SEDIMENT NUTRIENT FLUX AND OXYGEN DEMAND STUDY FOR CANYON LAKE WITH NUTRIENT MONITORING AND ASSESSMENT OF IN-LAKE ALTERNATIVES: JANUARY – MARCH, 2007

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Introduction

This report summarizes the results from water column and sediment sampling conducted during the winter quarter 2007 to assess water quality and evaluate potential in-lake treatments to improve water quality in Canyon Lake.

Approach

Nutrient Monitoring

Water column sampling during this reporting period was conducted monthly. As previously reported, field measurements included Hydrolab casts and water column sampling for a large number of constituents at 5 sites (M1, M2, M3, E1, and E2) on Canyon Lake (Fig. 1).

Fig. 1. Canyon Lake sampling sites.

Sediment Nutrient Flux and In-Lake Treatment Evaluation

Separate studies were also conducted to quantify the forms of phosphorus in the sediments, as well as the rate of internal recycling of nutrients. Sediments from the five sites were extracted following Lewandowski et al. (2003) to quantify the concentrations of phosphorus in labile-, iron-, calcium-, aluminum- and organic-bound forms. The labile+Fe-P forms are generally considered potentially available for release, and are thus used to guide alum dose requirements. Sediment cores were also collected at the very end of the quarter to quantify winter nutrient flux rates as well as assess effects of aeration and oxygenation on rates of nutrient release. The nutrient analyses associated with these measurements were not available at the time of this report, and so will be discussed in the draft final report for this phase of the project to be completed later this month.

Results

Temperature and Dissolved Oxygen

The water column properties of the main body of Canyon Lake reversed the trends found in the previous reporting period. Cool, isothermal conditions continued into January, with water temperatures dropping to about 9 °C during an unusually cold interval in mid-January (Fig. 2a). The water column warmed in February with stratification present on the March 22nd sampling date following a period of very warm weather (Fig. 2a).

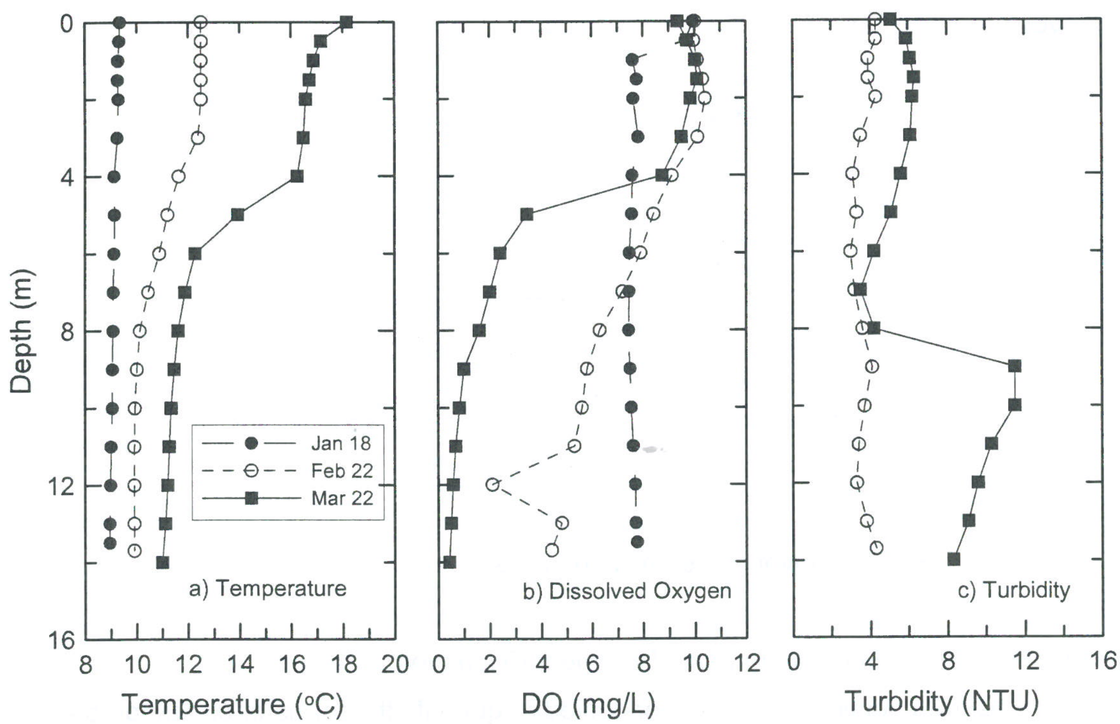

Fig. 2. Selected profiles from site M1: a) temperature, b) DO and c) turbidity.

The water column was well-mixed with respect to DO concentration on January 18th, with uniform concentrations of about 8 mg/L at all depths except the very surface where slightly higher concentrations were found (Fig. 2b). As the lake warmed however, (Fig. 2a), DO concentrations increased near the surface and declined lower in the water column, with anoxic conditions (DO <1.0 mg/L) already in place on the March 22nd sampling (Fig. 2b). The turbidity sensor on the Hydrolab was no functioning properly in the field on the January sampling date, so no data is available for that date. Turbidity averaged about 4 NTU throughout the water column in February, although turbidity levels increased from 4 NTU to 11 NTU below 8 m on the March 22nd sampling (Fig. 2c).

