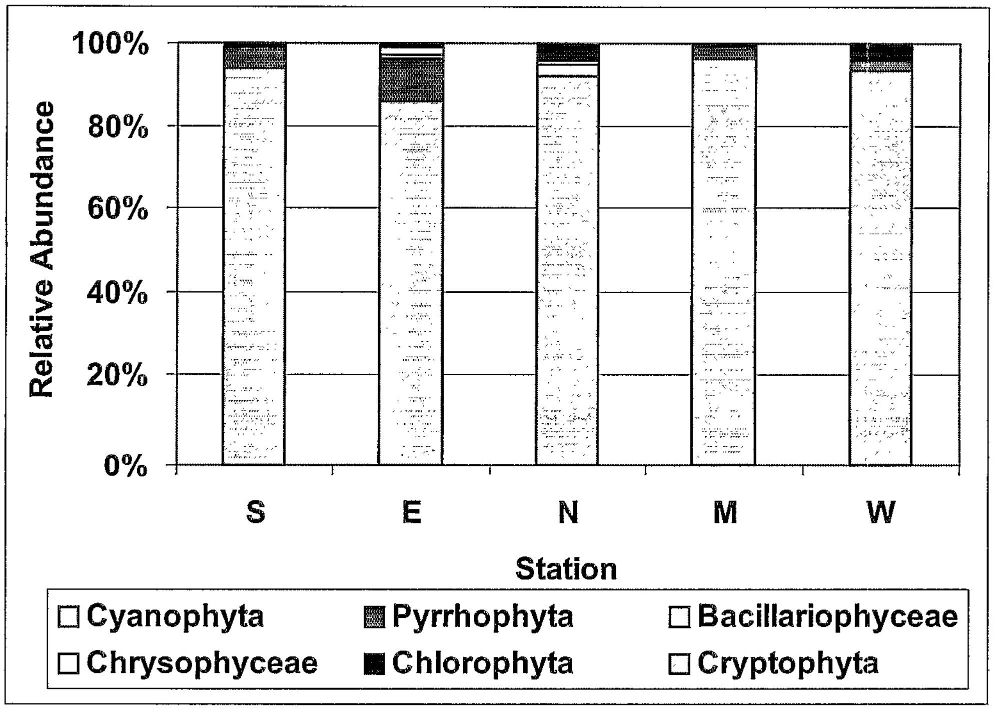
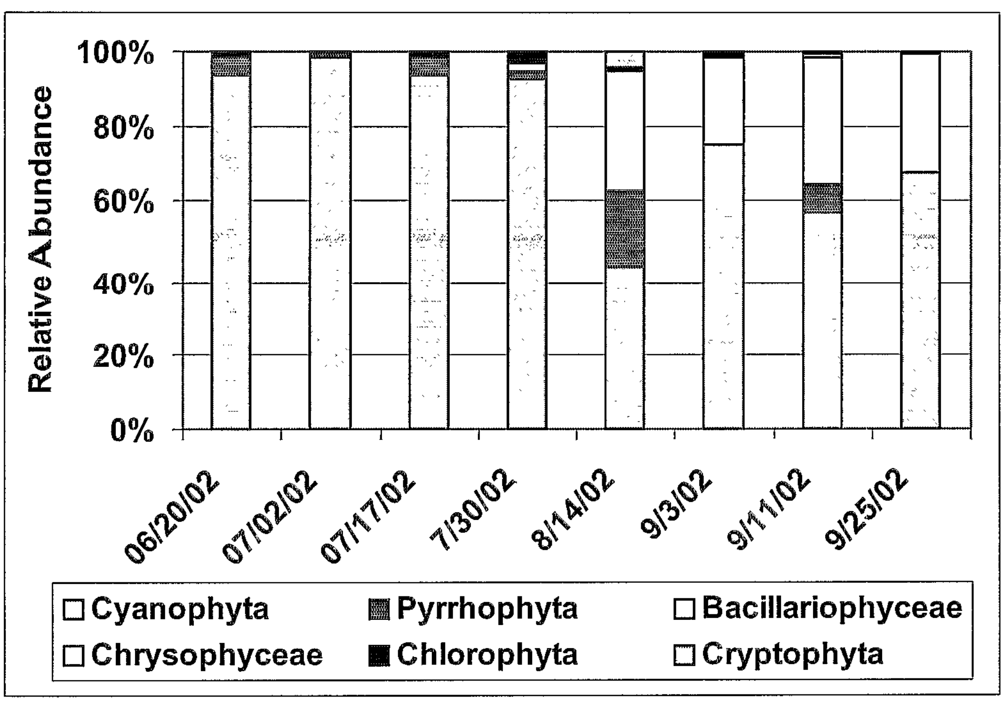


Fig. 24. Relative abundance of Phytoplankton at South Station during 2002.



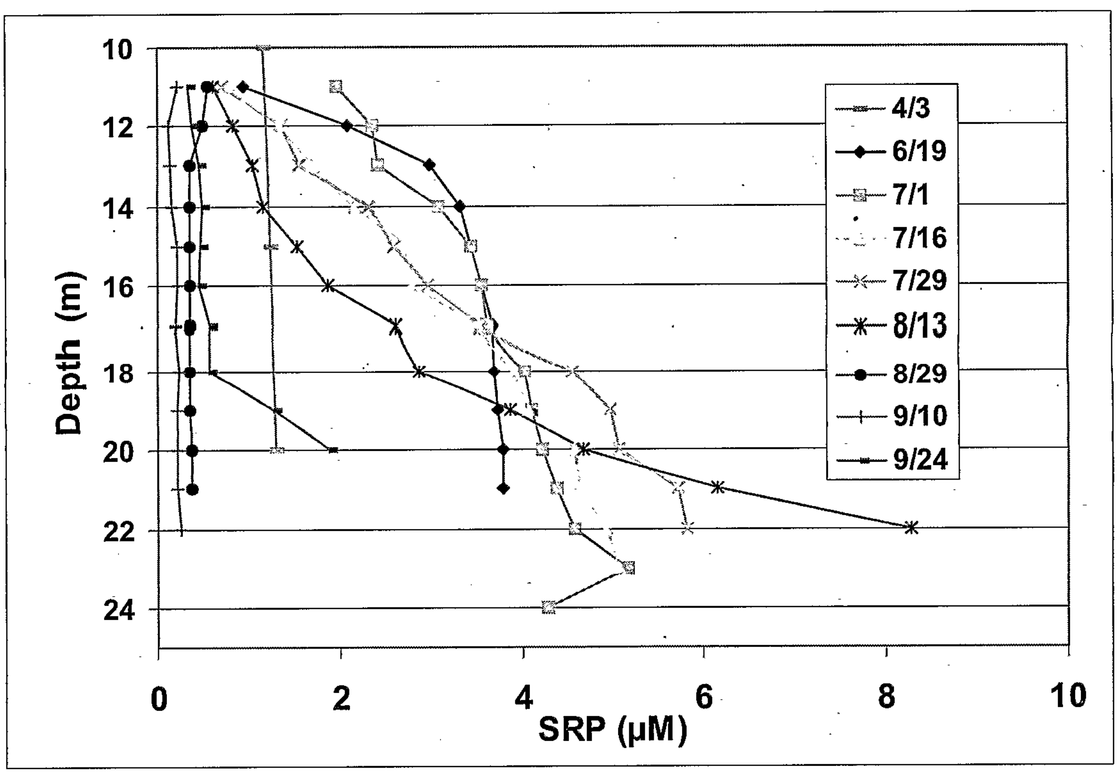
Hypolimnetic ammonium, nitrate, and phosphorus accumulation

Nutrients accumulate beneath the seasonal thermocline in eutrophic temperate lakes. During 2002 we measured the accumulation of nutrients beneath the seasonal thermocline in Crowley Lake by analyzing NH_4, SRP, and NO_3 collected at 1-m intervals from 11 m depth to the bottom at the deep E and S stations.

In 2002, ice-off occurred about the third week of March, several weeks earlier than normal. On the first survey date, 3 April 2002, SRP concentrations at the deep, S station were nearly uniform throughout the water column ranging from 1.2 µM in the upper 5-m integrated sample to 1.3 µM at 20 m (Fig. 25). SRP accumulated beneath the seasonal thermocline during April-June and by the 19 June sampling had reached concentrations between 3-4 µM beneath 13 m. Hypolimnetic concentrations continued to increase and by 13 August exceeded 8 µM at 22 m. The nutricline (region of strong nutrient gradient) descended through the summer following the thermocline as the mixed layer deepened.

On 29 August, SRP concentrations were nearly uniform with depth at the S station ranging only from 0.34-0.56 µM indicating that mixing throughout the water

Fig. 25 Hypolimnetic accumulation of SRP at S station during 2002



column had occurred since the 13 August sampling. The SRP profile on 10 September was also nearly uniform with somewhat lower concentrations ranging from 0.14-0.25. On the final survey, 24 September, mixed-layer concentrations were slightly higher at

0.3-0.6 μM and increased to 1.9 μM at 20 m indicating continued rapid release from the sediments.

A similar seasonal pattern of hypolimnetic SRP accumulation was observed at the other deep station (E) (Fig. 26). On 19 June, SRP concentrations from the two stations were nearly identical (Fig. 27). While upper water column concentrations were similar between the two stations on other dates, the lowest depth at E was often significantly higher than comparable depths at S. This most likely reflect high concentration gradients in proximity to the sediments at the shallower E station and is parallel to the lower dissolved oxygen concentrations observed at the lower depths of the E station.

Fig. 26 Hypolimnetic accumulation of SRP at E station during 2002

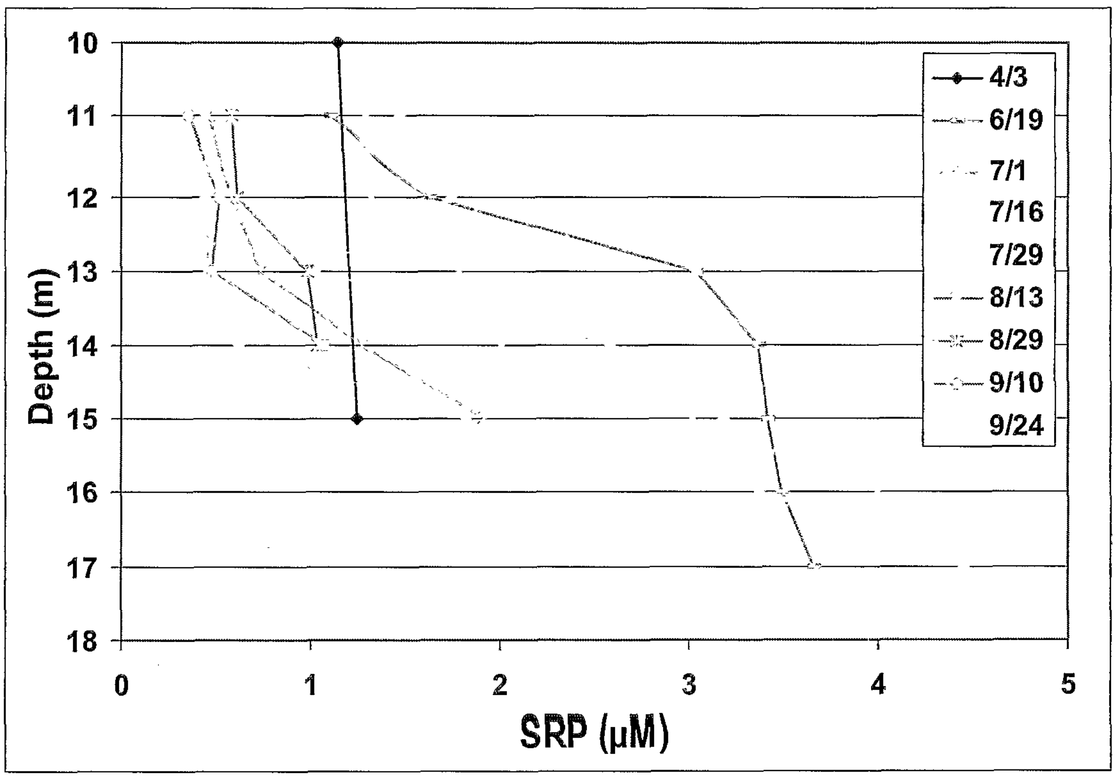
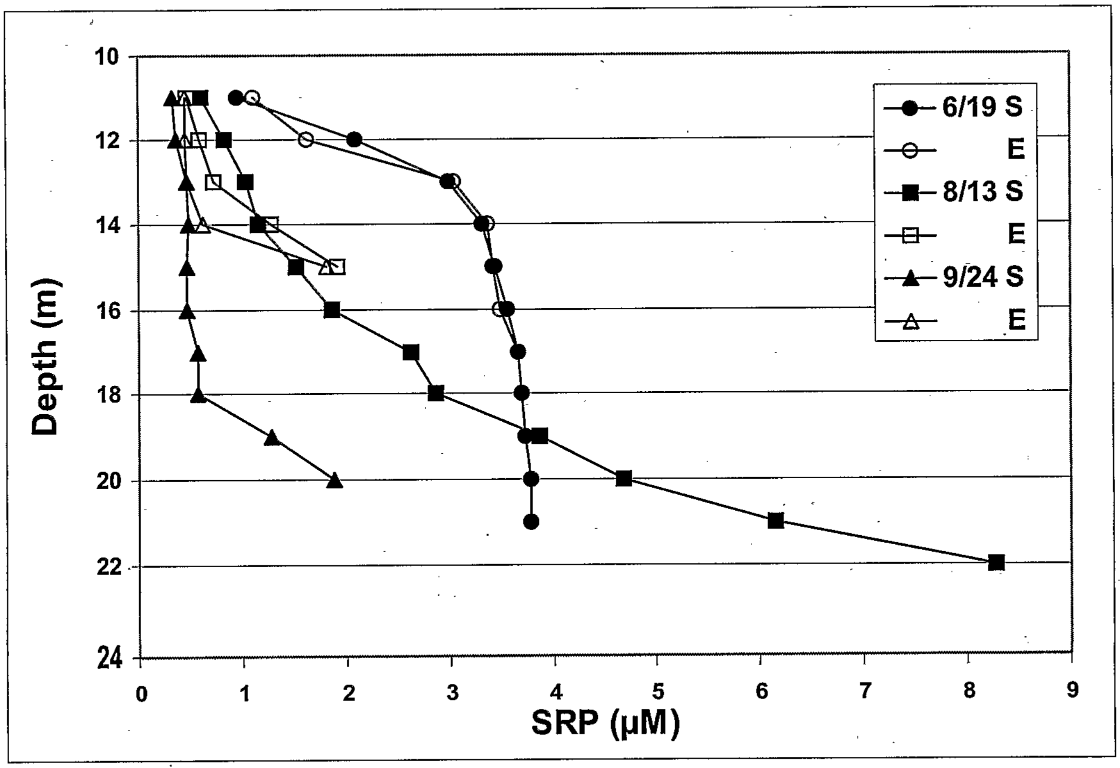


Fig. 27 Comparison of hypolimnetic SRP accumulation at E and S station



On 3 April, ammonium already displayed a depth gradient, increasing from 0.4 µM at 5 m to 4.4 µM at 20 m (Fig. 28). Ammonium concentrations increased to 13-16 µM below 13 m by 19 June. Hypolimnetic concentrations continued to increase reaching greater than 60 µM by 29 July. Peak concentrations were observed on 13 August when they exceed 80 µM at 22 m. As with SRP concentrations, hypolimnetic concentrations were uniform on 29 August only varying between 1.8-2.8 µM between 13 and 21 m. These decreased to 0.3-1.3 µM by 10 September before increasing to 1.5-5.0 from 11 to 18 m and further to 16 µM at 20 m on 24 September. This pattern is identical to that observed for SRP.

Fig. 28 Hypolimnetic accumulation of NH_4 at S station during 2002

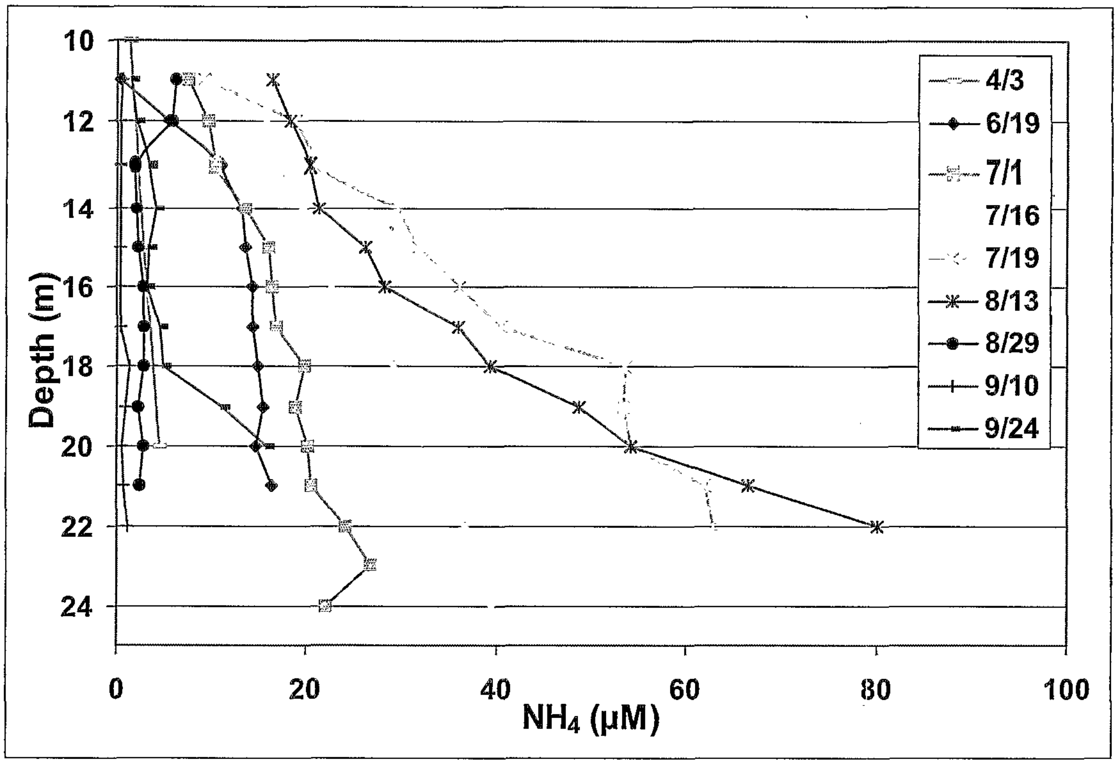


Fig. 29 Hypolimnetic accumulation of NH_4 at E station during 2002

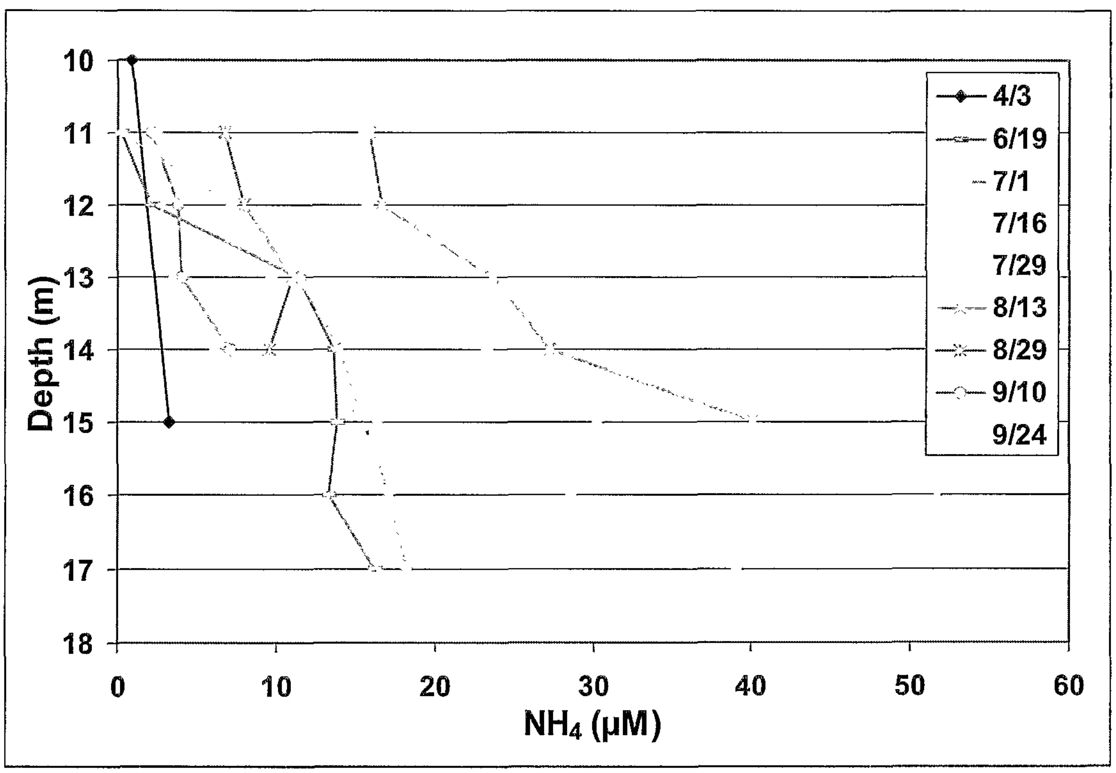
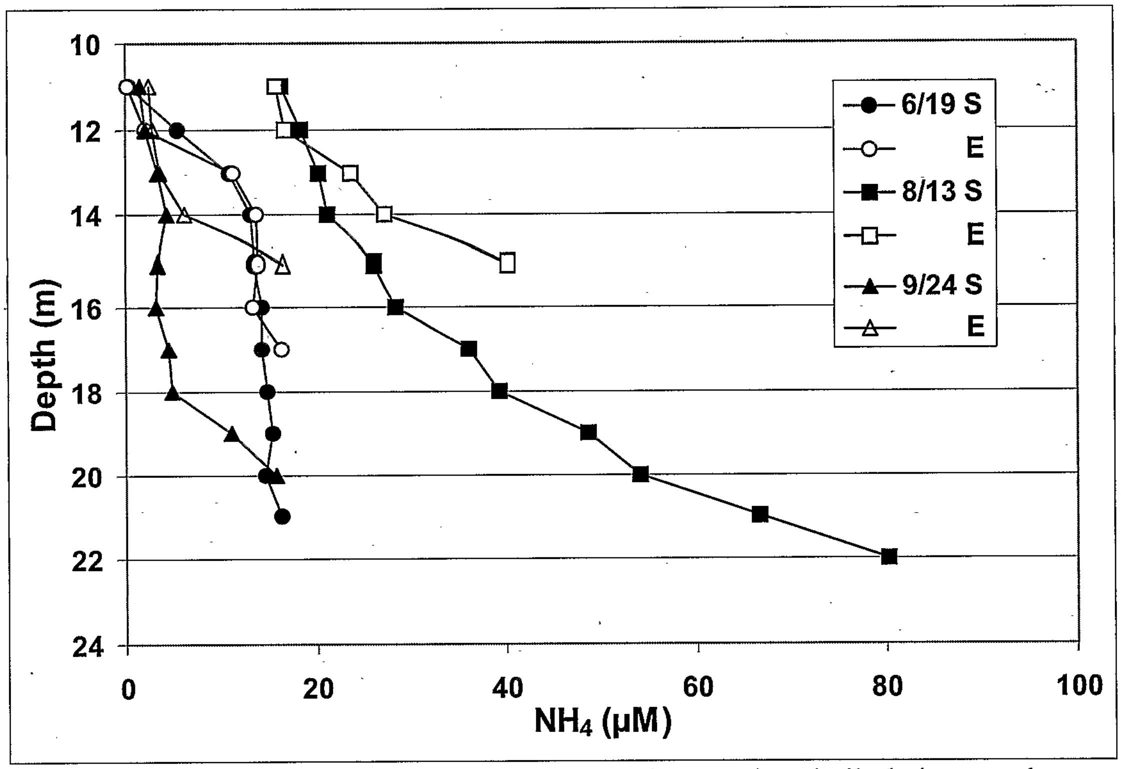