Conditions in East Bay mirrored those in the uppermost 3-4 m of the water column in the main body of the lake. Temperature, DO and turbidity were fairly uniform with depth (Fig. 3), with temperatures increasing from 9 °C to 18°C during this period. Dissolved oxygen concentrations varied from about 6-12 mg/L (Fig. 3b), reflecting higher daytime photosynthetic O_2 production later in the quarter. Turbidity levels increased from about 8 NTU found on February 22nd to about 15 NTU in March (Fig. 3c).

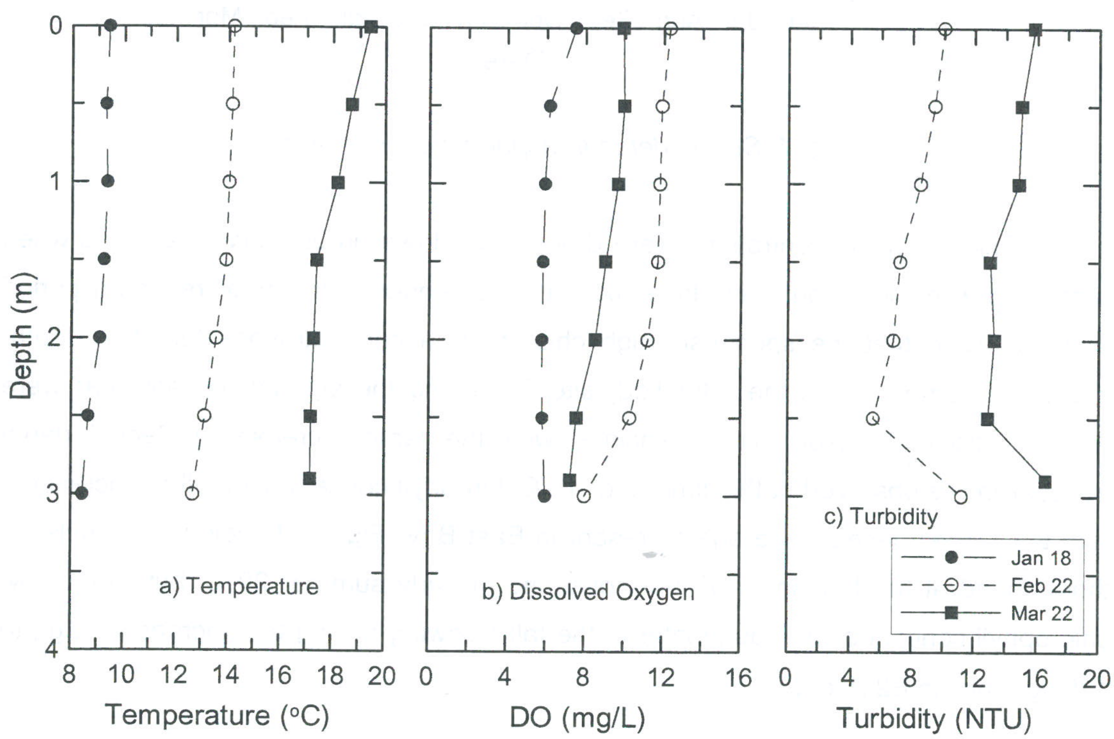

Fig. 3. Selected profiles from site E2: a) temperature, b) DO and c) turbidity.

Transparency and Chlorophyll Concentrations

Transparencies measured with a Secchi disk increased dramatically at most sites in January, and then decreased to levels similar to those found in the fall (Fig. 4). Thus by March, Secchi disk depths ranged from 50 cm at site E2 to 75 cm at site M2. As has been found throughout most of the past 10 months, the lowest Secchi depth values were found at site E2, well into East Bay (Fig. 1).

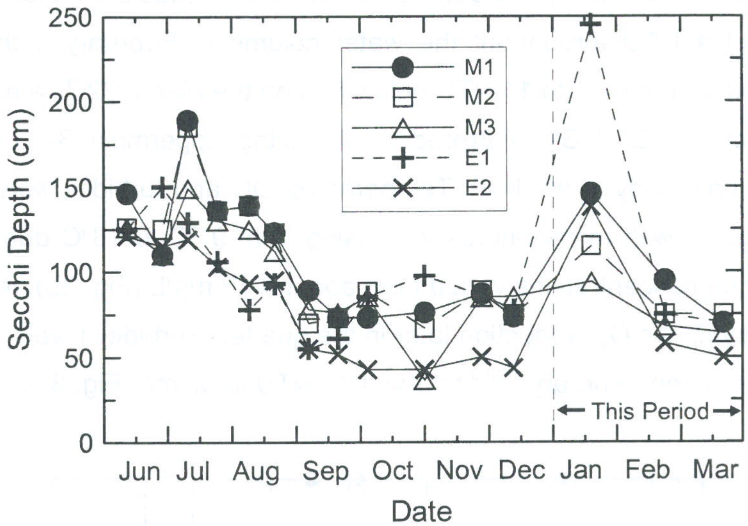

Fig. 4. Secchi depth transparencies over time.

Chlorophyll concentrations were dramatically lower in January at all sites when compared with those found in November and December of the prior reporting period (Fig. 5). (Note that the spuriously high chlorophyll a concentrations found in depth-integrated samples from the (stratified) site E1 during the summer of last year were removed from this plot.) This coincides with the large increase in Secchi depth transparencies observed at this time (Fig. 4). Chlorophyll concentrations then increased, with the highest levels once again present in East Bay (Fig. 5). Levels were similar to those found at the beginning of the monitoring in early summer 2006, but well below chlorophyll concentrations found later in the fall following mixing that increased, e.g., to 120 μg/L at site E2 (Fig. 5).

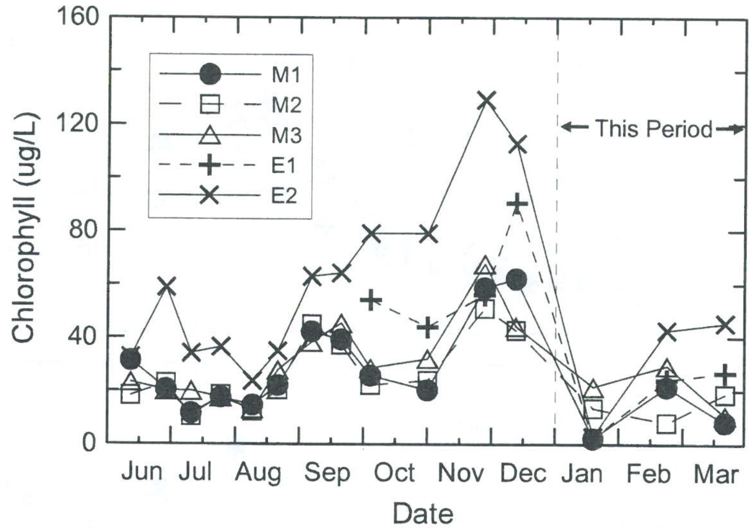

Fig. 5. Chlorophyll concentrations over time.

Nutrient Concentrations

Total P concentrations declined slightly from the values found in samples collected in November and December (Fig. 6). (Since the main body of the lake mixed earlier in November, depth-integrated samples were collected at all sites from November through March; for continuity, the depth-integrated concentrations for sites M1-M3 are also shown in plots for the thermocline and hypolimnion.) Notwithstanding, these total P concentrations are very high. Moreover, these concentrations are due principally to internal recycling of nutrients from the sediments, with the increases in the fall due to mixing of nutrient-rich hypolimnetic water into the upper water column (Fig. 6). The minimal rainfall this winter (<0.5 inches this calendar year) has contributed very little runoff to the lake and thus very little external loading of nutrients as well.

As previously noted, concentrations of soluble-reactive P (SRP) followed very closely observed trends in total P. SRP concentrations declined more substantially than total P in February, with readily available P in the East Bay sites declining to levels near or below 0.05 mg/L (Fig. 7). Concentrations increased at all sites in March however, with levels higher in the main body of the lake than in East Bay due to inclusion of some hypolimnetic water in the depth-integrated samples collected at that time.