Fig. 30 Comparison of hypolimnetic ammonia accumulation at E and S station



Hypolimnetic accumulation of ammonia at the E station similarly increased through the season with concentrations peaking at 51.6 on 29 July at 16 m (Fig. 29). As with SRP, the ammonia accumulated rates were similar between the two stations (Fig. 30). The two stations were nearly identical 19 June but diverged later in the year with the deep depths at E being higher than comparable depths at S.

Nitrate profiles at the two stations were low and variable and showed no significant seasonal, depth, or station to station differences. The overall mean concentration of samples collected from 11 to 22 m at the two stations was 0.23 μM (Std Dev, 0.08) with individual samples ranging from 0.09 to 0.44 μM.

The total accumulation of SRP and NH_4^+ beneath 11 m was estimated by interpolating the nutrient concentrations to 0.25 m intervals and multiplying by the appropriate incremental volumes (Table 3). The concentrations at the two stations were averaged excluding the lowest depth at the east station which was not included. During the 77-day period from 3 April to 19 June, lakewide SRP beneath 11 m increased at 619 moles d^{-1} while NH_4 increased at 3,688 moles d^{-1}. The N:P molar ratio of accumulation was ~6. As the area beneath 11 m during this period was ~6.7 km^2, this yields accumulation rates of 92 and 550 μmoles m^{-2} d^{-1}, for SRP and NH4, respectively.

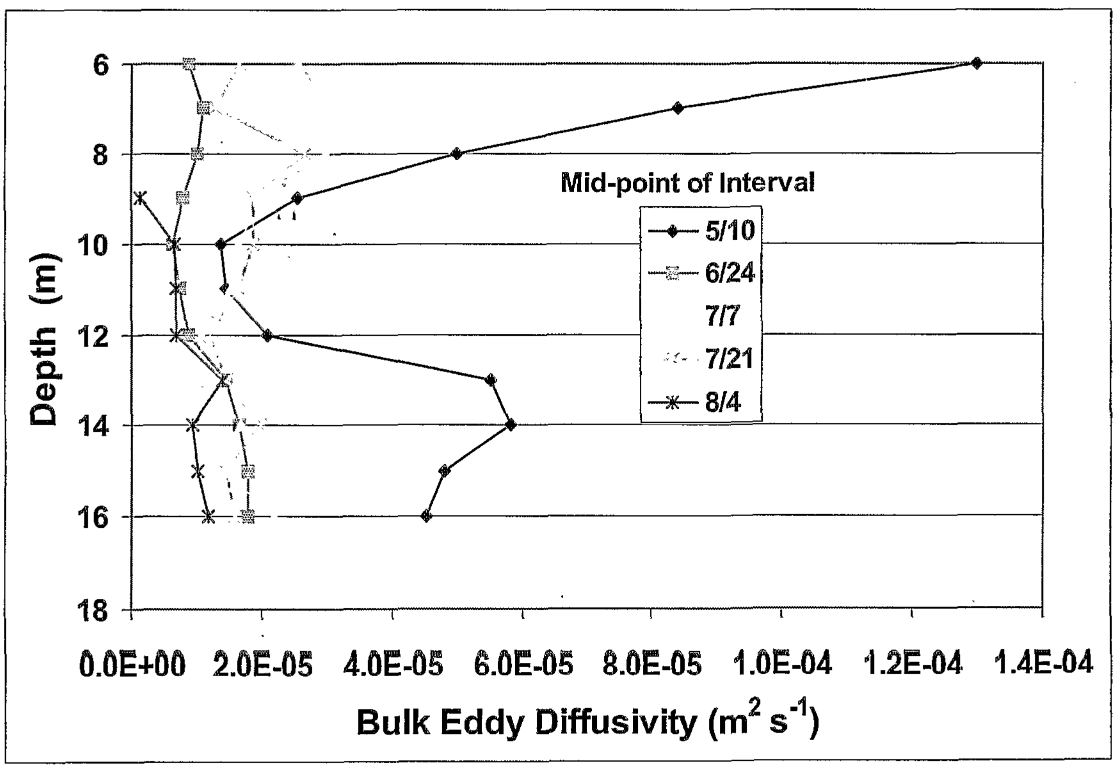
Table 3 Hypolimnetic accumulation of SRP and NH_4 beneath 11 m depth.

Date	SRP (moles)	NH4 (moles)
4/3/2002	43945	52155
6/19/2002	91597	336144
7/1/2002	90701	406263
7/16/2002	63352	543748
7/29/2002	57840	704888
8/13/2002	32253	529985
8/29/2002	6917	58392
9/10/2002	3050	8073
9/24/2002	8178	59047

Eddy diffusivity and upward nutrient fluxes

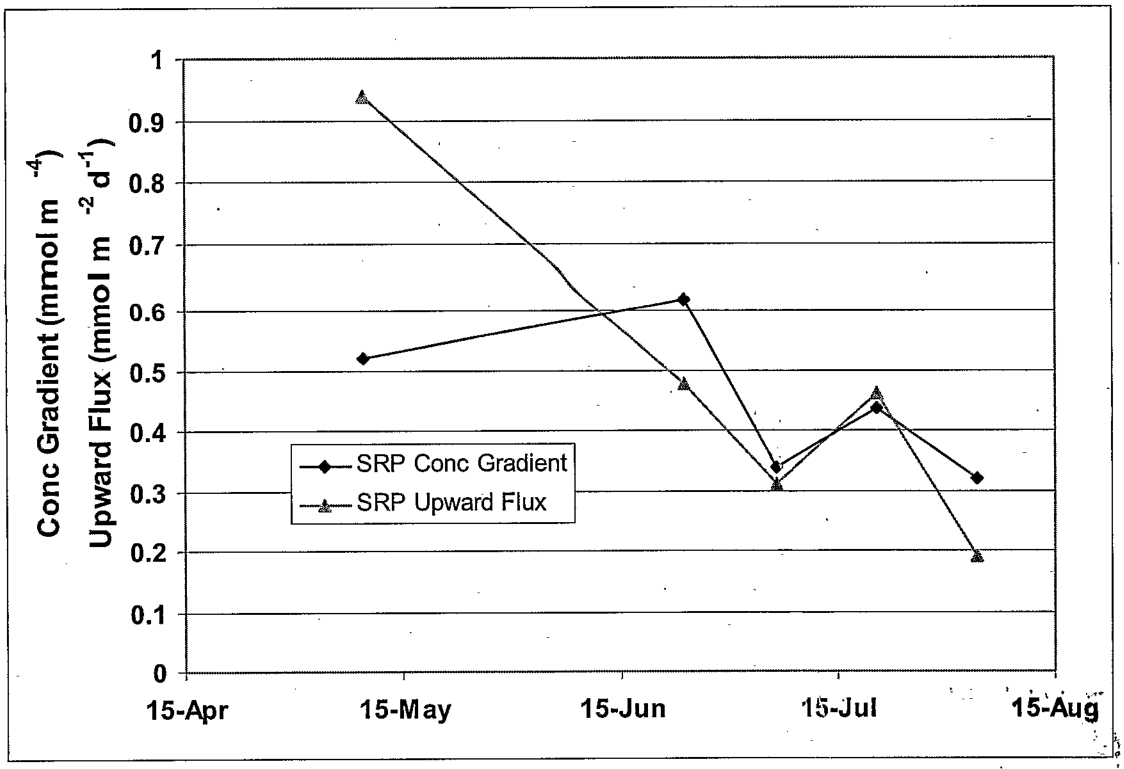
The flux-gradient heat method of estimating bulk eddy diffusivities uses heat as a tracer of mixing during periods in which heat is being mixed downward in the lake. Eddy diffusivities were estimated from 6 to 18 m depth for the period 3 April through 29 August (Fig. 31). Values ranged from 1.4 x 10^{-6} m^2 s^{-1} (~10 times molecular conductivity) to 1.3 x 10^{-4} m^2 s^{-1} (~1000 molecular conductivity). Minimum values were located between 10 and 12 m at the region of maximum thermal stratification.

Fig. 31 Bulk eddy diffusivities estimated from the flux-gradient heat method.



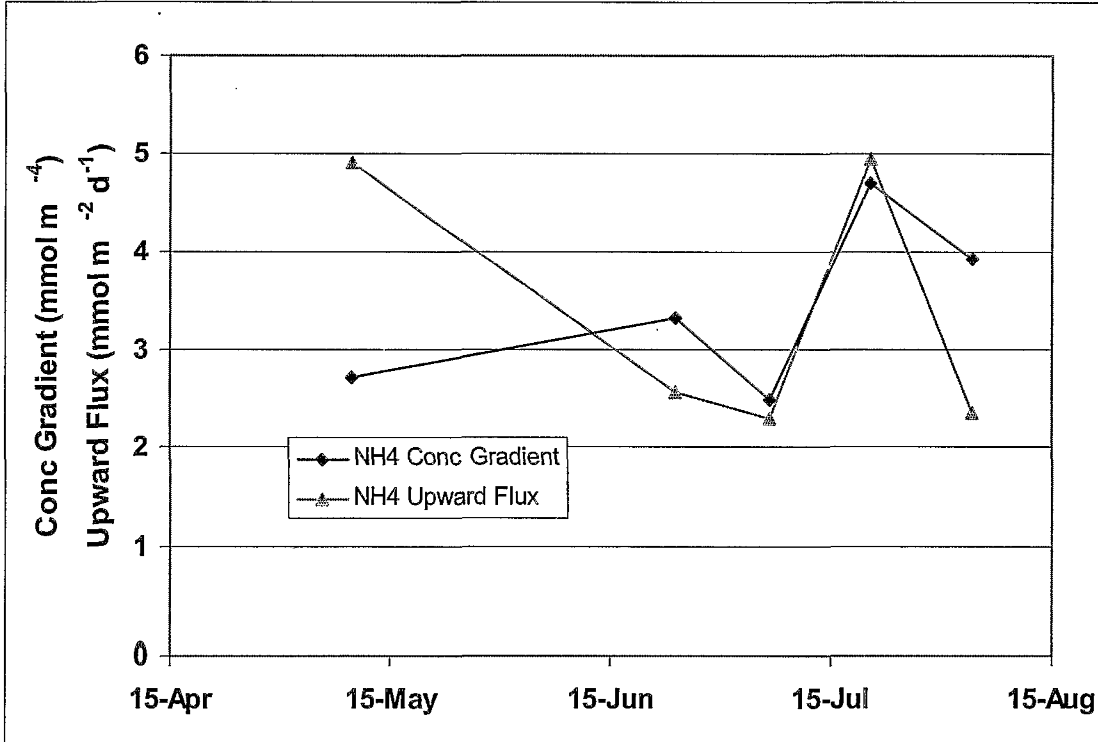
The average SRP concentration gradients at 12 m over the 5 periods ranged from about 0.3 to 0.6 mmole m^{-4} (Fig. 32). Combining these with the estimated eddy diffusivities yields upward SRP fluxes ranging from 0.94 mmole m^{-2} d^{-1} for the 3 April to 19 June to a minimum of 0.2 mmole m^{-2} d^{-1} for the period, 29 July to 14 August.

Fig. 32 SRP concentration gradients and estimated upward fluxes at 12 m



The average NH_4 concentration gradients at 12 m over the same periods ranged from about 2.4 to 4.7 mmole m^{-4} (Fig. 33). Combining these with the estimated eddy diffusivities yields upward NH_4 fluxes ranging from 2.2 to 5 mmole m^{-2} d^{-1}. In contrast to SRP fluxes, the estimated ammonia flux was high for the first period, declined during the next two and increased in mid summer.

Fig. 33 NH_4 concentration gradients and estimated upward fluxes at 12 m



Nitrogen Fixation

Planktonic nitrogen fixation was estimated from measurements of nitrogenase activity based on the acetylene reduction technique. Acetylene reduction was measured on 8 dates in freshly collected plankton samples from 5 stations. A plankton sample was collected from the Crowley Lake marina dock on 29 May for time course and saturation tests. Acetylene reduction was linear over the 6 hr test period and the average nitrogen fixation rate for three replicates was 34.6 µmol N m^{-3} h^{-1}. This was higher than any other rates measured on the eight surveys. Results from all eight surveys are shown below (Fig. 34).

On the June survey, rates at the highest light level of 95 µE m^{-2} s^{-1} ranged from 3.9 to 10.2 µmol N m^{-3} h^{-1} or only about one fifth that measured on 29 May. Rates were much lower and variable on the following survey (2 July). As rates appeared to not be saturated at the highest light levels on the first two dates, the remaining surveys included two treatments in which samples were incubated in the stream and exposed to much higher (1000-1800 µmol N m^{-3} h-1) light intensities. On these six remaining surveys, several exhibited inhibition at the highest light level, and most exhibited a maximum at the 400-800 µE m^{-2} s^{-1} treatment.

On the next two dates in July rates dropped even lower. In August and September rates increase. Rates were slightly higher on the 15 August survey and increased further on 3 September. The last two September dates were slightly lower but still higher than

June and July values. On three of the four August and September surveys, one station was higher than the rest and indicative of pronounced spatial variability.

Fig. 34 Nitrogen fixation estimates based on acetylene reduction measurements

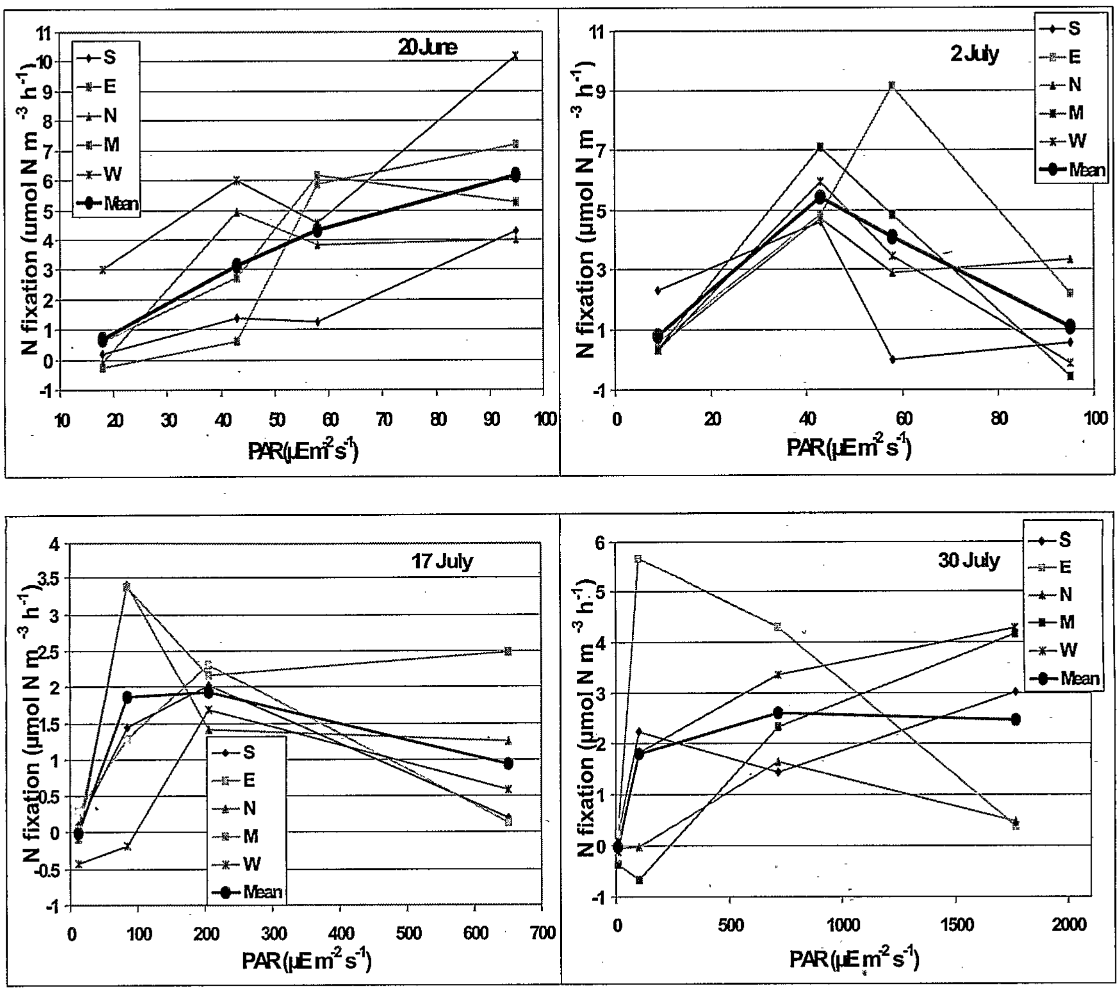
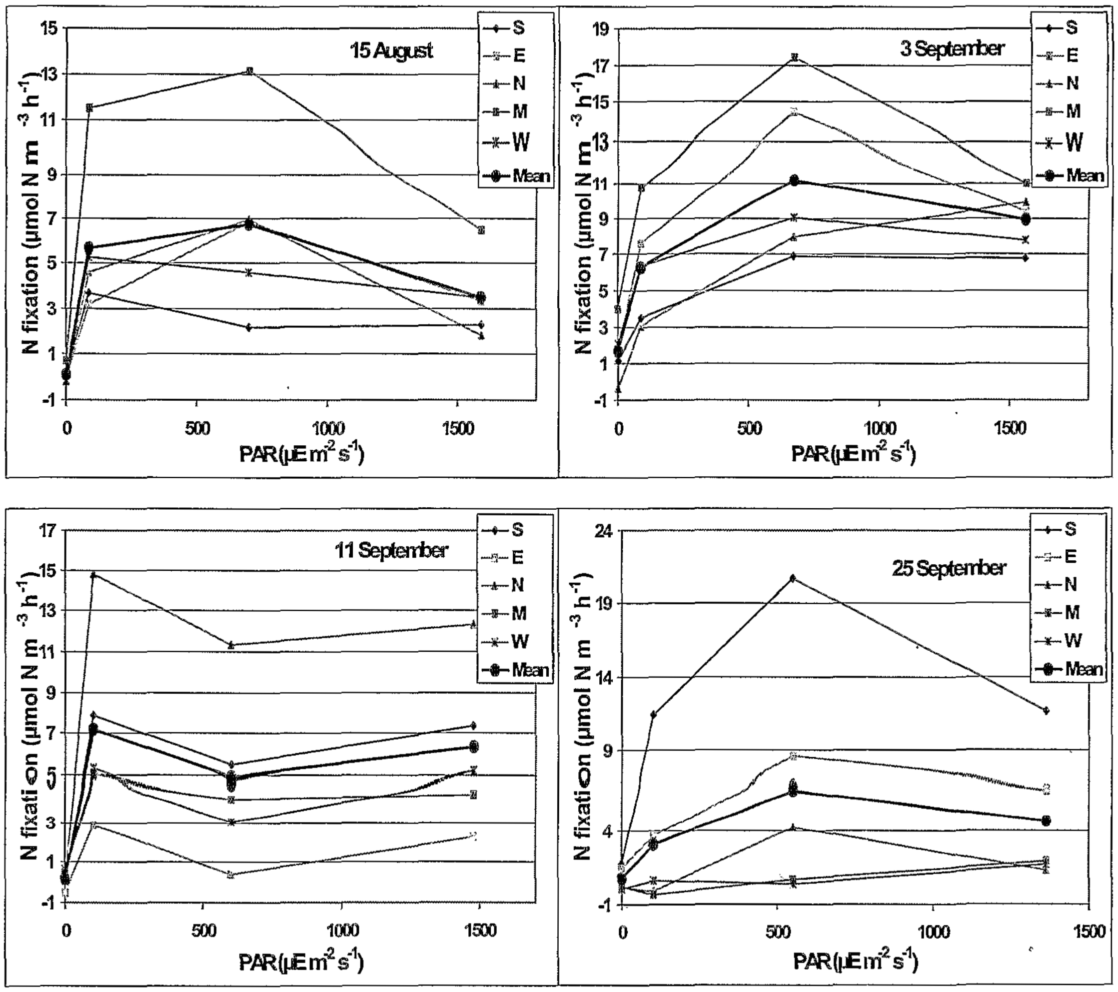