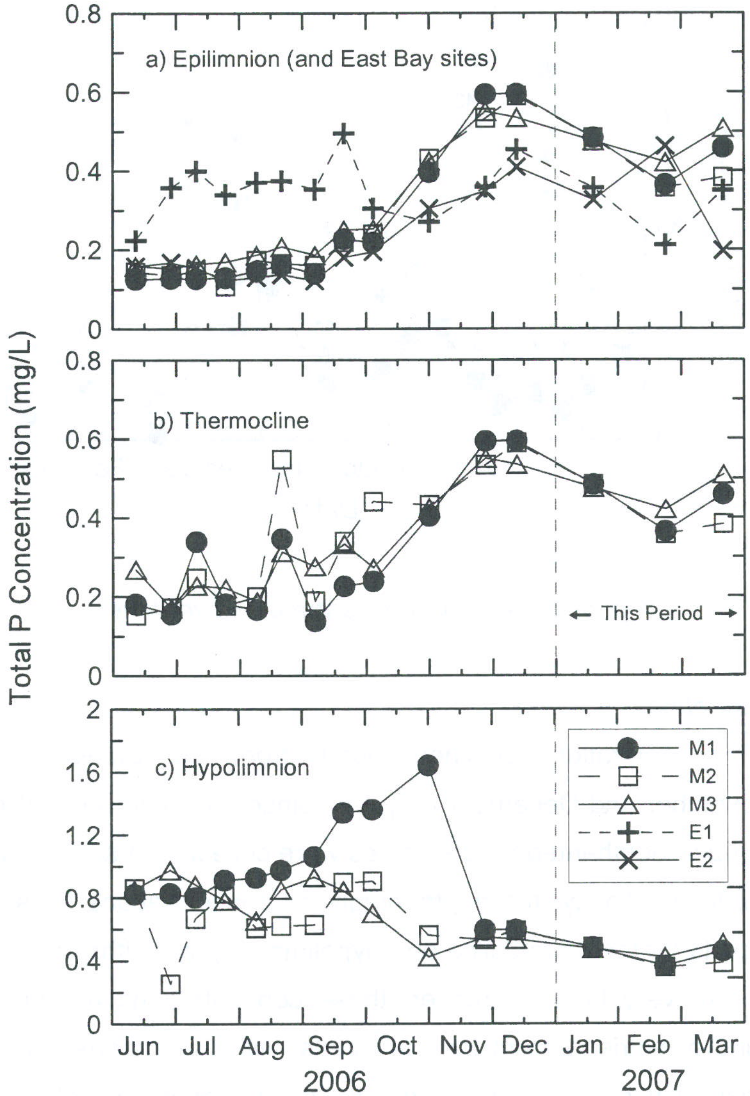

Fig. 6. Total P concentrations over time: a) epilimnion and East Bay sites, b) thermocline and c) hypolimnion. Thermocline and hypolimnion samples from the main lake sites only.

Total N concentrations in the main body of the lake decreased during this reporting period, from maximal values of about 1.4 mg/L in December to 0.8 – 1.0 mg/L (Fig. 8). Total N levels in East Bay reached higher levels in January before subsequently declining.

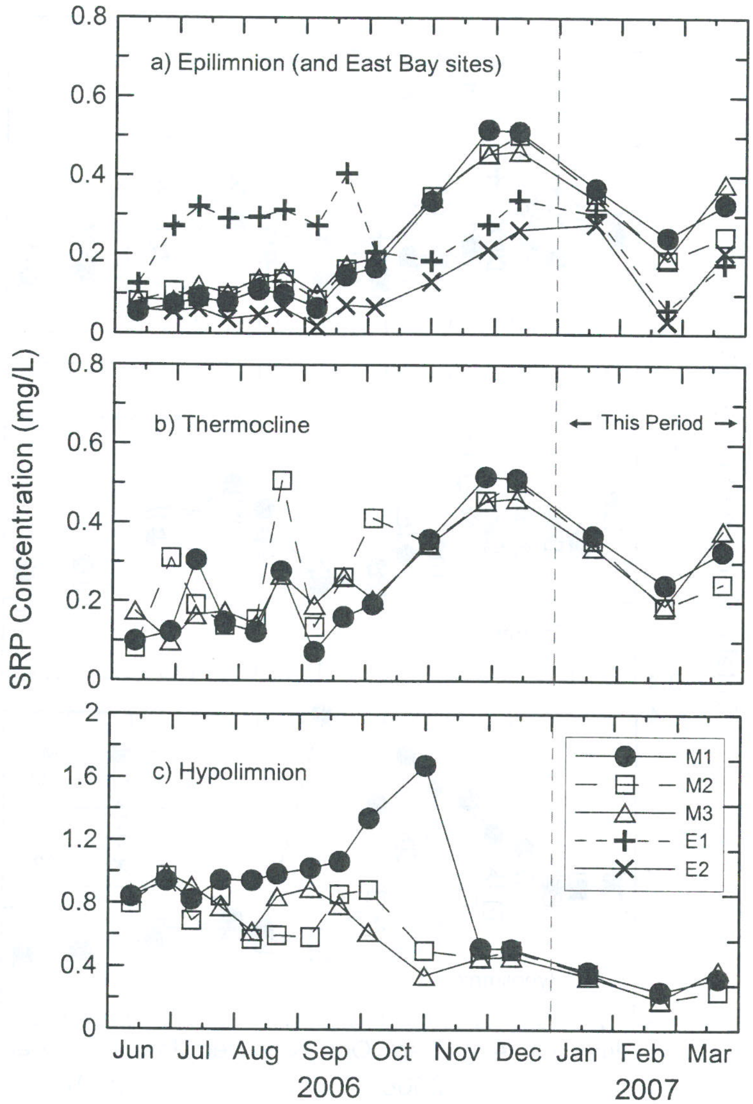

Fig. 7. SRP concentrations over time: a) epilimnion and East Bay sites, b) thermocline and c) hypolimnion. Thermocline and hypolimnion samples from the main lake sites only.

Ammonium-N levels in the lake declined more dramatically than total N from the levels found following turnover (Fig. 9). Concentrations as high as 0.95 mg/L were found in East Bay in January, while levels declined to <0.1 mg/L by March. Levels were somewhat higher at sites M1-M3, but the dramatic declines are attributed to increased phytoplankton production (Fig. 5). That is, maximum transparencies were associated with high levels of available NH_4-N, while the loss of NH_4-N (Fig. 9) was correlated with loss of transparency (Fig. 4) and increased chlorophyll concentrations (Fig. 5).