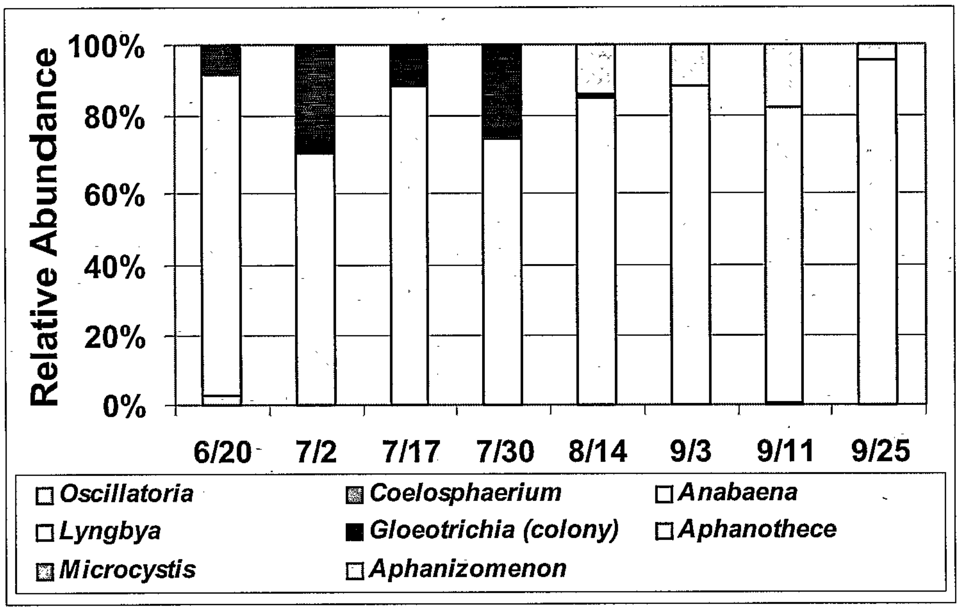
Fig. 34 (cont) Nitrogen fixation estimates based on acetylene reduction measurements



Nitrogen fixation was quite variable both spatially and temporally throughout the summer. Rates appeared to be fairly well correlated with the abundance of the cyanophyte, *Gloeotrichia*, during the months of June and July and with *Aphanizomenon* during September.

General trends can be described using the South station as a typical representation of other stations in the lake. *Lyngbya* was found throughout the lake in fairly high abundance relative to other cyanophytes throughout the summer. *Gloeotrichia*, present in June and July, was replaced by *Aphanizomenon* in August through September (Fig 35).

Fig. 35 Relative abundance of Cyanophytes at South Station during 2002



While overall abundance can vary substantially between stations on any given date, the general trend was similar to that found at the S station (Fig. 36) and paralleled the pattern of chlorophyll concentration (Fig. 22). Abundance was highest on 2 July, and then declined to a minimum on 14 August. Abundance then increased through September until the 25th, after which all stations except S, started to decline. Higher fixation rates at S (Fig. 37) during August and September corresponded with the appearance of *Aphanizomenon* (Fig. 36). *Aphanizomenon* was most abundant on 11 September, and decreases (in order) on 3 and 25 September. The highest fixation rates occurred on 24 September and decreased in order from 11 and 3 September. *Gloeotrichia* was present in June and July and most abundant on 2 July. Nitrogen fixation rates were higher on 2 July than other dates in June and July. However, it should be noted that the first two sets of incubations on June 20 and July 2 were done inside under artificial light and PAR was well below normal values observed in the lake. Beginning 17 July, two sets of incubations were done with one in Convict Creek under higher more natural light.

Fig. 36 Abundance of Cyanophytes at South Station during 2002

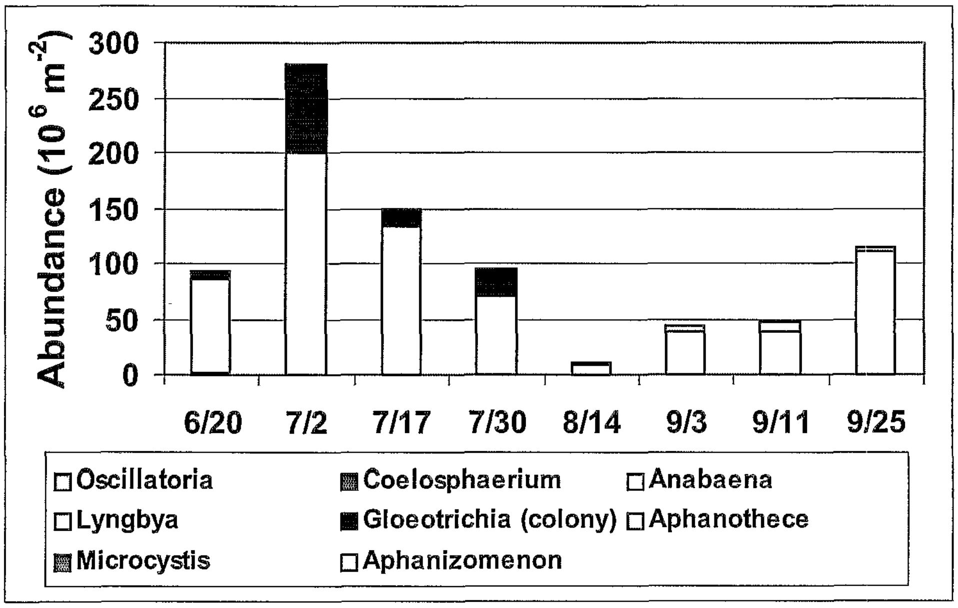
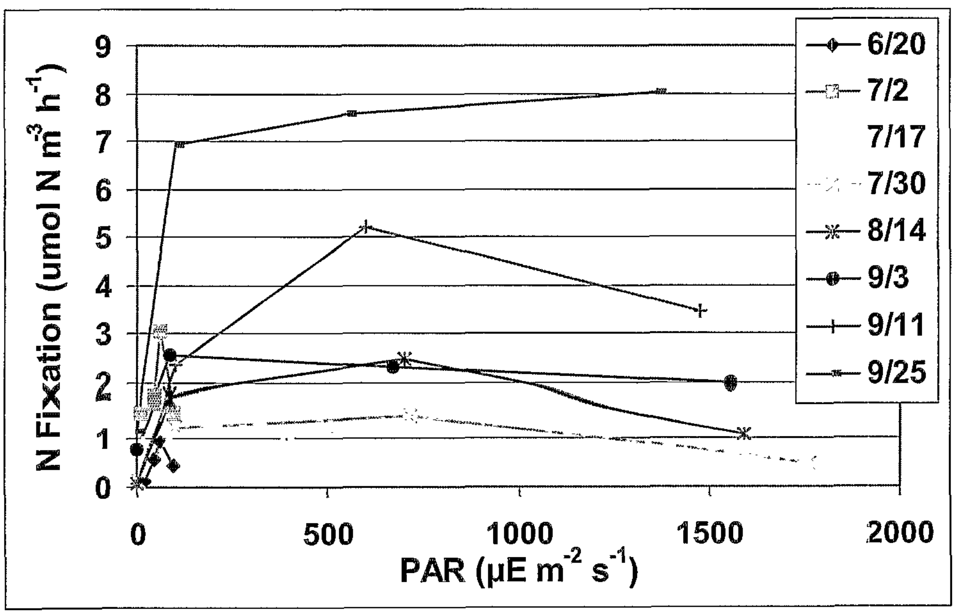


Fig 37 Nitrogen fixation at South station during 2002.



Fixation rates obtained on specific dates correspond well to Cyanophyte abundance at each of the five stations. The highest rates we obtained occurred during incubations on September 3 (Fig. 38). If we compare these rates to the amount of *Aphanizomenon* at each location (Fig. 39), we find that M has the highest fixation rates and the highest abundance of *Aphanizomenon*. Both fixation rates and abundance of *Aphanizomenon* decrease in order from E, W, S and N stations.

Fig.38 Nitrogen fixation rates obtained on September 3, 2002 (from Fig. 34)

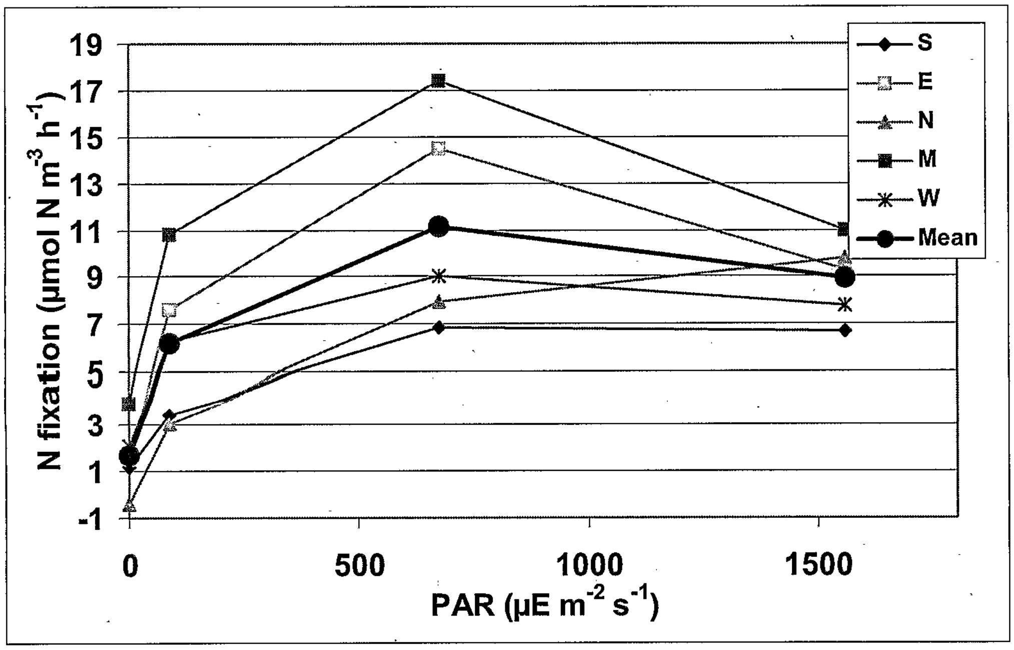
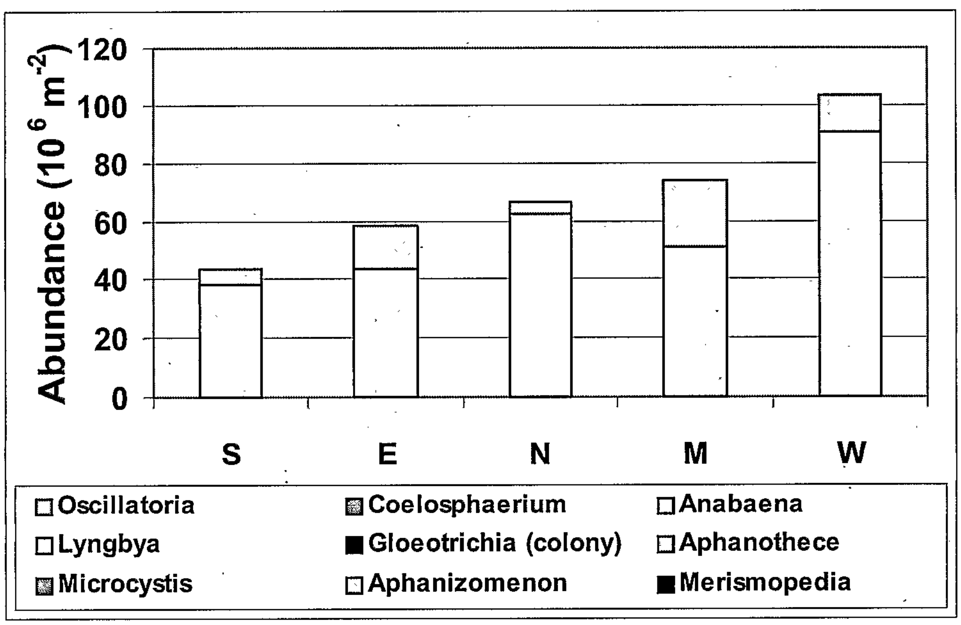


Fig. 39 Cyanophyte abundance on September 3, 2002.



The same comparison on a date with a low fixation rate, indicated a similar trend; 20 June had the 6th ranking fixation rate out of 8 trials and is very close to values obtained on July 17 and 30. Values up to 10 µmol N fixed m^{-3} h^{-1} were obtained at W and descended in order of M, N, E, S (Fig 40). At this time of year, *Aphanizomenon* was not present, but colonies of *Gloeotrichia* were abundant around the lake. Abundance of this genera of cyanophyte also correlated with fixation rates. *Gloeotrichia* was most abundant at M followed by W, N, E, and S (Fig. 41).

Fig. 40 Nitrogen fixation rates on June 20, 2002 (from Fig. 34).

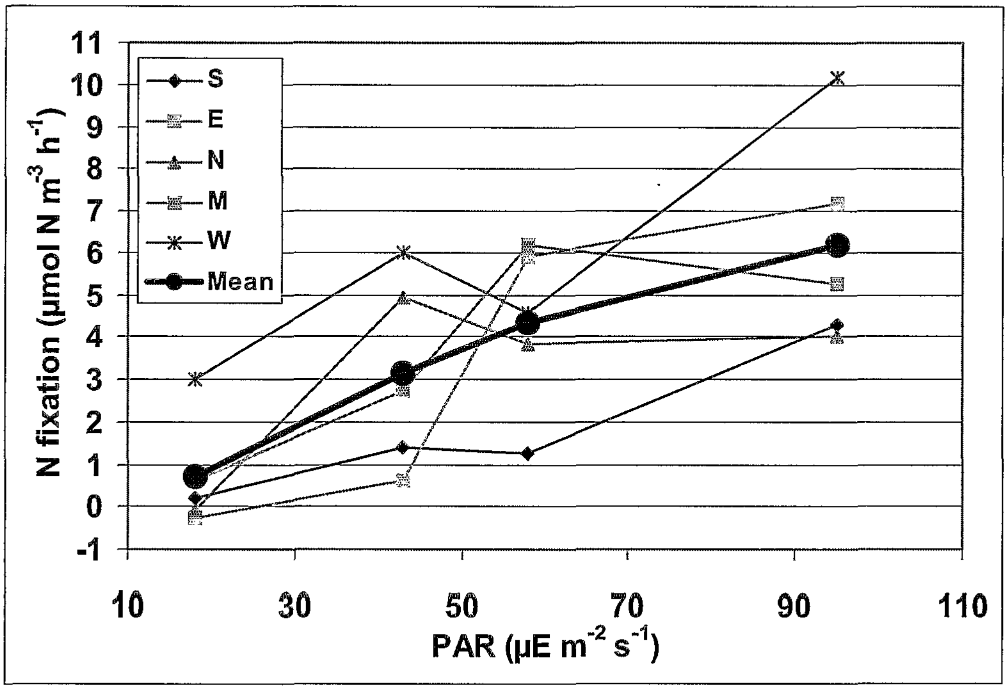
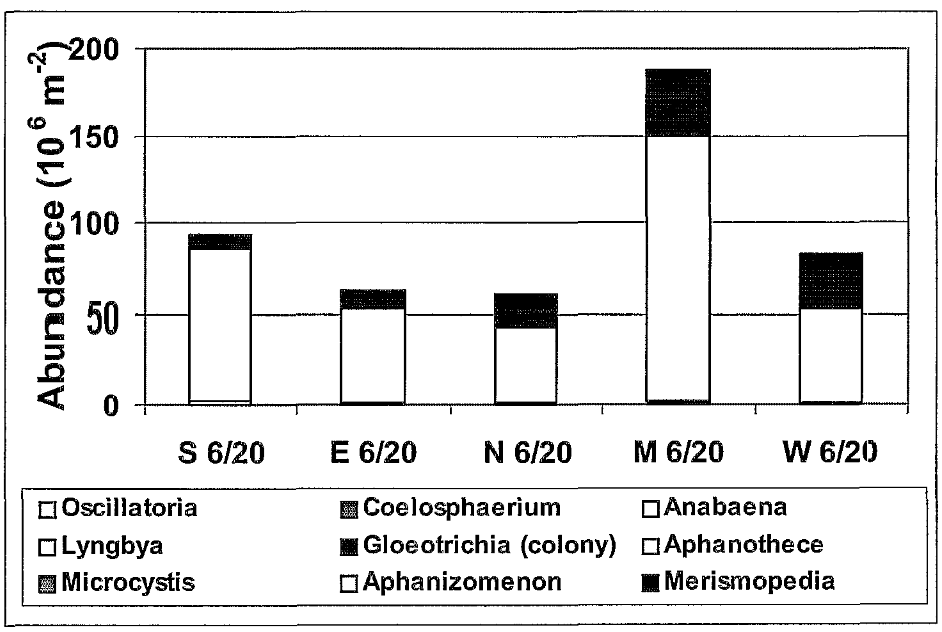


Fig. 41 Cyanophyte abundance on June 20, 2002.



Phytoplankton abundance was lowest on the 14 August sampling date. At this time, a mixture of *Gloeotrichia* and *Aphanizomenon* occured at stations within the lake. *Aphanizomenon* was present at S, E, M and W, while *Gloeotrichia* was present at E, M and W (Fig. 42). Fixation rates were highest at the M station (Fig.43) which had the highest abundance of *Aphanizomenon* and the 2nd highest abundance of *Gloeotrichia*. West had the 2nd highest fixation rates and the highest abundance of *Gloeotrichia* and the 2nd highest abundance of *Aphanizomenon*. E had the 3rd highest abundance of both genera and was approximately 3rd highest in measured nitrogen fixation rates. However, E shows a higher fixation rate than W at the mid PAR range. North shows a rather inexplicably high fixation rate as neither *Gloeotrichia* nor *Aphanizomenon* was counted in the sample. However, the nitrogen fixer, *Anabaena,* was present at N, as well as S and M, and may contribute substantially to fixation rates. The fixation at South was low and can be explained by the low abundance of *Aphanizomenon* present there.

Fig.42 Cyanophyte abundance on August 14, 2002.

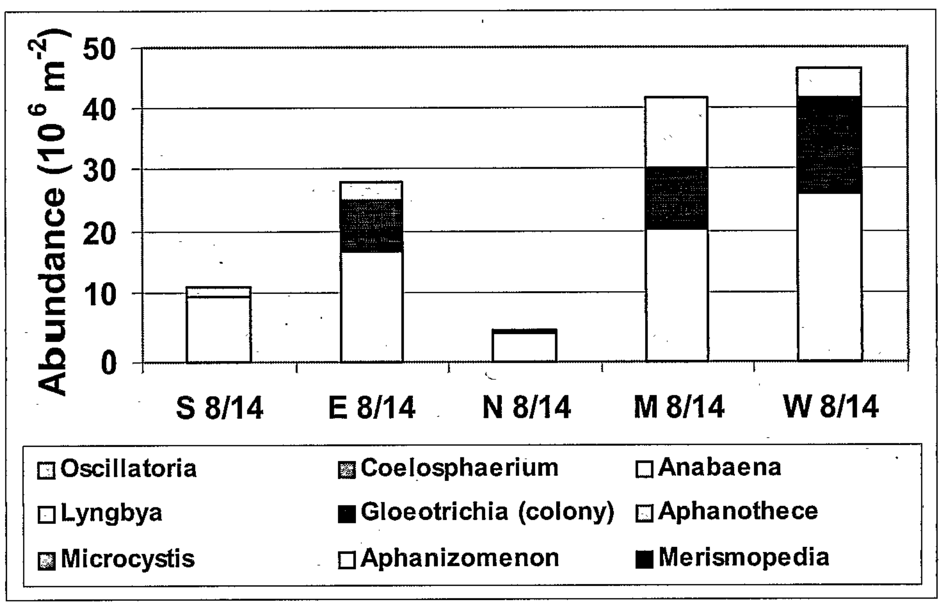
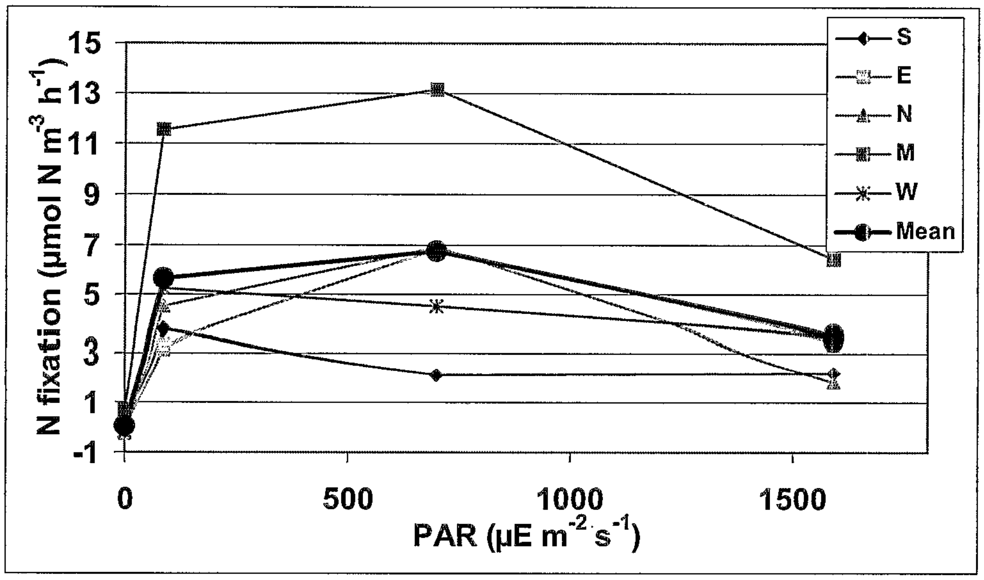


Fig. 43 Nitrogen Fixation rates on August 14, 2002 (from Fig. 34).

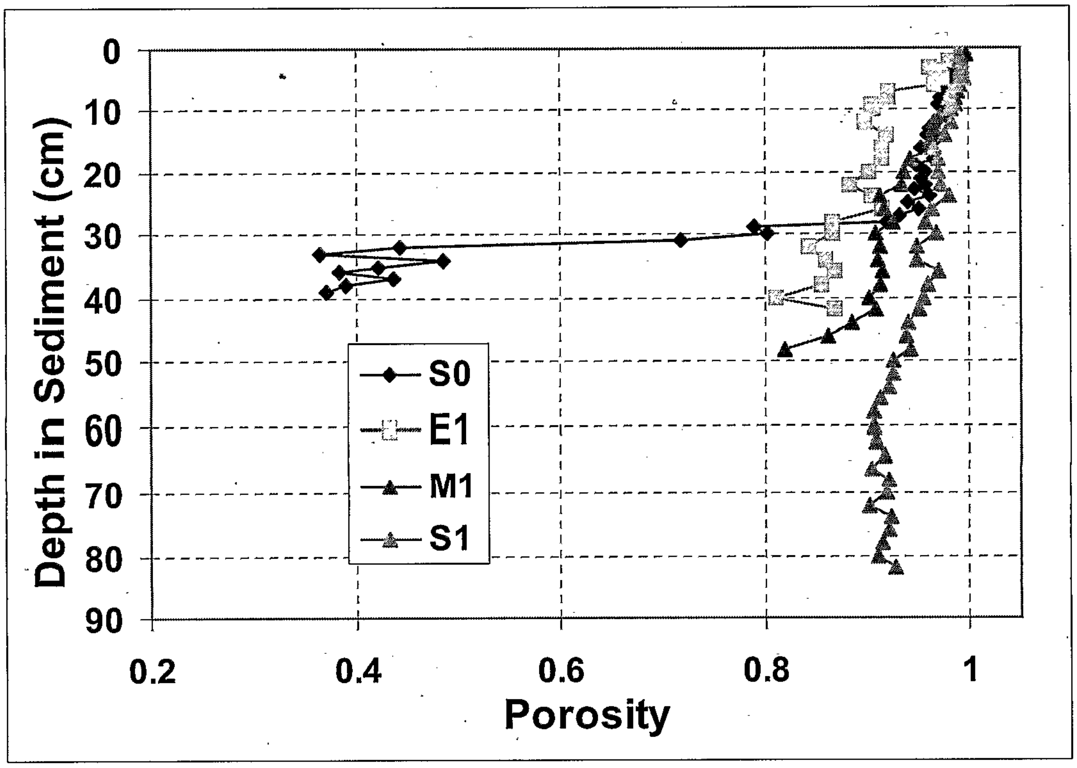


Sediment cores

Four sediment cores were collected from Crowley Lake during September 2002. One core was collected at the S station on 15 September (S0, 40 cm length) and one core from each of stations S (S1, 82 cm length), E (E1, 42 cm length) and M (M1, 48 cm length) was collected on 30 September. The sediments were amorphous, dark-green to black in color characteristic of gyttja. There was little evidence of lamination and they were highly porous.

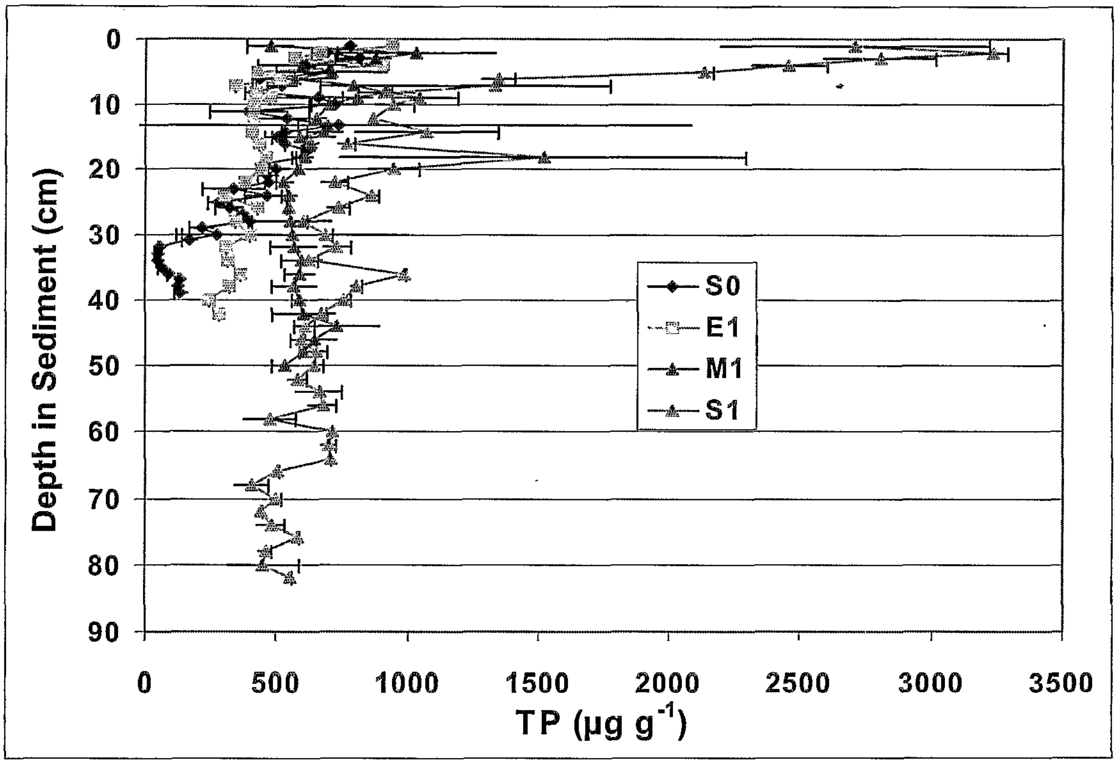
Porosity ranged from 80 to 99.5 (Fig. 44) in all but the bottom 10 cm of the first core (S0) taken at the S station. Below 27 m, core S0 showed a distinct drop in porosity. This was reflected in the texture of the dry sediment, which became quite gravelly at this point whereas all other cores remained quite fine. E1 was noticeably less porous, dropping below 90% at 7m where porosity continued to be approximately 10% lower than that of other cores. The bottom 4 cm of M1 decreased in porosity from ~0.9 to 0.81. In contrast, porosity in the bottom 30 cm of the longest core (S1) remained near 0.9.

Fig. 44 Sediment porosity



Total phosphorus content of the core generally ranged from 300-1000 μg g^{-1} (Fig. 45). It was significantly lower (50-140 μg g^{-1}) in the bottom 8 cm of S0, corresponding to the low porosities observed there. TP was markedly higher (1300-2700 μg g^{-1}) in the upper 7 cm of S1. Except for these two exceptions, the TP profiles were relatively constant with depth. A slight general decrease with depth below 10 cm (7.2 μg g^{-1} cm^{-1}, r^2=0.53) is apparent within S1.

Fig. 45 Total phosphorus (TP) in Crowley Lake sediment cores.



Non-apatite inorganic phosphorus (NAIP) generally ranged from 50-450 µg g^{-1}, except that as with TP it was lower in the bottom 10 cm of S0 and higher in the upper portion of S1 (Fig. 46). At the E station (E1) it was nearly uniform at 50-70 µg g^{-1} except for the upper 7 cm where it increased to 220-230 µg g^{-1}. This increase in the upper 7 cm was more pronounced in S1 where values increased to over 1500 µg g^{-1}. Both southern cores and the core from station M showed a slight but general decrease with depth. The mean ratio of NAIP:TP was 0.36 (1SE, 0.13) and showed no trend with depth.

NAIP is generally considered the biologically active sediment phosphorus. Plotted by volume (5-pt running mean), it displays only a slight increasing trend with depth (0.09 µg cm^{-4}, r^2=0.41) in S1, while TP increases more sharply with depth (1.2 µg cm^{-4}, r^2=0.85)(Fig. 47). The mean NAIP:TP ratio in S1 was 0.2, generally decreasing with depth.

Porewater ammonia differed markedly among the three cores (Fig. 48). In S1, the longest and most porous core, NH_4 concentrations increased from 600 µM in the top few cm to 1600-1750 µM in the bottom 20 cm. In the other south station core, S0, the values only increased to near 400 µM near the bottom. Core M1 concentrations were similar to S0 except that the upper 10 cm gradients were distinctly different. As with porosity and

Fig. 46 Non-apatite inorganic phosphorus (NAIP) in Crowley Lake sediment cores

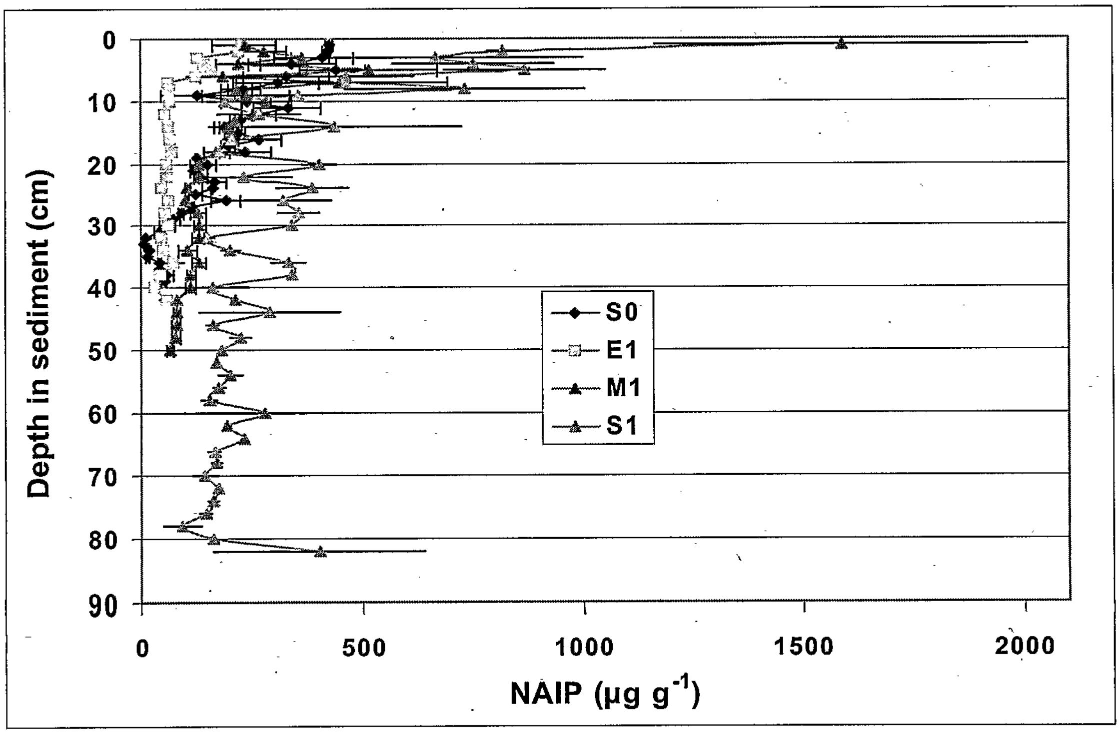


Fig. 47 NAIP and TP in Crowley Lake sediment cores (by volume). Five point mean.

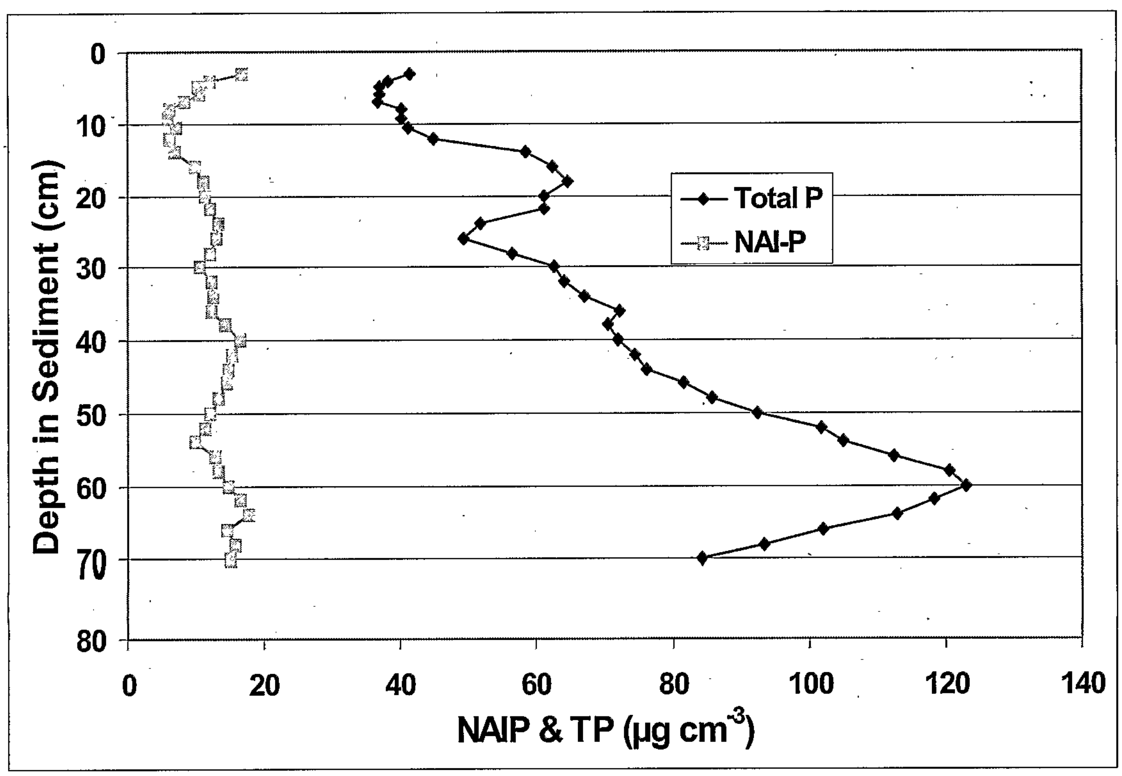
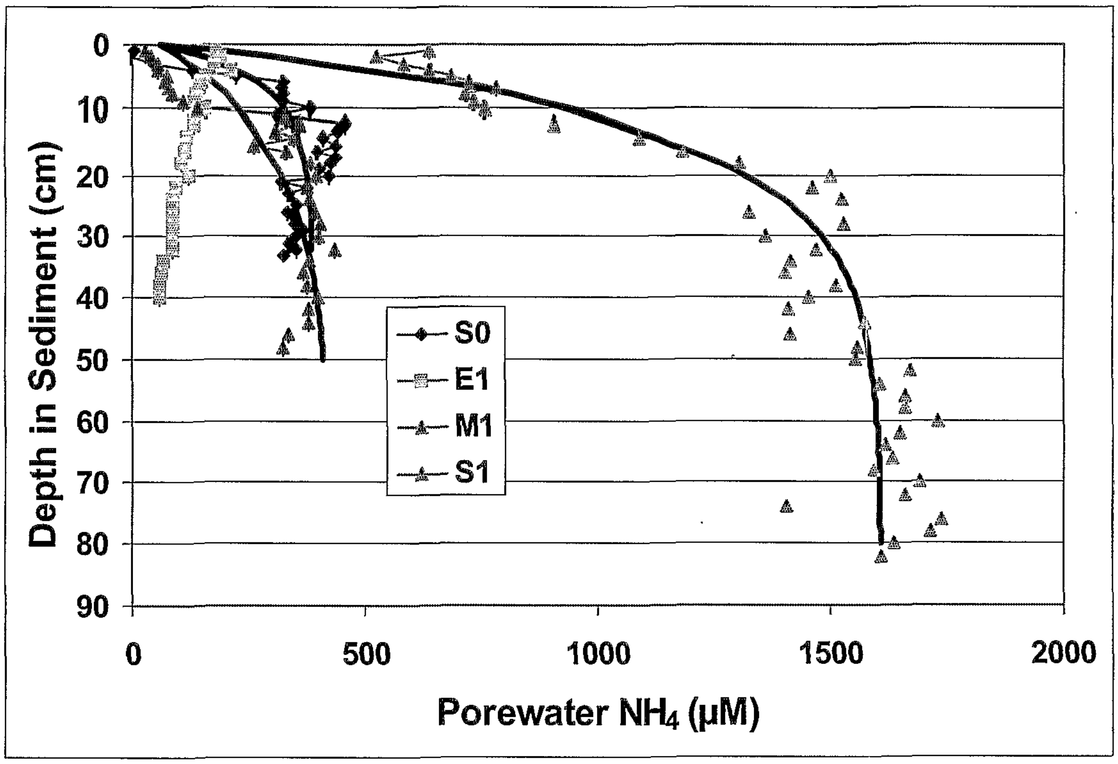


Fig. 48 Porewater ammonia profiles and fitted concentrations



TP, porewater NH_4 at E1 was distinctly different from the other cores and decreased from near 200 µM near the surface to about 60 µM at 40 cm. As this core appears anomalous, it is not further considered here.

The porewater concentrations were modeled to calculate gradients at the sediment water interface (Fig. 48). Estimated gradients ranged from 56 to 225 µM cm^{-1} (Table 4). S0, S1, and M1 the porewater profiles and fitted lines suggest a marked change in the upper 10 cm that is poorly modeled. Therefore, these porewater concentrations in these three profiles were also fitted to just the top 10 cm concentrations (Fig 49.) resulting in estimated concentration gradients of 15 to 78 µM cm^{-1}at the sediment-water interface. Although the concentration gradients derived from the upper 10 cm probably provide more accurate estimates, we calculated the estimated flux rates for both as an indication of the uncertainty in the estimates. Estimated NH_4 fluxes out of the sediments based on concentration gradients using the upper 10 cm samples ranged from 0.2 in M1 to 1.1 mmol m^{-2} d^{-1} at S0 with S1 lying in the middle of the range at 0.7 mmol m^{-2} d^{-1}.