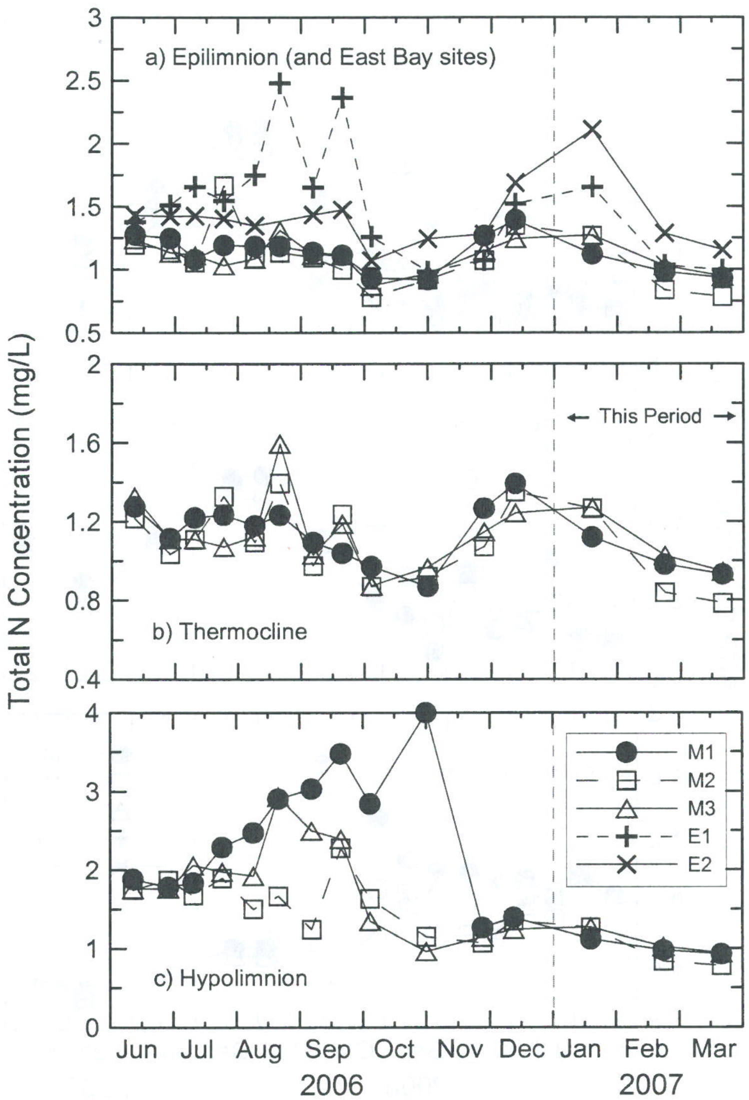

Fig. 8. Total N concentrations over time: a) epilimnion and East Bay sites, b) thermocline and c) hypolimnion. Thermocline and hypolimnion samples from the main lake sites only.

Concentrations of NO_3+NO_2-N have been below detection (<0.04 mg/L) through all of last year, although measurable levels were found during this reporting period. Concentrations in the main body were 0.44-0.46 mg/L on January 18th, although levels declined to 0.31-0.34 mg/L on February 22nd and to <0.04 mg/L by March 22nd. Slightly lower concentrations were found in East Bay in January (0.29-0.30 mg/L), although levels there also declined below detection by March. It thus appears that some limited runoff may have added nitrate to the lake, although it was quickly denitrified or used up by phytoplankton in this N-limited system.