Fig. 49 Porewater ammonia profiles and concentrations in the upper 10 cm fitted

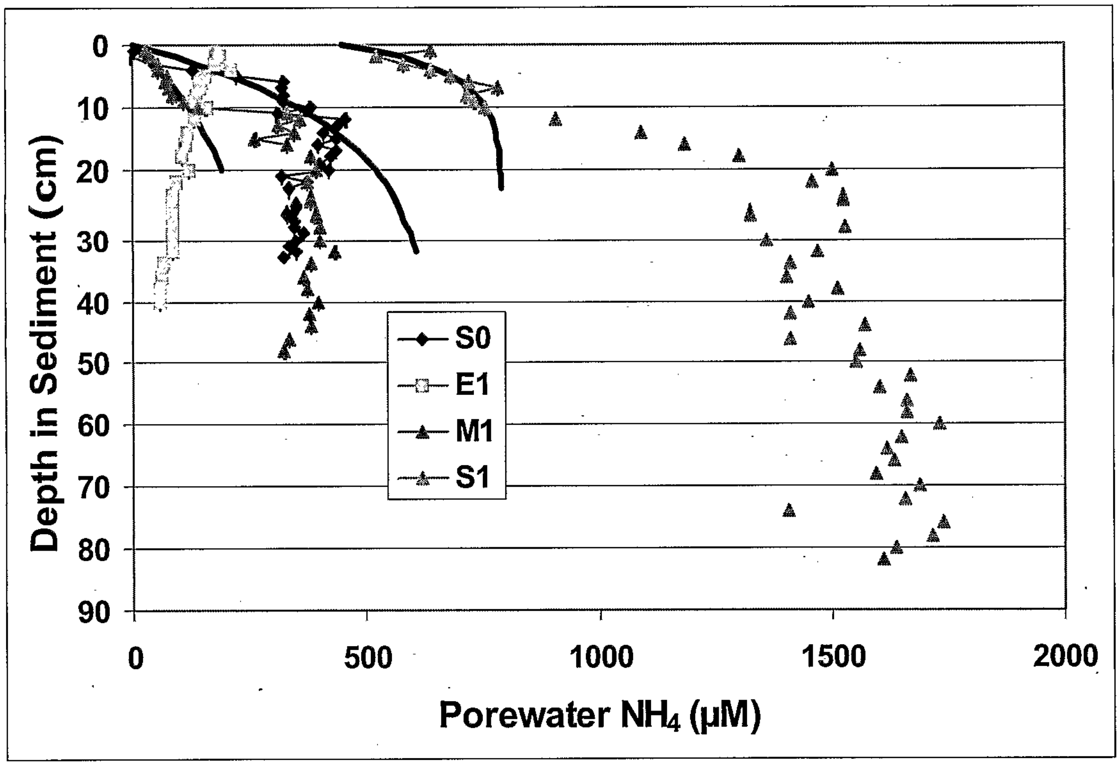
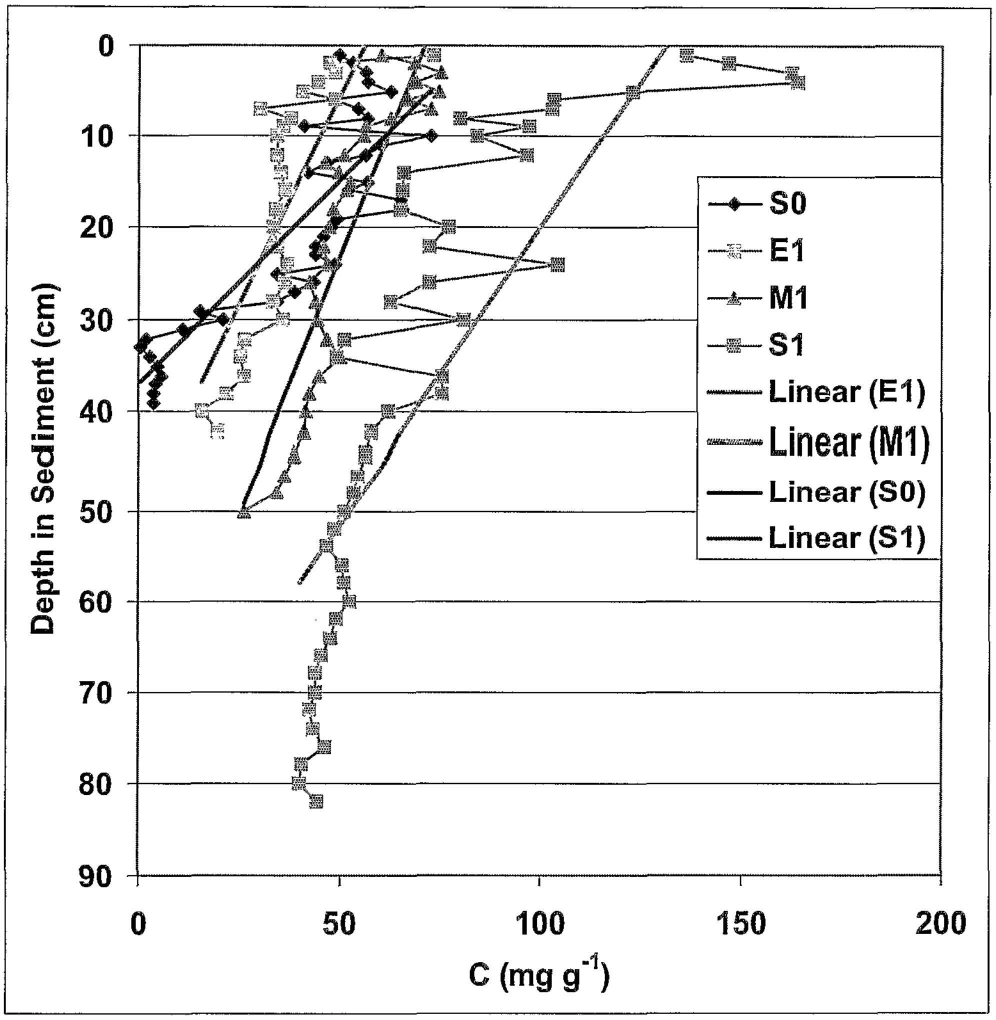


Table 4 Estimated sediment-water ammonia fluxes

Core	Porosity (upper 10 cm)	NH4 gradient $\mu M\ cm^{-1}$	NH4 Flux $mmol\ m^{-2}\ d^{-1}$
Based on sediment-water gradients using only the upper 10 cm value			
S0	0.98	77.8	1.1
S1	0.99	50.3	0.7
M1	0.98	15.3	0.2
Based on sediment-water gradients using all data			
S0	0.98	56	0.8
S1	0.99	129	1.8
M1	0.98	225	3.2

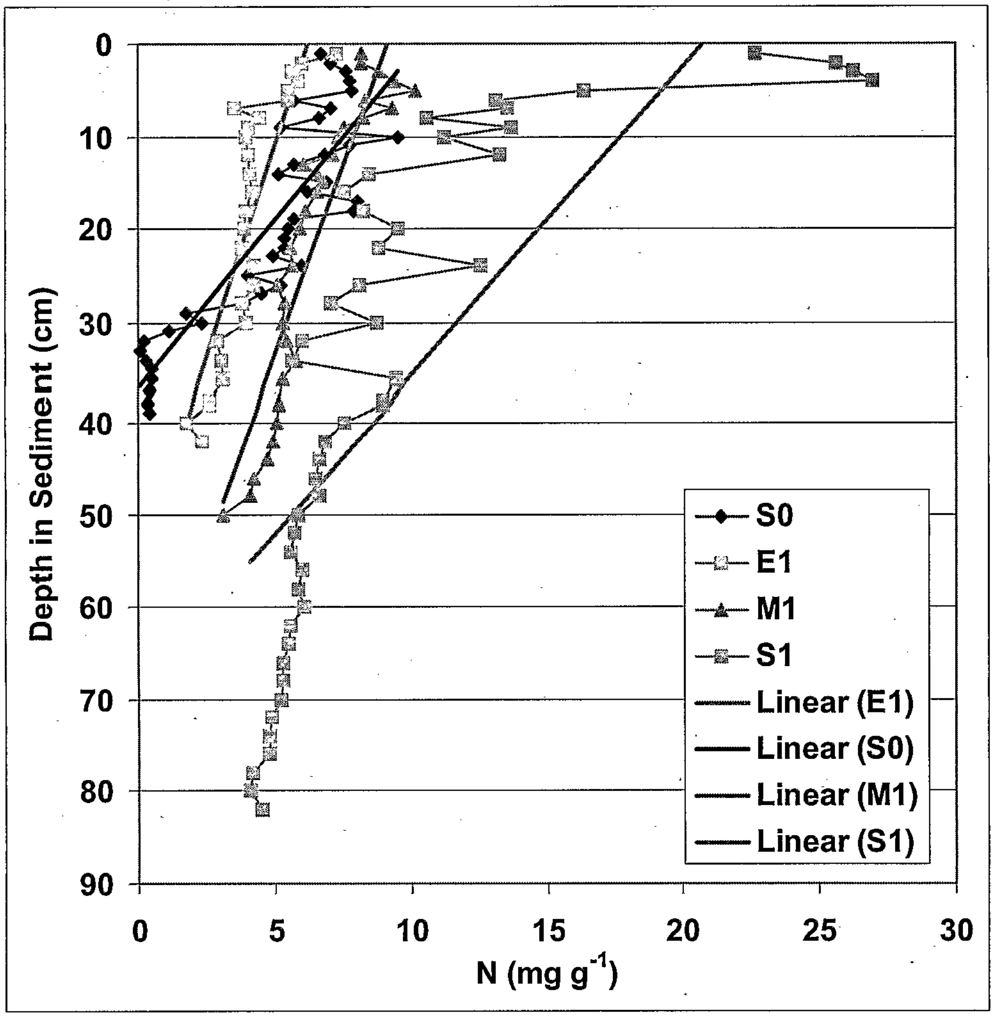
Sediment particulate inorganic carbon ranged from 11.1 - 164.2 mg g^{-1} with the exception of the bottom 8 cm of S0 where values declined to 0.69 mg g^{-1} (Fig. 50). As seen with TP and NAI-P, there is a higher PC content in the upper few cm of S1. There was an overall trend for carbon to decrease with depth ($r^2 = 0.6106 - 0.7757$) (Fig. 50).

Fig. 50 Particulate carbon content in sediment cores.



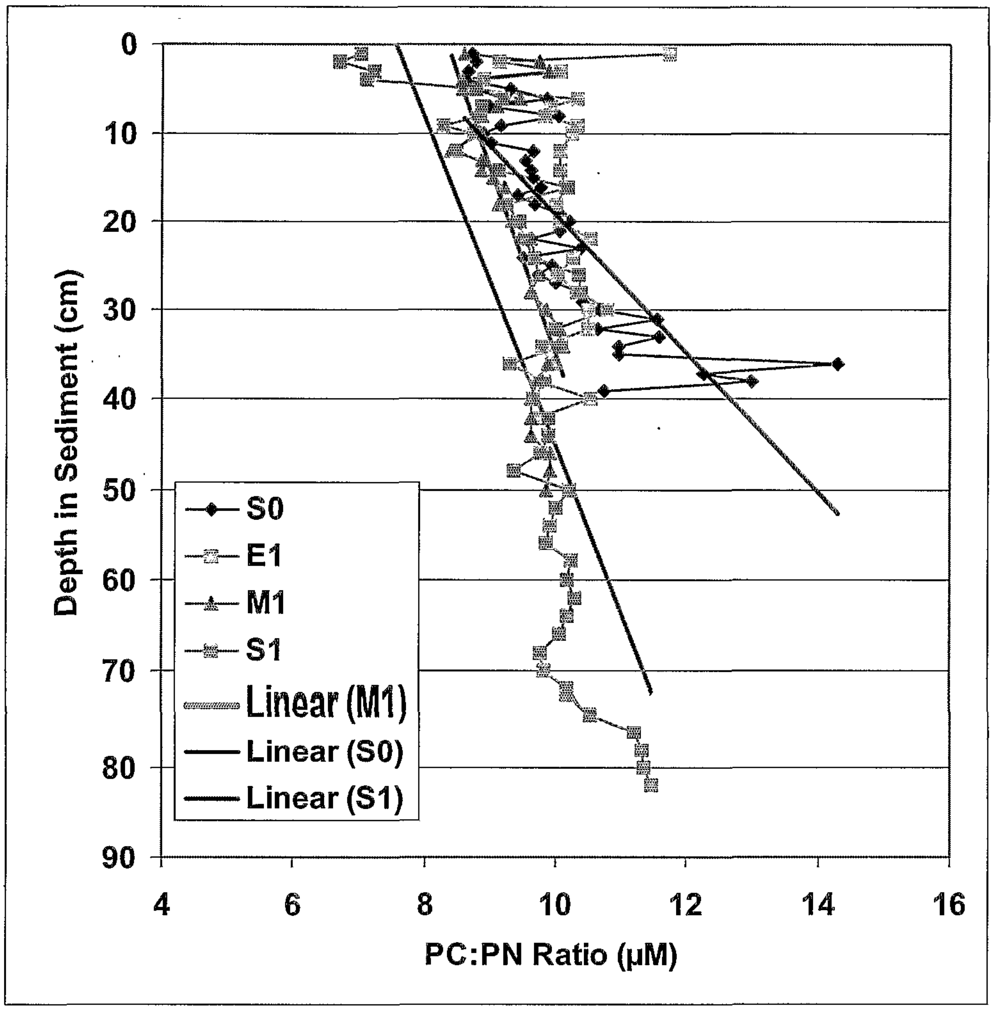
Sediment inorganic nitrogen ranged from .07 to 27 mg g^{-1} sediment with the characteristic decrease at the bottom of S0 and increase in the top of S1 (Fig. 51). Nitrogen also showed a decreasing trend with depth ($r^2 = 0.58 - 0.83$). Removing the top 5 cm of S1 increases the $r^2 = 0.58$ to $r^2 = 0.75$.

Fig. 51 Particulate nitrogen content in sediment cores.



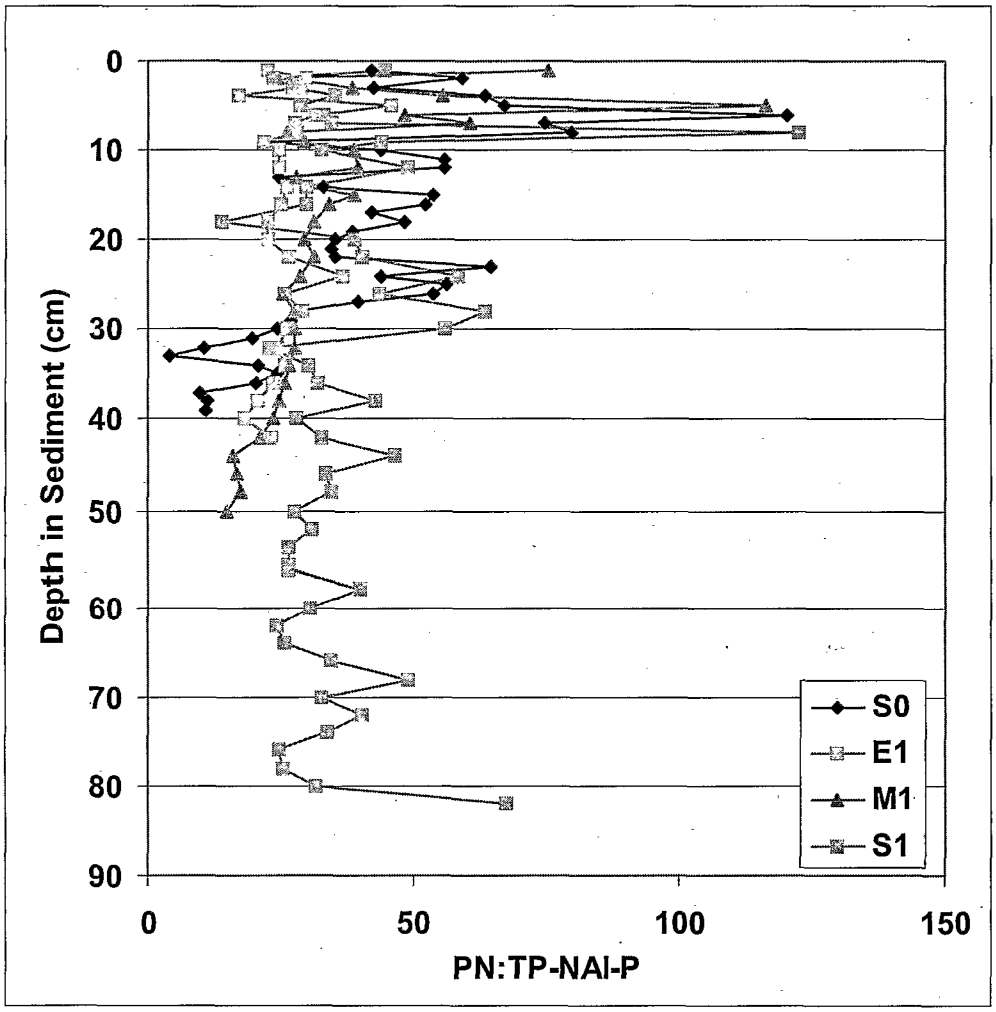
The Sediment C:N ratio varied from 6.69 to 14.32 (Fig. 52). Mean values ranged from 9.38 to 10.11 with an overall mean of 9.79 (1SE, 0.08), which is slightly higher than the Redfield ratio of 6.6 (Wetzel, 2001). Ratios are relatively constant (possibly a slight increase in S0, M1, S1) with depth indicating that nitrogen is decreasing with depth at a faster rate than carbon.

Fig. 52 Molar ratio of particulate carbon to particulate nitrogen in sediment cores.



The sediment inorganic N:TP-NAI-P ratio varied from 3.89 – 122.47 (Fig.53). The mean ratios ranged from 26.04 – 40.76 with an overall average of 35.55 (1SE, 1.56) which is more than double the redfield ratio of 16 (Wetzel, 2001). There is no trend below 10 cm.

Fig. 53 Sediment nitrogen to total phosphorus less non-apatite inorganic phosphorus for sediment cores.



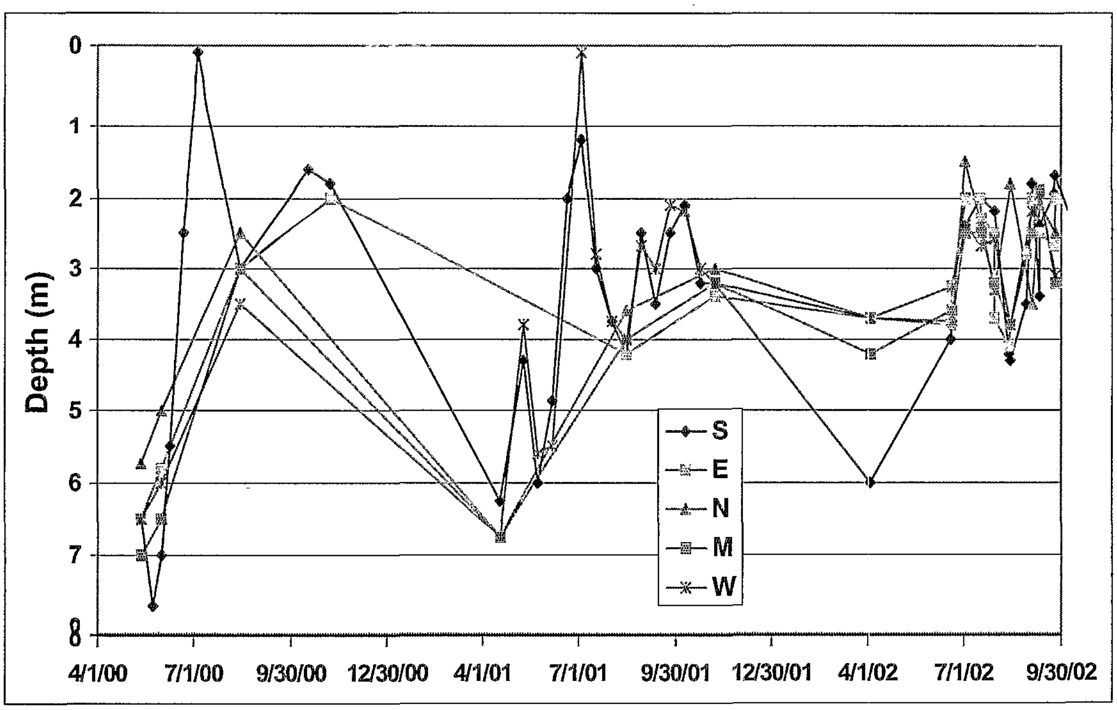
DISCUSSION

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.

Plankton characteristics during summer 2002

During June through September, 2002, chlorophyll *a*, the rapid development of an anoxic hypolimnion, and Secchi depths were all indicative of the eutrophic status of Crowley Lake. The phytoplankton abundance, as measured by chlorophyll *a*, peaked in early July at 35 to 48 μg Chl *a* l^{-1}, followed by a mid-August decrease to 5-12 followed by an early September peak of 28-38 μg Chl *a* l^{-1}. This summer pattern and magnitude of Chl *a* concentration is remarkably similar to that observed at a deep water station in 1964 (Warner 1965). Secchi depths were generally between 2 to 4 m throughout the summer (Fig.54). An accurate comparison of transparency to 2000 and 2001 is not possible due to the sparse sampling in those years and the rapid temporal changes in transparency. The 2002 summer transparencies were generally within the range observed during 2000 and 2001. The 2002 spring decrease appears to have occurred somewhat earlier in 2002. Ice-off was quite early (mid-March) in 2002 and may account for this difference. Also, during 2002, no algal blooms in which Secchi depths were reduced to near zero as observed in 2000 and 2001 were encountered. However, blooms are spatially and temporally highly variable and no confidence can be placed in the significance of differences between only a few stations.

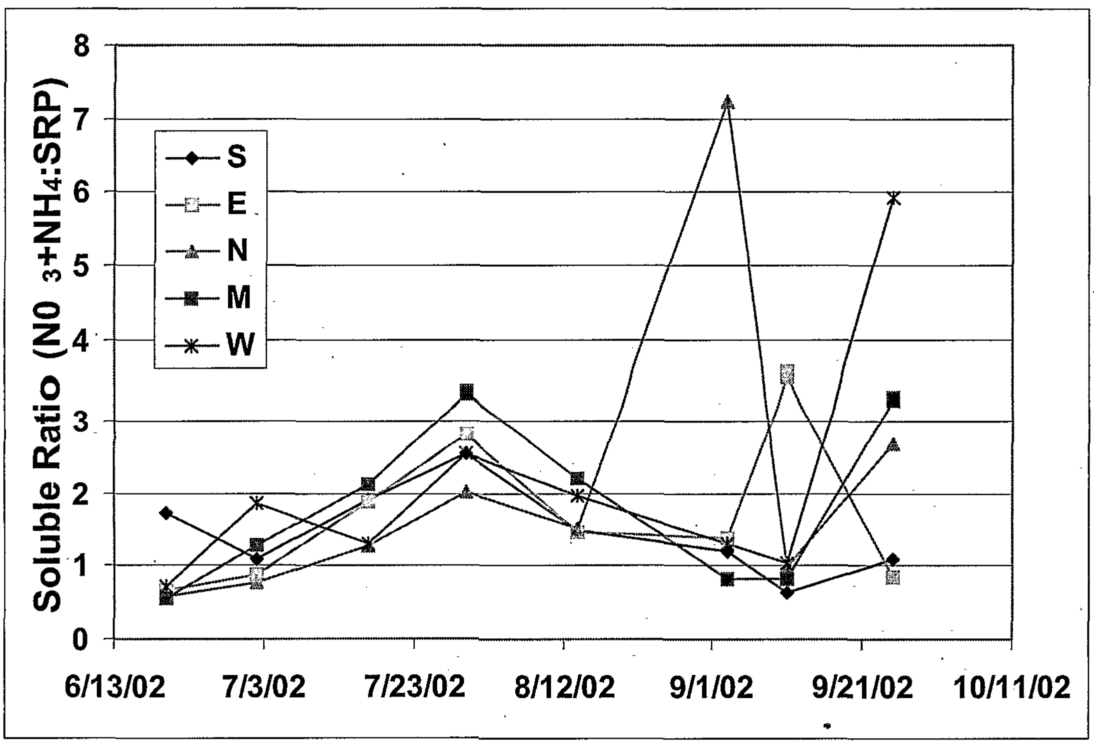
Fig. 54 Comparison of Secchi depths between this study and 2000 and 2001 surveys.



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).

The total phosphorus in the upper 5 m of the water column was ~3 μM (0.09 mg l^{-1}) early in June and July, decreased slightly in August and then increased to ~2.5 μM in September. While these values lie within the range of those observed during a 1982 study (Melack and Lesack 1982), we did not observe any of the elevated mixed-layer concentrations (8-10 μM) noted in that study. Ammonia was generally less than 1 μM except on the final survey on 25 September and NO_3 was generally ~0.2 μM. Thus, dissolved inorganic nitrogen to phosphorus ratio was well below the molar Redfield ratio of 16, (Wetzel, 2001) throughout the study period (Fig. 55). The molar ratio of dissolved inorganic N ($NO_3 + NH_4$) to SRP was low (<3) throughout the summer except for the outlier on 3 September at the N station and an increase observed on the last two sample dates. The ratio increased from ~1 in mid-June to a peak of 2-3.5 at the end of July before decreasing back to ~1 by mid-September.

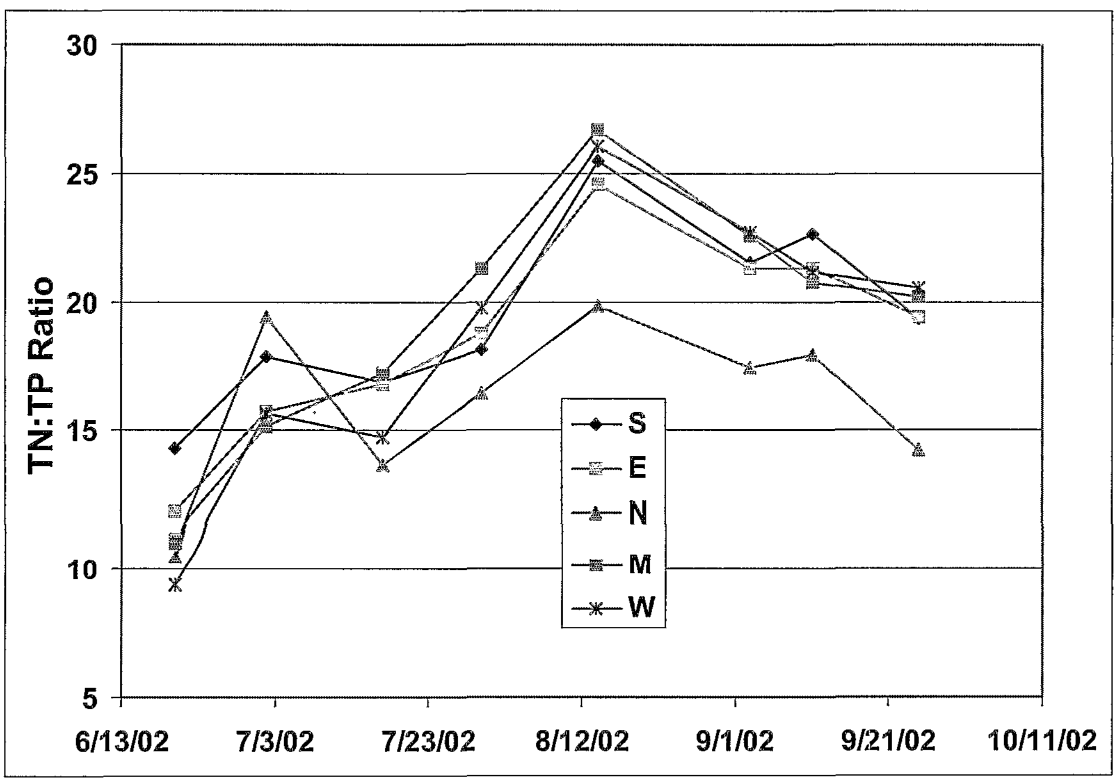
Fig. 55 Dissolved inorganic N:P ratio in upper 5 m of the water column



Given the overall rates of phosphorus loading to Crowley Lake, the molar ratio of TN to TP was surprisingly high through most of the summer with the lakewide mean value ranging from 9.4 to 26.7 (Fig. 56). The seasonal trend of the lakewide mean was a minimum value of 11.5 on 19 June, increasing to 24.5 in mid-August and then declining to 18.7 by the end of September. Only on the June date were values significantly below the Redfield ratio of 16. As with TN and TP, the N station differed from the other four stations through the period beginning in late July. Consistently lower ratios at the N station reflect the high phosphorus loading associated with Owens River inflows. The overall summer mean concentration was 18.5 (±0.7, 1 SE). However, 2002 ratios are much higher compared to the ratios over a similar period in 2001. The ratios reported in 2001 indicate that the lake was most likely N limited throughout most that summer.

Because various pools of inorganic, organic, and particulate phosphorus and nitrogen may be recycled at different rates, dissolved inorganic pools may not accurately reflect the relative availability of nitrogen versus phosphorus. The use of particulate elemental ratios as a measure of nutrient limitation was developed with both marine (Goldman, 1980) and freshwater phytoplankton (Healey & Hendzel, 1980) and has become widely used. Molar carbon to nitrogen ratios of summer seston (planktonic particulates) in the upper 5 m ranged from 5 to 7 and were thus near the Redfield ratio of 6.6 (Fig. 57). There was little variation among stations and only a slight seasonal decrease from a lakewide mean of 6.7 on 19 June to 5.9 on 25 September. The overall summer mean was 6.2 (SE, 0.1; n, 40).

Fig. 56 Ratio of total N to total P in upper 5 m of the water column



The molar nitrogen to phosphorus ratio of summer seston ranged from 14.5 to 83.3 and would suggest phosphorus-limited growth by the plankton during most of the summer (Fig. 58). Only at the N station on 19 June and on the 15 August sampling date did sestonic N:P ratios approach the Redfield ratio of 16. A marked increase from lakewide average of 21-31 during June-August occurred following the 15 August survey as September values climbed to 50-83. The overall mean of June-August samples was 28 (SE, 3) while the September mean of three sample dates was 66 (SE, 2). Both the C:N and N:P ratios are surprising given the low N:P loading ratios. They suggest no nitrogen deficiency and severe phosphorus limitation during September.

Fig. 57 C:N ratio of seston in upper 5 m of water column

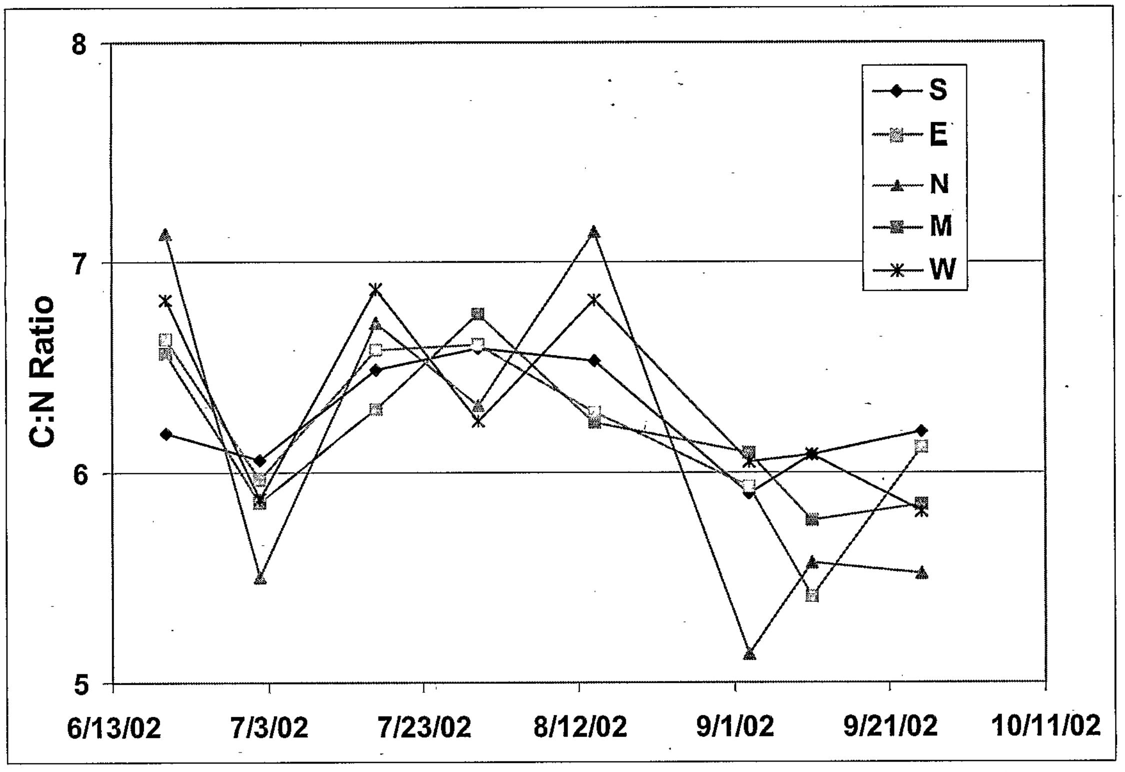
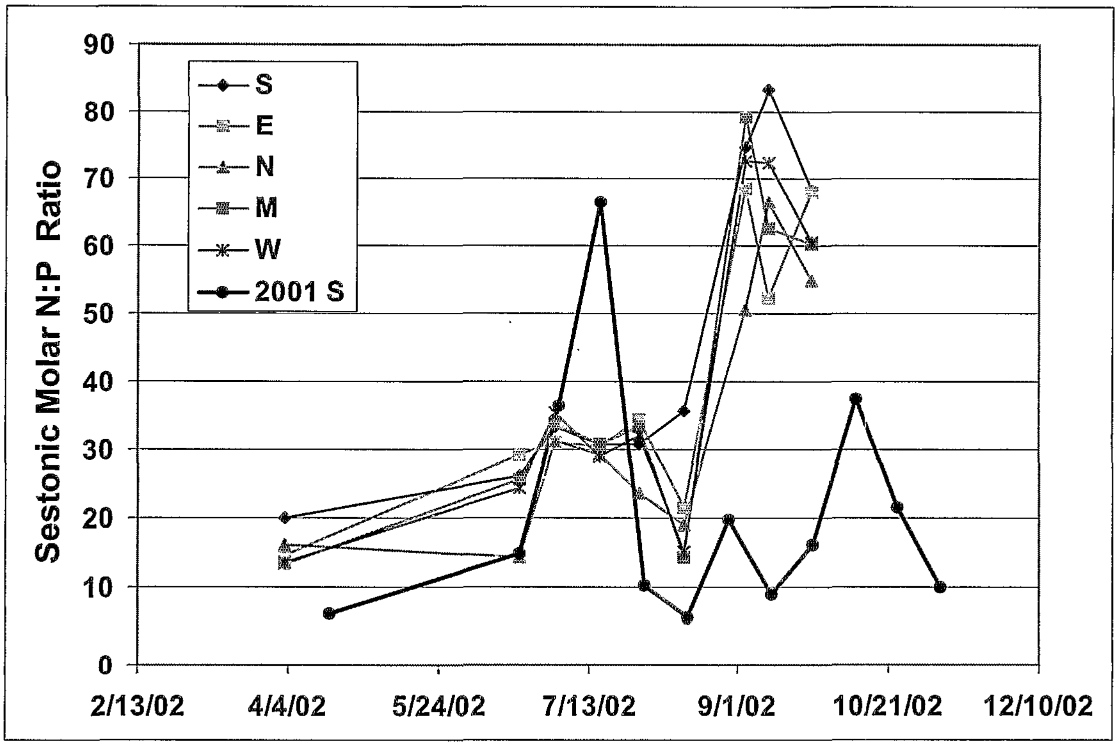


Fig. 58 N:P ratio of seston in upper 5 m of water column



Internal nitrogen loading and pelagic nitrogen fixation

Freshwater lakes are generally limited by phosphorus, in part, because nitrogen fixation by cyanobacteria (blue-green algae) is often able to relieve nitrogen limitation. Many factors, including nutrient availability, pH, light penetration, turbulence, temperature and zooplankton community structure, play a role in cyanophyte abundance and in turn, nitrogen fixation (MacKay & Elser, 1998; Elser, 1999; Paterson et al, 2002). As a result timing, intensity, predictability and species composition of blooms vary substantially (Elser, 1999). The presence of heterocystic cyanobacteria in Crowley Lake, the recurring algal blooms, and the low N:P loading ratios all suggest nitrogen fixation is an important part of the overall nitrogen budget. However, nitrogen fixation rates measured in pelagic samples during summer 2002 were low except for a slight increase to ~15 μM N m^{-3} h^{-1} in September. This increase coincided with the appearance of the nitrogen fixer, *Aphanizomenon flos-aquae*. *Aphanizomenon* has been reported previously in the lake as appearing late in the season (Melack and Lesack 1982, Warner 1965, EPA 1978). The nitrogen fixer, *Gloeotrichia*, was present during the early summer. Measured rates on the 20 June and 2 July may not fully represent the nitrogen fixing capacity of this cyanophyte due to the low PAR under which the samples were incubated. Studies show that cyanophytes will utilize ammonia, urea and nitrate from the water column before fixing nitrogen from the atmosphere (Presing et al, 2001). During midsummer, sestonic ratios suggest phosphorus rather than nitrogen limitation. *Aphanizomenon* appears in Crowley late in the season. The appearance of *Aphanizomenon* in autumn coincides with lower N:P ratios. These low ratios favor cyanophytes not only due to the ability to fix nitrogen from the atmosphere but also due to their higher storage capacity of nitrogen compared to other algal species (MacKay & Elser, 1998).

The estimated lakewide nitrogen fixation from 3 April to 25 September was only ~0.6 g N m^{-2} y^{-1} or ~1.0 g N m^{-2} y^{-1} if you include the higher rate measured from a sample collected at the dock on 29 May. These annual rates lie in the median of 17 eutrophic lakes reported by Howarth et al. (1988). The surplus of measured exports over inputs during 2000-2001 runoff years was 4.8 and 5.8 g N m^{-2} y^{-1}, respectively. Thus, the measured nitrogen fixation during 2002 could only account for a fifth of the imbalance observed during the two previous years.

Nutrient cycling can be linked to food web structure (Paterson et al, 2002). *Daphnia*, a freshwater planktonic crustacean, has a low N:P body ratio and retains P while releasing nitrogen to the surrounding water. Therefore, an increase in *Daphnia* populations can increase N:P ratios reducing the cyanophyte advantage (Elser, 1999). MacKay and Elser (1999), show evidence from the Experimental Lakes area in Ontario, Canada that *Daphnia* were not present during cyanophyte blooms and that cyanophytes were not able to establish themselves in enclosures containing *Daphnia*. The zooplankton community was not considered during this study, but cascading trophic level effects may accompany fish kills or the timing and magnitude of stocking events in Crowley Lake.

While sediments usually act as a net sink, they may act as a source on seasonal time scales and over longer periods if the sediments are in disequilibrium due to long-term changes in loading or release rates. High ammonia content in pore water is indicative of nitrification, the decomposition of organic material by heterotrophic bacteria. Denitrifying bacteria are well adapted to rapidly changing conditions in sediments. They are abundant and can have a large effect on nitrogen turnover (Hakanson and Jansson, 2002). While bacteria do not create new biomass or fix new energy, they act as a link returning nitrogen back into the water column. When external loading is reduced, sediments can release nutrients back into the water column in sufficient concentration to support algal growth for extended periods thus delaying improvement in water quality (Hu et al, 2001).

While we were unable to measure sediment ammonia release with benthic chambers, ammonia release estimates were estimated based on porewater profiles. The estimated release rates ranged from 0.2 to 1.1 mmol N m^{-2} d^{-1} or 1.0 - 5.6 g m^{-2} y^{-1}. While this is of similar magnitude to the "missing" nitrogen source, in terms of the lakewide nitrogen budget, it will be offset by any deposition and burial occurring. This can only act as a net source if there has been a significant change in the retentive properties of the sediments or a large decrease in deposition so that current high rates of sediment release are due to high rates of deposition in the past. The porewater profiles of three of the four cores all showed a significant discontinuity at approximately 10 cm depth. This could be a result of either of these two possibilities.

It is informative to examine hypolimnetic accumulation and upward fluxes of nitrogen compared to estimated sediment release rates. The upward flux estimates and hypolimnetic accumulation are much larger than the estimated sediment release rates (Table 5). This implies depositional fluxes and remineralization rates within the hypolimnion are large relative to sediment-water interface fluxes. The estimated upward fluxes are large relative to the imbalance in the lakewide nitrogen budget. Thus, remineralization of decaying algal matter from one or two years previous may be contributing significantly to these fluxes. In this case, the nitrogen imbalance observed in 2000 and 2001 may just represent temporal time lags. However, the thermal regimes were nearly identical among all three years and all were below normal runoff years (68, 57, and 51% of normal for April-September).

Table 5 Hypolimnetic accumulation, diffusive fluxes, and sediment release

	Hypolimnetic accumulation (mmol m-2 d-1)	Upward Diffusive Flux at 12 m (mmol m-2 d-1)	Estimated sediment release based on porewater profile
P	0.6	0.2-0.9	NA
N	3.7	2.2 – 5	0.2-1.1

SUMMARY AND CONCLUSIONS

Summer (June – August) 2002 nitrogen fixation rates were generally low and, surprisingly, sestonic particulate ratios throughout the summer (including September) suggested P rather than N limitation. Estimates of lakewide nitrogen fixation were within the range observed in other eutrophic lakes, but could only account for one fifth of the imbalance between measured inputs and outputs of nitrogen during 2000 and 2001. However, no massive algal blooms, as have been observed during past years, were present at any of the stations sampled on the eight summer surveys during 2002. Also, sestonic molar N:P ratios were higher in 2002 compared to 2001, most likely indicating less nitrogen limitation. Nitrogen fixation may also continue into October-November and rates may have been higher during spring 2002 as evidenced by higher rates in a sample collected at the dock in late May. However, it is unlikely that these factors could account for the entire imbalance. Both sediment release rates and upward ammonia fluxes were of similar magnitude to the imbalance in the N budget observed during 2000 and 2001 but they do not necessarily constitute net sources. The discontinuity at ~10 cm in sediment ammonia porewater raises the intriguing possibility that either overall nutrient loading rates have decreased, possibly due to range best management practices initiated over the past ten years, or the sediment environment has changed in a manner which has reduced its retentive capacity. We are not able to distinguish between these two possibilities with the present limited data. However, sedimentation rates are fairly high (>1 cm yr^{-1}) in Crowley Lake and revisiting the sediments in several years would allow distinguishing between these two possibilities.