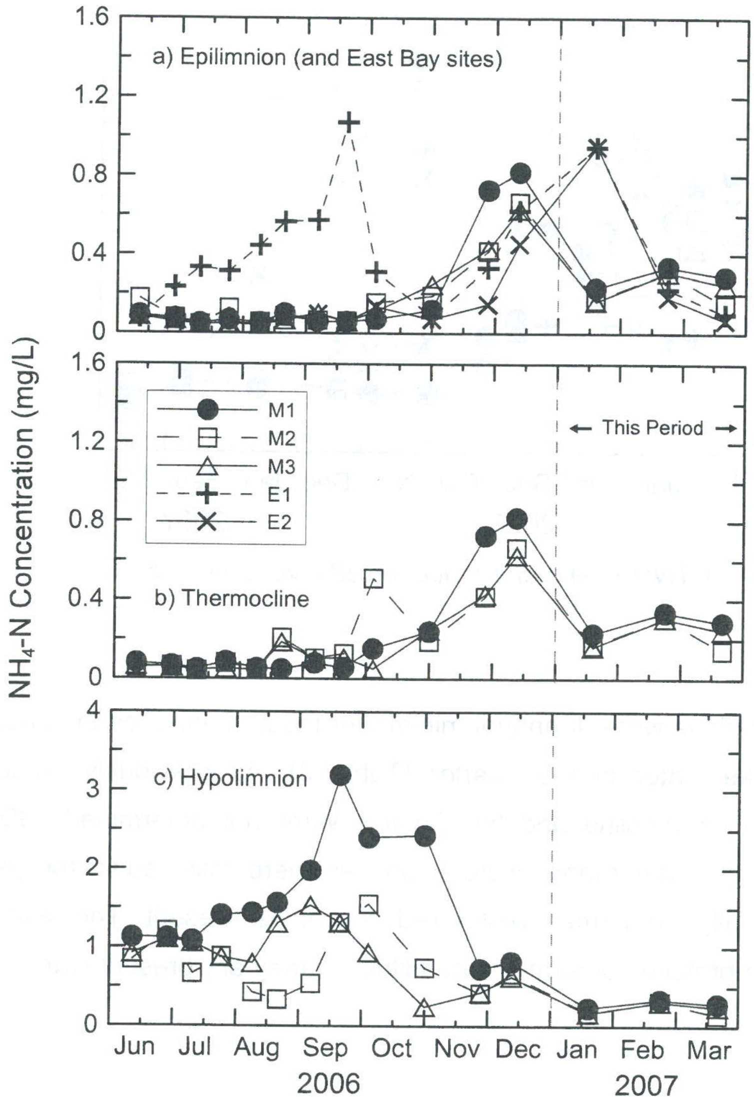

Fig. 9. Ammonium-N concentrations over time: a) epilimnion and East Bay sites, b) thermocline and c) hypolimnion. Thermocline and hypolimnion samples from the main lake sites only.

The total N:total P ratios confirm tendencies toward N-limitation, with TN:TP ratios declining to about 2 in the main body and 2-6 in East Bay (Fig. 10). These ratios are well below those found last summer, that were closer to the Redfield ratio and averaged about 8 in June-August (Fig. 10)

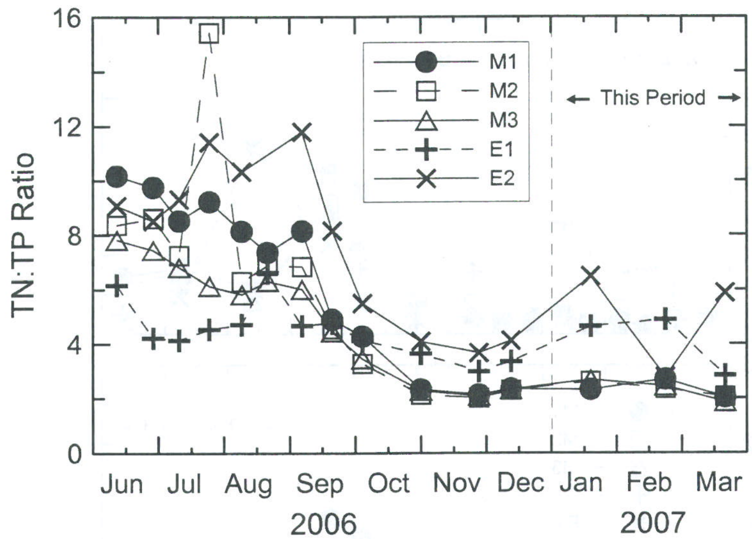

Fig. 10. TN:TP ratio of surface mixed layer samples.

Oxygen Demand

BOD concentrations were at annual minima for most of the sites in January, but increased quite marked later in the quarter (Table 3). As previously noted, BOD concentrations in the thermocline and hypolimnion were not determined (ND) since depth-integrated samples, rather than discrete samples, were collected for this period as a result of the generally isothermal, well-mixed conditions present. The lake will be sampled following the protocol for stratified conditions if they are present when sampled in April.

Table 3. BOD concentrations (mg/L).

Site	Sample	9-Aug	6-Sep	31-Oct	27-Nov	12-Dec	18-Jan	22-Feb	22-Mar
M1	Epilimnion	6.4	4.9	0.3	2.8	2.8	1.9	2.3	2.1
	Thermocline	5.0	3.9	1.3	ND	ND	ND	ND	ND
	Hypolimnion	9.7	18.5	15.0	ND	ND	ND	ND	ND
M2	Epilimnion	6.6	3.9	2.3	2.0	2.0	2.8	3.6	3.4
	Thermocline	7.4	4.7	2.3	ND	ND	ND	ND	ND
	Hypolimnion	9.1	7.7	4.5	ND	ND	ND	ND	ND
M3	Epilimnion	7.8	4.0	2.3	2.5	2.5	2.8	3.9	3.8
	Thermocline	7.0	3.2	2.3	ND	ND	ND	ND	ND
	Hypolimnion	10.8	14.8	2.3	ND	ND	ND	ND	ND
E1	Depth-Intregr	10.3	6.0	2.6	2.2	2.2	1.0	5.4	4.5
E2	Depth-Integr	8.8	4.4	5.0	4.5	4.5	1.3	6.1	6.7

Chemical oxygen demand (COD) remained much higher than BOD through this quarter, although they too were near annual minimum values in January that then increased later in the quarter (Fig. 11). Since depth-integrated samples were collected at all sites, the same COD values were plotted in each of the three panels to maintain continuity in the figures.