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Draft
Environmental Impact Report for the Review of Mono Basin Water Rights of the City of Los Angeles

Lead Agency:

California State Water Resources Control Board
Division of Water Rights
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May 1993

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This document should be cited as:

Jones & Stokes Associates. 1993. Environmental impact report for the review of Mono Basin water rights of the City of Los Angeles. Draft. May. (JSA 90-171.) Sacramento, CA. Prepared for California State Water Resources Control Board, Division of Water Rights, Sacramento, CA.

21. Respondent's formal education level:

	Number
High school not completed	8
High school completed	23
Some college	36
College graduate	26
Graduate school	6

22. Respondent's household income:

	Number
Under $10,000	5
$10,000-$20,000	7
$20,000-$30,000	15
$30,000-$40,000	19
$40,000-$50,000	12
$50,000-$60,000	11
$60,000-$80,000	15
$80,000-$100,000	4
$100,000-$200,000	5
More than $200,000	1
Refused	5

LAKE CROWLEY RESERVOIR

Use-Estimating Methods

Survey respondents at Lake Crowley were presented with information on planned reservoir water operations in 1992 and on four alternative scenarios. Scenarios 1 and 2 maintained stable water levels, and Scenarios 3 and 4 were characterized by fluctuating water levels. The median water level under Scenario 1 exceeded that under Scenario 2 by 18 feet, the same amount that the median level under Scenario 3 exceeded that under Scenario 4. Planned 1992 operations were moderately stable at a median level between that of Scenarios 1 and 2. The four alternative scenarios are presented in Figure W-2.

Almost all respondents ranked Scenarios 1 and 3 over Scenario 2, and Scenario 2 over Scenario 4. Scenarios 1 and 3 were not directly compared. These results indicate that users prefer higher water levels over lower levels and, at least at lower levels, prefer relatively stable water levels over fluctuating levels.

Respondents were asked how their use would change if various scenarios were substituted for planned 1992 operations, under which the lake level would average 6,767 feet. Under this scenario, use of Lake Crowley reservoir by all respondents would average 13.0 days. Relative to anticipated use, Scenario 4 elicited the largest use response, an average decrease of 5.1 days per visitor. Under Scenario 3, average annual use would decrease by an average of 3.7 days. Annual per-visitor use would increase by an average of 3.1 days under Scenario 2 and by 4.4 days under Scenario 1.

These results indicate that, on average, per-visitor use would increase by approximately 0.46 days for each 1-foot increase in the reservoir's median water level, a substantially greater rate of change than was estimated for Grant Lake reservoir (0.1 day per foot).

Summary of User Survey Results

Results from the user surveys conducted at Lake Crowley reservoir between August and October 1991 and during April 1992 are summarized below.

1. Location of interview:

	Number
South Landing	184
North Landing	87
Pleasant Valley reservoir	52
Total	323

2. Place of residence:

	Number
Metropolitan Southern California	196
San Francisco Bay area	4
Mono Basin	32
Elsewhere in California	88
Out of state	3
Total	323

3. Mean number of people in vehicle of respondent: 2.60

4. Mean length of current trip (days): 8.31

5. Mean length of time visiting Inyo and Mono Counties this trip (days): 6.95

6. Other destinations on this trip:

Other Destinations on This Trip	Number
Bishop	86
Convict Lake/Convict Creek	57
Mammoth Lakes	47
June Lake Loop	20
Owens River	17
Twin Lakes	13
Lone Pine	7
Hot Creek	6
Pleasant Valley Reservoir	5
McGee Creek	4
Big Pine	4
Saddlebag/Tioga/Ellery Lakes	4
Mono Lake	3
Mt. Whitney	3
Other	26

7. Percent of respondents for whom Lake Crowley reservoir is the principal destination for current trip: 61

8. Mean expenditures in Mono and Inyo Counties on this trip ($/person/day):

Groceries and supplies	$3.60
Restaurants	2.84
Lodging	4.05
Camping	0.49
Auto expenses	3.31
Other	0.19
Total	$14.48

9. Mean number of days spent at Lake Crowley reservoir this trip: 3.79

10. Mean number of hours spent at Lake Crowley reservoir today: 6.22

11. Activities participated in at Lake Crowley reservoir this trip (for respondents interviewed at Lake Crowley reservoir only:

Activity	Number Participating	Number for Whom Activity is Main Reason for Visiting
Boating	107	26
Waterskiing	39	21
Windsurfing	7	0
Trolling for trout	96	66
Float-tubing for trout	46	30
Shore fishing for trout	209	110
Fishing for other species	65	7
Wading	41	1
Birdwatching/nature study	56	1
Picnicking	68	2
Camping	90	3
Hiking	44	2
Bicycling	5	0
Hunting	1	0

12. Percent who visited Mono/Inyo County region in 1990: 80

13. For 1990 visitors, mean number of separate visits to region in previous year: 4.04

14. For 1990 visitors, mean number of days spent at Lake Crowley reservoir in previous year: 12.96

15. Number of respondents visiting other eastern Sierra Lakes in previous year: 152

16. Mean number of days spent at, or expected to be spent at, Lake Crowley reservoir in 1991:

Fall 1991 survey respondents	20.3
Spring 1992 survey respondents	5.6
All respondents	13.0

17. Percent of 1991 respondents who visited Lake Crowley reservoir before June 1: 48

18. Respondent satisfaction with Lake Crowley reservoir recreation opportunities in 1991 (for respondents who visited Lake Crowley reservoir in 1991):

	Number
Very satisfied	51
Generally satisfied	137
Not satisfied	55
Total	243

19. Preferred reservoir level management alternative (see Figure W-2 for scenario description):

Scenarios Compared	Scenarios 1	2	3	4	Doesn't Matter
(4,3)	NA	NA	63	6	18
(4,1)	49	NA	NA	2	7
(3,2)	NA	20	31	NA	19
(2,1)	50	1	NA	NA	11
(4,2)	NA	22	NA	5	14

20. Mean number of people in respondent's household: 2.84

21. Percent belonging to environmental or conservation group: 25

22. Respondent's year of birth:

	Number
Before 1926	31
1926-1935	42
1936-1945	76
1946-1956	100
1956-1965	58
1966-1975	15
After 1985	0
Total	322

21. Respondent's formal education level:

	Number
High school not completed	24
High school completed	61
Some college	105
College graduate	92
Graduate school	38
Refused	2
Total	322

22. Respondent's household income:

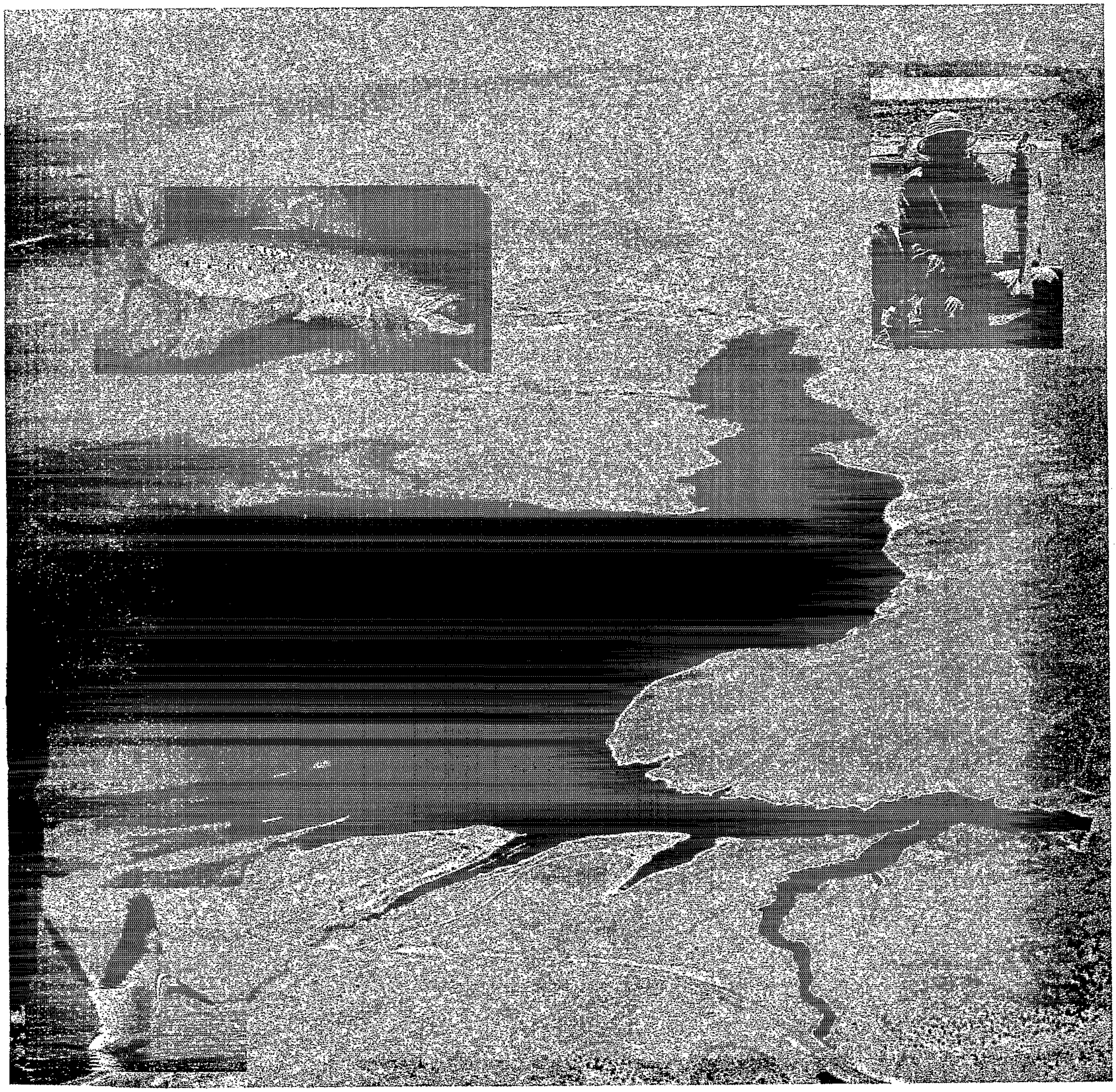
	Number
Under $10,000	4
$10,000-$20,000	24
$20,000-$30,000	33
$30,000-$40,000	45
$40,000-$50,000	46
$50,000-$60,000	24
$60,000-$80,000	58
$80,000-$100,000	32
$100,000-$200,000	34
More than $200,000	12
Refused	10
Total	322

A FISHERIES MANAGEMENT PLAN FOR

CROWLEY LAKE AND TRIBUTARIES

MONO COUNTY, CALIFORNIA

1997



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME

State of California
The Resource Agency
DEPARTMENT OF FISH AND GAME

A FISHERIES MANAGEMENT PLAN FOR CROWLEY LAKE AND TRIBUTARIES, MONO COUNTY, CALIFORNIA, 1997

by

Curtis Milliron
Associate Biologist
Inland Fisheries, Bishop

SPORT FISH RESTORATION

Under the Supervision of

Alan Pickard
Senior Biologist
Inland Fisheries, Bishop

CONTENTS

PREFACE

"Of the many fishable waters in the Inyo-Mono area of eastern California, Crowley Lake is the largest and perhaps the most used" (Pister, 1960). This statement, made over three decades ago, remains true with anglers seeking sustained high catch rates of quality put-and-grow rainbow trout; fast action and trophy Sacramento perch angling; and trophy catch-and-release trout angling. High angler satisfaction, even under heavy angling pressure, has become the Crowley trademark. Yet, these fishery resources remain dependent on weather cycles and human intervention.

A decline in Crowley Lake angling success, beginning in 1987 and persisting through several seasons, roused much public concern. Angling groups, including a newly-formed "Committee to Save Crowley Lake", requested action from the California Department of Fish and Game (Department). A study to evaluate the Department's management of put-and-grow hatchery stocks and to better understand wild trout fisheries was initiated in 1989. In June, 1991, a meeting held at the Department's Bishop office provided a forum for participation by concerned organizations and agencies to develop a management plan for Crowley Lake and its tributary waters. Issues identified by the group are addressed in this management plan.

The Department emphasizes management of fish and wildlife resources on an ecosystem or watershed basis using strategic planning and management concepts. These "units" represent specific geographical areas requiring coordinated resource management. Programs need to be developed and implemented which "manage diverse fish, wildlife, and plant resources, including the habitats upon which they depend, for their ecological values and their use and enjoyment by the public" (Department Mission Statement). The "unit" covered by this plan includes Crowley Lake and tributary waters which are linked to Crowley Lake fisheries, along with the lands associated with these resources. This plan does not include the upper reaches of some tributary waters.

This plan incorporates certain recommendations from *A FISHERIES MANAGEMENT PLAN FOR THE MAMMOTH LAKES BASIN AND CERTAIN ADJACENT WATERS, MONO AND MADERA COUNTIES, CALIFORNIA* (von Geldern, 1989). Two issues regarding Crowley Lake and tributary waters that were discussed in the Mammoth Lakes Basin management plan have been, or are being, remedied. These are "Damage by grazing cattle on public portions of the Owens River and other tributaries", and

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

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Lake Crowley
Mono County, California

(U.S.) National Eutrophication Survey, Corvallis, OR

Prepared for

Corvallis Environmental Research Lab, OR

Jun 78

U.S. ENVIRONMENTAL PROTECTION AGENCY
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26

TECHNICAL REPORT DATA

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Prepared in cooperation with the U.S. Environmental Protection Agency, National Environmental Research Center, Las Vegas, Nevada 89114

16. ABSTRACT

Annual total phosphorus and total nitrogen loadings to the lake were estimated and subdivided according to either point or non-point source origin. An assessment of the lake's trophic condition and limiting nutrient is also provided. All data collected by the U.S.E.P.A. National Eutrophication Survey during the one year study of the lake and its tributaries are included in the report.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
eutrophication lakes nutrients phosphorus nitrogen loading		48G

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REPORT

ON

LAKE CROWLEY

MONO COUNTY

CALIFORNIA

EPA REGION IX

WORKING PAPER No. 743

WITH THE COOPERATION OF THE

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

AND THE

CALIFORNIA NATIONAL GUARD

JUNE, 1978

CONTENTS

FOREWORD

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to freshwater lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement in lake watersheds.

ANALYTIC APPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed. Mass-balance

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader based correlations between nutrient concentration (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's fresh water lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by EPA and to augment plans implementation by the states.

ACKNOWLEDGEMENT

The staff of the National Eutrophication Survey (Office of Research & Development, U.S. Environmental Protection Agency) expresses sincere appreciation to the California State Water Resources Control Board and the nine Regional Water Quality Control Boards for professional involvement, to the California National Guard for conducting the tributary sampling phase of the Survey, and to those California wastewater treatment plant operators who voluntarily provided effluent samples and flow data.

The staff of the Division of Planning and Research of the State Water Resources Control Board provided invaluable lake documentation and counsel during the Survey, coordinated the reviews of the preliminary reports, and provided critiques most useful in the preparation of this Working Paper series.

Major General Glen C. Ames, the Adjutant General of California, and Project Officer Second Lieutenant Terry L. Barrie, who directed the volunteer efforts of the California National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

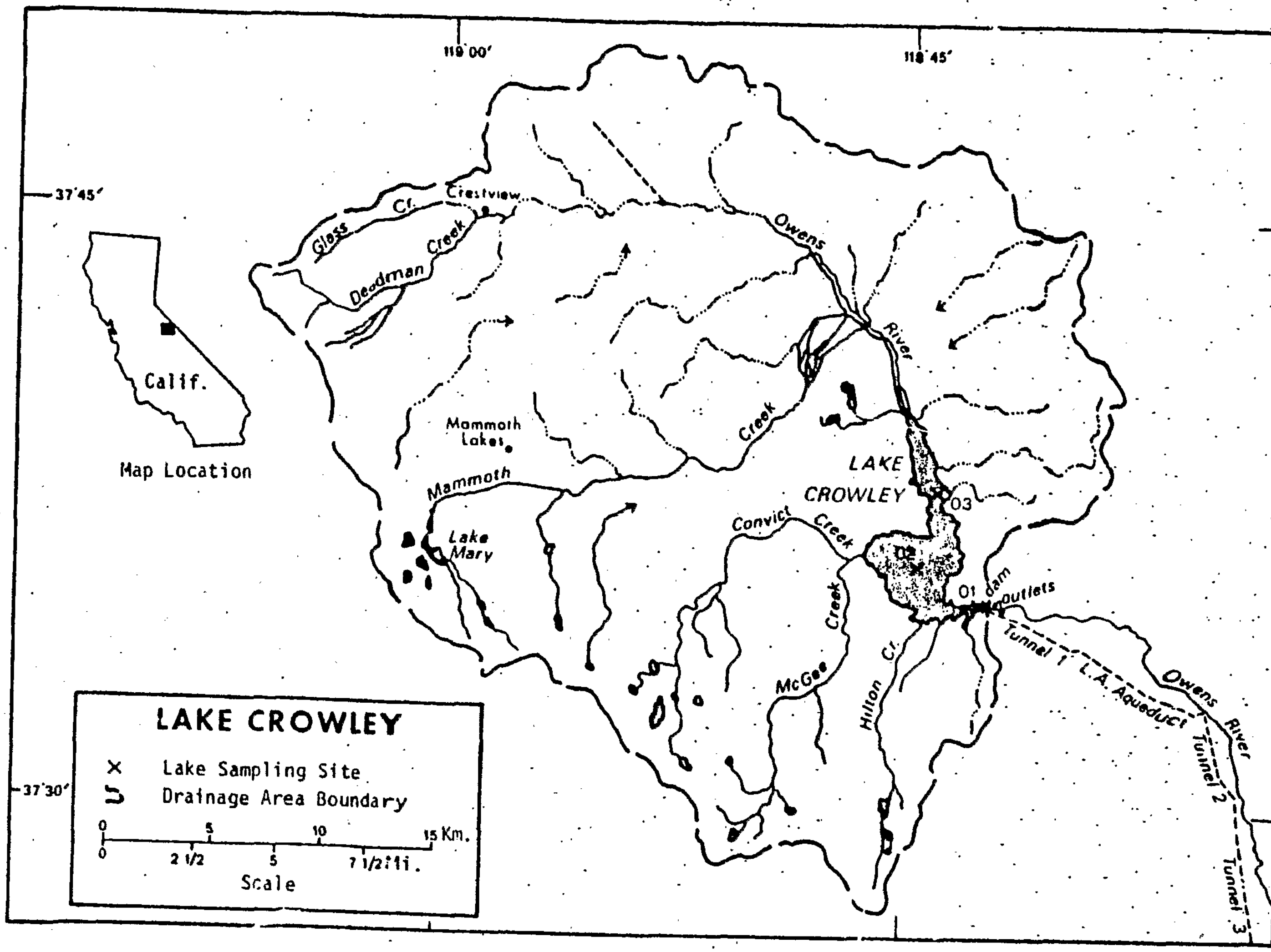
NATIONAL EUTROPHICATION SURVEY

STUDY RESERVOIRS

State of California

Name	County
Amador	Amador
Boca	Nevada
Britton	Shasta
Casitas	Ventura
Crowley	Mono
Don Pedro	Tuolumne
Elsinore	Riverside
Fallen Leaf	El Dorado
Hennessey	Napa
Henshaw	San Diego
Iron Gate	Siskiyou
Lopez	San Luis Obispo
Mary	Mono
Mendocino	Mendocino
Nicasio	Marin
Lower Otay	San Diego
Pillsbury	Lake
Santa Margarita	San Luis Obispo
Shasta	Shasta
Shaver	Fresno
Silver	Mono
Tahoe	El Dorado, Placer, CA; Carson City, Douglas, Washoe, NV
Tulloch	Calaveras, Tuolumne
Lower Twin	Mono
Upper Twin	Mono

Mono County really received a lot of attention!



3 lake surface samples

LAKE CROWLEY

STORET NO. 0605

I. INTRODUCTION

Lake Crowley was included in the National Eutrophication Survey as a water body of interest to the California State Water Resources Control Board. Tributaries and nutrient sources were not sampled, and this report relates only to reservoir sampling data.

Oh!

II. CONCLUSIONS

A. Trophic Condition*:

Survey data indicate that Lake Crowley is eutrophic It ranked fourteenth in overall trophic quality when the 24 California lakes and reservoirs sampled in 1975 were compared using a combination of six parameters**. Sixteen of the water bodies had less median total phosphorus, 18 had less median dissolved orthophosphorus, five had less median inorganic nitrogen, 13 had less mean chlorophyll a, and eight had greater mean Secchi disc transparency. Depression of hypolimnetic dissolved oxygen occurred at sampling station 1 in June (2.8 mg/l at 25.9 meters).

Survey limnologists noted surface concentrations of algae in June and November, and depression of dissolved oxygen and fish kills have been reported to occur in the reservoir (Johns, 1975).

---

* Trophic assessment is based on levels of nutrients, dissolved oxygen, and chlorophyll a; phytoplankton kinds and numbers; and transparancy (Allum et al., 1977).

** See Appendix A

B. Rate-Limiting Nutrient:

The algal assay results indicate the reservoir was nitrogen limited in early June. The reservoir data indicate nitrogen limitation at all sampling stations and times.

III. RESERVOIR AND DRAINAGE BASIN CHARACTERISTICS†

A. Morphometry††:

1. Surface area: 21.38 kilometers^2. = 8.25 mi^2 = 5283 Ac.

2. Mean depth: 10.6 meters. = 35 ft

3. Maximum depth: 38.4 meters. = 126 ft

4. Volume: 226.628 x 10^6 m^3. = 184 TAF

B. Precipitation*

1. Year of sampling: 8.1 centimeters. 3.2"

2. Mean annual: 14.5 centimeters. 5.7"   Long term at LV 10"

† Table of metric equivalents--Appendix B.
†† Dendy, 1974.
* See Working Paper No. 175, "... Survey Methods, 1973-1976".

IV. LAKE WATER QUALITY SUMMARY

Lake Crowley was sampled three times during the open-water season of 1975 by means of a pontoon-equipped Huey helicopter. The first time, samples for physical and chemical parameters were collected from a number of depths at two stations and thereafter from three stations on the reservoir (see map, page v). During each visit, a single depth-integrated (4.6 m 15' to surface) sample was composited from the stations for phytoplankton identification and enumeration; and during the first visit, a single 18.9-liter depth-integrated sample was composited for algal assays. Also each time, a depth-integrated sample was collected from each of the stations for chlorophyll *a* analysis. The maximum depths sampled were 25.9 meters at station 1, 14.6 meters at station 2, and 7.9 meters at station 3.

The sampling results are presented in full in Appendix C and are summarized in the following table.

A. SUMMARY OF PHYSICAL AND CHEMICAL CHARACTERISTICS FOR CROWLEY LAKE
STORET CODE 0605

	1ST SAMPLING (6/10/75)			2ND SAMPLING (6/30/75)			3RD SAMPLING (11/ 5/75)		
	2 SITES			3 SITES			3 SITES		
PARAMETER	RANGE	MEAN	MEDIAN	RANGE	MEAN	MEDIAN	RANGE	MEAN	MEDIAN
TEMP (C)	10.0 - 17.6	14.1	15.3	13.8 - 20.3	17.2	16.9	7.5 - 8.2	7.9	7.9
DISS OXY (MG/L)	5.4 - 7.8	6.9	7.3	2.8 - 8.8	6.7	7.6	8.0 - 9.4	8.6	8.6
CNDCTVY (MCROMO)	169. - 233.	211.	213.	231. - 271.	250.	250.	235. - 248.	241.	241.
PH (STAND UNITS)	7.9 - 8.5	8.3	8.4	7.8 - 8.8	8.4	8.5	8.6 - 8.8	8.7	8.7
TOT ALK (MG/L)	87. - 116.	108.	110.	98. - 121.	110.	111.	64. - 109.	95.	97.
TOT P (MG/L)	0.034 - 0.068	0.047	0.042	0.049 - 0.446	0.104	0.070	0.027 - 0.071	0.037	0.033
ORTHO P (MG/L)	0.032 - 0.072	0.046	0.042	0.026 - 0.122	0.046	0.039	0.011 - 0.016	0.013	0.013
NO2+NO3 (MG/L)	0.020 - 0.030	0.021	0.020	0.020 - 0.030	0.021	0.020	0.020 - 0.020	0.020	0.020
AMMONIA (MG/L)	0.020 - 0.050	0.026	0.020	0.030 - 0.120	0.041	0.035	0.020 - 0.020	0.020	0.020
KJEL N (MG/L)	0.200 - 0.200	0.200	0.200	0.400 - 0.600	0.507	0.500	0.200 - 0.400	0.246	0.200
INORG N (MG/L)	0.040 - 0.070	0.047	0.040	0.050 - 0.150	0.062	0.055	0.040 - 0.040	0.040	0.040
TOTAL N (MG/L)	0.220 - 0.230	0.221	0.220	0.420 - 0.820	0.529	0.520	0.220 - 0.420	0.266	0.220
CHLRPYL A (UG/L)	1.0 - 1.7	1.3	1.3	4.8 - 6.8	5.5	5.0	8.8 - 9.3	9.0	9.0
SECCHI (METERS)	5.5 - 5.5	5.5	5.5	1.5 - 3.0	2.4	2.7	******	-******************	

low

Same

No chlorophyll yet

B. Biological characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Algal Units per ml
06/10/75	1. *Chroomonas* (?) *sp.*	1,049
	2. *Asterionella sp.*	504
	3. *Dinobryon sp.*	378
	4. *Fragilaria sp.*	252
	5. *Cryptomonas sp.*	84
	Total	2,267
06/30/75	1. *Chroomonas* (?) *sp.*	892
	2. *Anabaena sp.*	803
	3. *Asterionella sp.*	758
	4. *Schroederia sp.*	580
	5. *Cryptomonas sp.*	312
	Other genera	668
	Total	4,013
11/05/75	1. *Aphanizomenon sp.*	421
	2. *Fragilaria sp.*	225
	3. *Chroomonas* (?) *sp.*	168
	4. *Oscillatoria sp.*	140
	5. *Stephanodiscus sp.*	112
	Other genera	29
	Total	1,095

→ algal assay

2. Chlorophyll a -

Sampling Date	Station Number	Chlorophyll a (μg/l)
06/10/75	1	1.7
	2	1.0
	3	-
06/30/75	1	6.8
	2	5.0
	3	4.8
11/05/75	1	9.0
	2	8.8
	3	9.3

missed the growing season!
Months: 7,8,9,10.

C. Limiting Nutrient Study:

1. Autoclaved, filtered, and nutrient spiked -

or purpose of Digestion??

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)	max contents N content	P
Control	0.040	0.050	2.7	2%	P=1.5
0.050 P	0.090 (.040+.050)	0.050	2.5		P 3.6%
0.050 P + 1.0 N	0.090 (.040+.050)	1.050 (.05+1.0)	~~24.8~~	4%	0.3%
1.0 N	0.040	1.050 (.05+1.0)	13.0	8%	0.3%

Became P limited

→ .05 P = 11.2

2. Discussion -

The control yield of the assay alga, Selenastrum capricornutum, indicates that the potential primary productivity of Lake Crowley was high at the time the sample was collected (06/10/75). Also, a significant increase in yield with the addition of nitrogen alone indicates that the reservoir was limited by nitrogen at that time. Note that the addition of phosphorus alone did not result in an increased yield.

The reservoir data also indicate nitrogen limitation; i.e., the mean inorganic nitrogen/orthophosphorus ratios were 3/1 or less each sampling time.

N=.05/2.7=1.8
P=.04/2.7=1.5
N=.05/2.5=2
P=.09/2.5=3.6
N=.09/24.8=.3
P=1.05/24.8
N=.04/13=.3
P=1.05/13

V. LITERATURE REVIEWED

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VI. APPENDICES

APPENDIX A

LAKE RANKINGS

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500- MEAN SEC	MEAN CHLORA	15- MIN DO	MEDIAN DISS ORTHO P
0601	AMADOR RESERVOIR	0.040	0.390	408.667	22.383	14.600	0.020
0602	BOCA LAKE	0.012	0.040	372.833	1.700	6.800	0.003
0603	LAKE BRITTON	0.067	0.115	448.500	4.811	11.200	0.047
0604	CASITAS RESERVOIR	0.029	0.050	400.250	3.192	14.000	0.014
0605	CROWLEY LAKE	0.046	0.045	374.750	5.800	12.200	0.034
0606	DON PEDRO RESERVOIR	0.013	0.060	381.733	3.564	11.400	0.004
0607	LAKE ELSINORE	0.469	0.120	489.214	70.572	8.000	0.092
0608	FALLEN LEAF RESERVOIR	0.007	0.040	24.357	0.786	8.800	0.005
0609	LAKE HENNESSEY	0.027	0.060	416.000	4.525	15.000	0.012
0610	LAKE HENSHAW	0.138	0.070	461.000	26.783	9.800	0.073
0611	IRON GATE RESERVOIR	0.184	0.690	440.333	6.217	13.800	0.124
0614	LOPEZ LAKE	0.371	0.090	372.000	8.658	15.000	0.343
0615	LAKE MARY	0.010	0.040	296.000	2.550	10.600	0.002
0616	LAKE MENDOCINO	0.020	0.050	436.500	3.100	9.400	0.008
0617	NICASIO RESERVOIR	0.055	0.345	482.778	6.633	9.800	0.013
0618	LOWER OTAY RESERVOIR	0.058	0.180	447.250	15.933	15.000	0.013
0619	LAKE PILLSBURY	0.022	0.060	466.667	6.389	8.200	0.008
0620	SANTA MARGARITA LAKE	0.037	0.070	400.000	9.122	14.800	0.014
0621	SHASTA LAKE	0.021	0.060	381.542	4.087	9.000	0.015
0622	SHAVER	0.014	0.060	346.400	1.700	7.400	0.004
0623	SILVER LAKE	0.012	0.055	356.000	1.800	7.000	0.003
0624	TULLOCK RESERVOIR	0.025	0.060	433.000	13.878	7.400	0.009
0625	UPPER TWIN LAKES	0.015	0.040	300.200	3.340	7.400	0.004
0626	LOWER TWIN LAKES	0.014	0.040	248.000	2.900	11.400	0.003

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500- MEAN SEC	MEAN CHLORA	15- MIN DO	MEDIAN DISS ORTHO P	INDEX NO
0601	AMADOR RESERVOIR	35 (8)	4 (1)	43 (10)	9 (2)	17 (4)	26 (6)	134
0602	BOCA LAKE	89 (20)	98 (22)	70 (16)	91 (21)	100 (23)	91 (20)	539
0603	LAKE BRITTON	17 (4)	22 (5)	17 (4)	48 (11)	43 (10)	17 (4)	164
0604	CASITAS RESERVOIR	43 (10)	74 (17)	48 (11)	70 (16)	22 (5)	37 (8)	294
0605	CROWLEY LAKE	30 (7)	78 (18)	65 (15)	43 (10)	30 (7)	22 (5)	268
0606	DON PEDRO RESERVOIR	83 (19)	54 (11)	57 (13)	61 (14)	37 (8)	78 (17)	370
0607	LAKE ELSINORE	0 (0)	17 (4)	0 (0)	0 (0)	78 (18)	9 (2)	104
0608	FALLEN LEAF RESERVOIR	100 (23)	87 (19)	100 (23)	100 (23)	70 (16)	70 (16)	527
0609	LAKE HENNESSEY	48 (11)	54 (11)	39 (9)	52 (12)	4 (0)	52 (12)	249
0610	LAKE HENSHAW	13 (3)	33 (7)	13 (3)	4 (1)	54 (12)	13 (3)	130
0611	IRON GATE RESERVOIR	9 (2)	0 (0)	26 (6)	39 (9)	26 (6)	4 (1)	104
0614	LOPEZ LAKE	4 (1)	26 (6)	74 (17)	26 (6)	4 (0)	0 (0)	134
0615	LAKE MARY	96 (22)	87 (19)	91 (21)	83 (19)	48 (11)	100 (23)	505
0616	LAKE MENDOCINO	65 (15)	70 (16)	30 (7)	74 (17)	61 (14)	63 (14)	363
0617	NICASIO RESERVOIR	26 (6)	9 (2)	4 (1)	30 (7)	54 (12)	46 (10)	169
0618	LOWER OTAY RESERVOIR	22 (5)	13 (3)	22 (5)	13 (3)	4 (0)	46 (10)	120
0619	LAKE PILLSBURY	57 (13)	41 (9)	9 (2)	35 (8)	74 (17)	63 (14)	279
0620	SANTA MARGARITA LAKE	39 (9)	33 (7)	52 (12)	22 (5)	13 (3)	37 (8)	196
0621	SHASTA LAKE	61 (14)	54 (11)	61 (14)	57 (13)	65 (15)	30 (7)	328
0622	SHAVER	78 (18)	41 (9)	83 (19)	96 (22)	87 (19)	78 (17)	463
0623	SILVER LAKE	89 (20)	65 (15)	78 (18)	87 (20)	96 (22)	91 (20)	506
0624	TULLOCK RESERVOIR	52 (12)	54 (11)	35 (8)	17 (4)	87 (19)	57 (13)	302
0625	UPPER TWIN LAKES	70 (16)	98 (22)	87 (20)	65 (15)	87 (19)	78 (17)	485
0626	LOWER TWIN LAKES	74 (17)	87 (19)	96 (22)	78 (18)	37 (8)	91 (20)	463

LAKES RANKED BY INDEX NOS.

RANK	LAKE CODE	LAKE NAME	INDEX NO.
1	0602	BOCA LAKE	539
2	0608	FALLEN LEAF RESERVOIR	527
3	0623	SILVER LAKE	506
4	0615	LAKE MARY	505
5	0625	UPPER TWIN LAKES	485
6	0626	LOWER TWIN LAKES	463
7	0622	SHAVER	463
8	0606	DON PEDRO RESERVOIR	370
9	0616	LAKE MENDOCINO	363
10	0621	SHASTA LAKE	328
11	0624	TULLOCK RESERVOIR	302
12	0604	CASITAS RESERVOIR	294
13	0619	LAKE PILLSBURY	279
14	0605	CROWLEY LAKE	268
15	0609	LAKE HENNESSEY	249
16	0620	SANTA MARGARITA LAKE	196
17	0617	NICASIO RESERVOIR	169
18	0603	LAKE BRITTON	164
19	0614	LOPEZ LAKE	134
20	0601	AMADOR RESERVOIR	134
21	0610	LAKE HENSHAW	130
22	0618	LOWER OTAY RESERVOIR	120
23	0607	LAKE ELSINORE	104
24	0611	IRON GATE RESERVOIR	104

APPENDIX B

CONVERSION FACTORS

CONVERSION FACTORS

Hectares x 2.471 = acres

Kilometers x 0.6214 = miles

Meters x 3.281 = feet

Cubic meters x 8.107 x 10^{-4} = acre/feet

Square kilometers x 0.3861 = square miles

Cubic meters/sec x 35.315 - cubic feet/sec

Centimeters x 0.3937 = inches

Kilograms x 2.205 = pounds

Kilograms/square kilometer x 5.711 = lbs/square mile

APPENDIX C

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 76/09/24

060501
37 35 16.0 118 42 33.0 3
CROWLEY LAKE
06051 CALIFORNIA

Site 1

11EPALES 751126 2111202
0080 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
75/06/10	13 50	0000	17.6	7.8	216	222	8.50	104	0.020	0.200	0.030	0.035
	13 50	0005	16.9	7.8	18'	225	8.20	104	0.020	0.200	0.020K	0.036
	13 50	0015	16.2	7.8		211	8.50	105	0.030	0.200	0.020K	0.035
	13 50	0031	11.2	6.6		169	8.20	87	0.030	0.200	0.020K	0.042
	13 50	0055	10.3	5.4		202	8.50	111	0.040	0.200	0.020	0.066K
	13 50	0076	10.0	5.4		205	7.90	115	0.050	0.200	0.020	0.072
75/06/30	15 45	0000	20.3	8.8	60	271	8.80	110	0.040	0.500	0.020K	0.027
	15 45	0005	20.2	8.8	5'	268	8.75	112	0.040	0.600	0.020K	0.026
	15 45	0020	16.8	7.0		249	8.50	111	0.030	0.500	0.020K	0.037
	15 45	0050	15.5	5.4		231	8.30	109	0.040	0.400	0.020K	0.045
	15 45	0085	13.8	2.8		251	7.85	121	0.120	0.600	0.030	0.122
75/11/05	11 30	0000	8.1	9.0		240	8.70	91	0.020K	0.200	0.020K	0.014
	11 30	0005	7.9	8.6		242	8.70	97	0.020K	0.200K	0.020K	0.011
	11 30	0016	7.9	8.2		237	8.70	100	0.020K	0.300	0.020K	0.018
	11 30	0045	7.9	8.6		245	8.70	97	0.020K	0.200	0.020K	0.015
	11 30	0082	7.5	8.2		241	8.70	95	0.020K	0.200	0.020K	0.013

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
75/06/10	13 50	0000	0.034	1.7	
	13 50	0005	0.039		
	13 50	0015	0.057		
	13 50	0031	0.039		
	13 50	0055	0.058		
	13 50	0076	0.064		
75/06/30	15 45	0000	0.446	6.8	
	15 45	0005	0.066		
	15 45	0020	0.049		
	15 45	0050	0.070		
	15 45	0085	0.142		
75/11/05	11 30	0000	0.030	9.0	
	11 30	0005	0.027		
	11 30	0016	0.032		
	11 30	0045	0.037		
	11 30	0082	0.071		

15' depth Integrated

P release

ammonia release

K VALUE KNOWN TO BE LESS THAN INDICATED

.077

~~Where is Site 2 & Site 3 Data?~~

16

STORET RETRIEVAL DATE 76/09/24

060502
37 36 14.0 118 44 48.0 3
CROWLEY LAKE
06051 CALIFORNIA

11EPALES 751126 2111202
0047 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
75/06/10	14 15	0000	17.4			233	8.50	110	0.020	0.200	0.020K	0.032
	14 15	0005	15.6	7.6		222	8.40	110	0.020	0.200	0.020K	0.042
	14 15	0015	15.3	7.6		222	8.40	110	0.020	0.200	0.020K	0.040
	14 15	0028	13.4	7.0		213	8.30	112	0.020	0.200	0.020K	0.051K
	14 15	0043	10.8	6.2		201	8.40	116	0.020	0.200	0.020K	0.055
75/06/30	15 10	0000	19.2	7.8	120 10'	260	8.50	111	0.030	0.600	0.020K	0.031
	15 10	0005	17.9	8.0		253	8.60	112	0.030	0.600	0.020K	0.032
	15 10	0015	17.0	7.6		252	8.50	111	0.030	0.500	0.020K	0.034
	15 10	0030	16.5	6.6		244	8.40	115	0.030	0.400	0.020K	0.046
	15 10	0046	15.5	5.2		244	8.10	113	0.040	0.400	0.030	0.064
75/11/05	11 00	0000	8.2	8.4		236	8.60	64	0.020K	0.200	0.020K	0.012
	11 00	0005	8.1	8.4		235	8.60	87	0.020K	0.200	0.020K	0.014
	11 00	0015	8.0	8.4		238	8.60	88	0.020K	0.200	0.020K	0.012
	11 00	0048	7.9	8.0		237	8.70	90	0.020K	0.300	0.020K	0.013

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
75/06/10	14 15	0000	0.043	1.0	
	14 15	0005	0.038		
	14 15	0015	0.038		
	14 15	0028	0.042		
	14 15	0043	0.056		
75/06/30	15 10	0000	0.055	5.0	
	15 10	0005	0.044		
	15 10	0015	0.064		
	15 10	0030	0.065		
	15 10	0046	0.091		
75/11/05	11 00	0000	0.030	8.8	
	11 00	0005	0.030		
	11 00	0015	0.032		
	11 00	0048	0.042		

15 ft' depth integrated

Site 2

2ITC 5

STORET RETRIEVAL DATE 76/09/24

060503
37 38 03.0 118 44 08.0 3
CROWLEY LAKE
06051 CALIFORNIA

11EPALES 751204 2111202
0030 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
75/06/30	14 40	0000	19.1	7.6	105	257	8.55	98	0.030	0.800	0.020K	0.040
	14 40	0005	17.4	7.6		242	8.60	107	0.040	0.400	0.020K	0.039
	14 40	0015	16.4	7.6	8.75'	237	8.50	108	0.030	0.400	0.020K	0.045
	14 40	0026	15.9	6.4		237	8.30	108	0.040	0.400	0.020K	0.049
75/11/05	11 50	0000	8.0	9.4		242	8.80	102	0.020K	0.300	0.020K	0.012
	11 50	0005	7.8	9.4		244	8.80	104	0.020K	0.200	0.020K	0.014
	11 50	0015	7.8	8.8		248	8.80	107	0.020K	0.300	0.020K	0.014
	11 50	0021	7.7	8.8		243	8.80	109	0.020K	0.400	0.020K	0.013

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
75/06/30	14 40	0000	0.049	4.8	
	14 40	0005	0.067		
	14 40	0015	0.071		
	14 40	0026	0.076		
75/11/05	11 50	0000	0.043	9.3	
	11 50	0005	0.037		
	11 50	0015	0.033		
	11 50	0021	0.034		

K VALUE KNOWN TO BE LESS THAN INDICATED