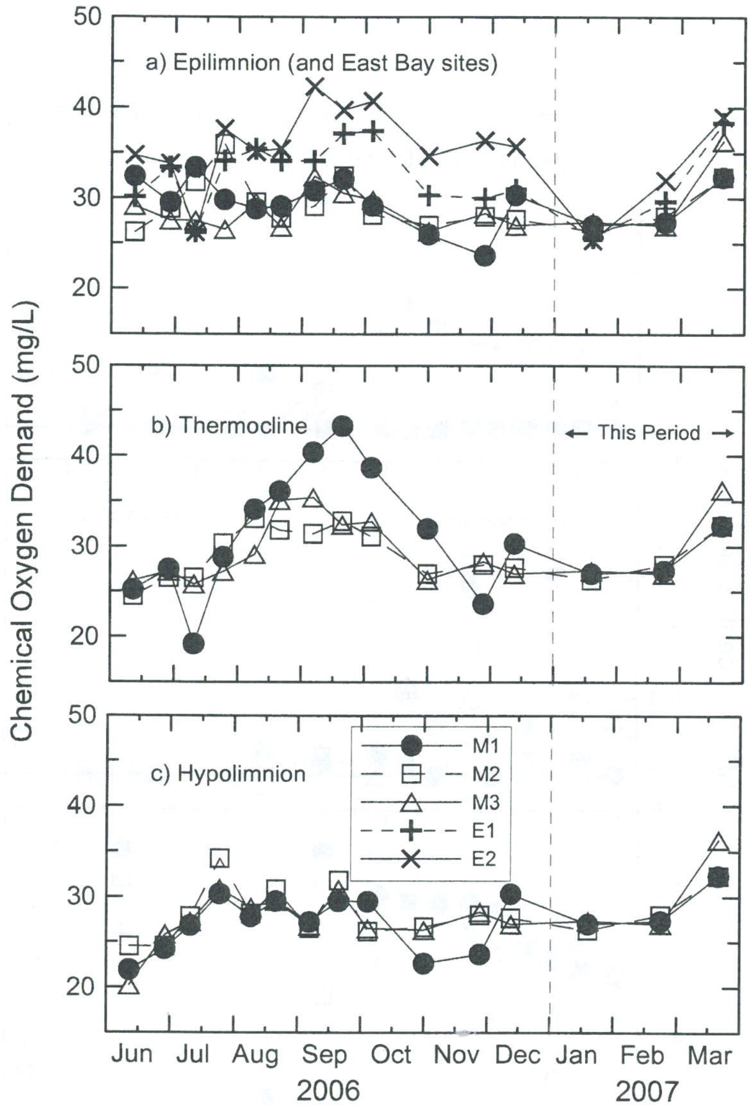

Fig. 11. Chemical oxygen demand (COD) concentrations over time: a) epilimnion and East Bay sites, b) thermocline and c) hypolimnion. Thermocline and hypolimnion samples from the main lake sites only when available.

Other Chemical Properties

A number of other chemical and physical properties were also determined, including alkalinity, hardness, total suspended solids, and total dissolved solids. Most of these parameters varied comparatively little over time and did not exhibit clear spatial trends. As a result, these will not be discussed until the final report. As previously noted, however, Mn concentrations varied strongly between sites, depths and sample dates (Fig. 12).

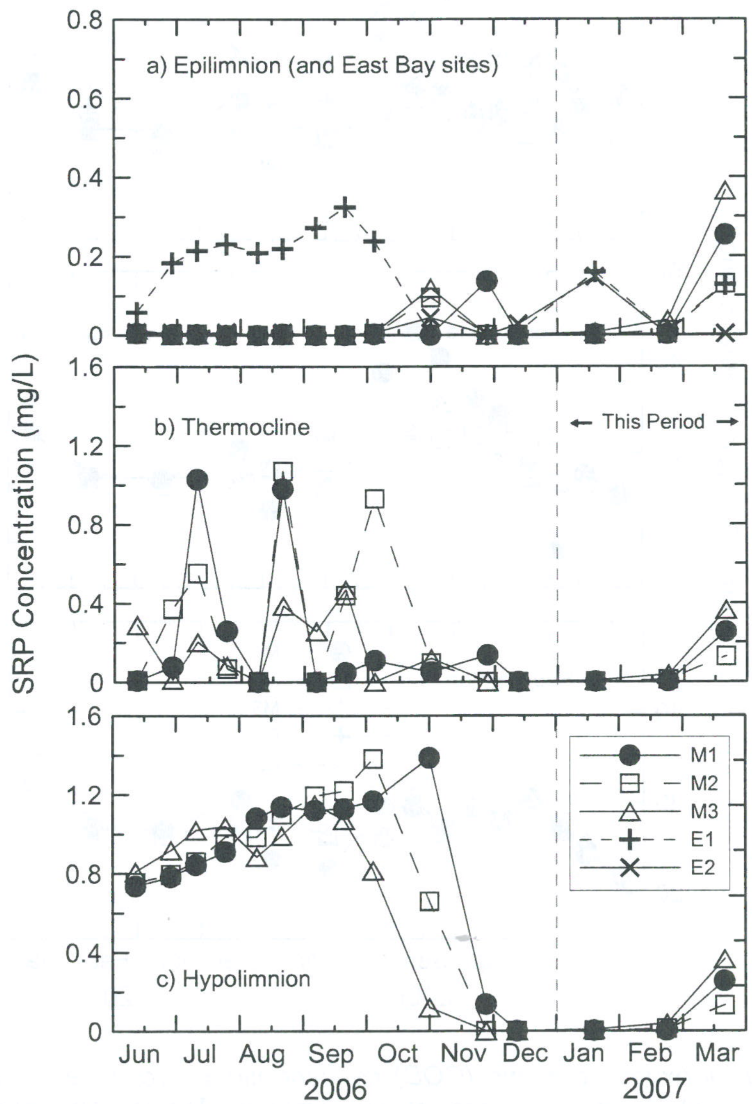

Fig. 12. Dissolved Mn concentrations over time: a) epilimnion and East Bay sites, b) thermocline and c) hypolimnion. Thermocline and hypolimnion samples from the main lake sites only.

Dissolved Mn concentrations were generally low at the end of last year as mixing increased DO levels that precipitated dissolved Mn^{2+} and suppressed reductive dissolution of Mn phases in the sediments (Fig. 12). This trend continued in January and February, although comparatively high Mn levels were present at sites E1 and E2 in January. Low concentrations were in place throughout the lake in February, while concentrations edged up in March. The increase in March is attributed to the initial development of stratification that lowered DO levels (Fig. 2) and thus promoted Mn dissolution and inclusion into depth-integrated samples collected at this time.

Sediment Nutrient Release and Evaluation of In-Lake Treatment Alternatives

It was previously shown that an alum treatment would substantially suppress phosphate release from sediments (Men and Anderson, 2007). It was further shown that Canyon Lake has sufficient alkalinity to receive an alum treatment of 35 mg/L Al or more. The extraction procedure of Lewandowski et al. (2003) was used on sediment samples from each of the 5 sites to quantify the forms and concentrations of P in Canyon Lake sediments (Fig. 13).

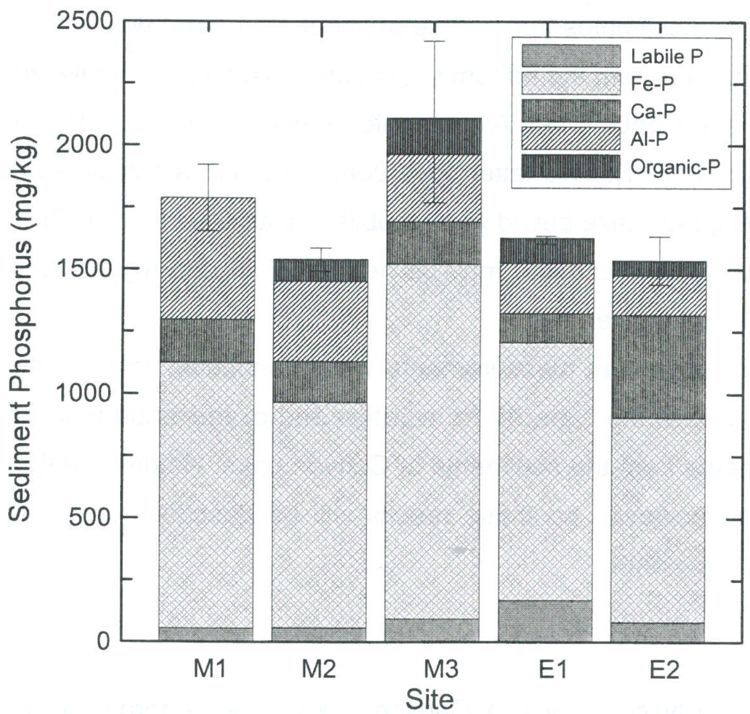

Fig. 13. Forms of phosphorus in sediments recovered using the sequential extraction technique of Lewandowski et al. (2003).

Phosphorus associated with reducible-Fe phases was the most abundant form of P in the sediments, with Fe-P averaging about 1000 mg/kg or 60% of the total P recovered by the extractions (Fig. 13). Aluminum-P was 2nd most abundant on average, accounting for 20-25% of the P in sites M1 and M2, although constituted a smaller fraction (10.4-12.9%) in the other sites. Calcium-P exhibited the largest spatial gradient, with over 400 mg/kg (27%) of the extracted P from sediments at site E2, while the other, deeper sites ranged from 117-174 mg/kg (7.2-10.7%). The higher Ca-P at site E2 may be due in part to greater local inputs to this site of eroded calcareous soils from the Salt Creek watershed relative to the other sites due simply to proximity to the creek inlet. Labile-P includes SRP in porewater as well as readily-exchangeable forms of P in the sediments and accounted for only about 5% of the extracted P (Fig. 13). Organic-P was also a minor component of the P in the sediments (Fig. 13).

The amount of mobile P (i.e., labile+Fe-P) in the uppermost 4-10 cm of sediment is often used to estimate the alum dose required to convert these potentially available forms of P to the more recalcitrant Al-P phase. Assuming a sediment bulk density of 1.1 g/cm^3, an active zone of 4 cm, and the average mobile P concentration at the 5 sites (1,144 mg/kg), one estimates that a dose of about 50 g Al/m^2 would be needed to curtail internal recycling of P from the bottom sediments. Assuming an active zone that extends 10 cm into the sediments, 125 g Al/m^2 would be needed (these calculations assume an added Al:P ratio of 10:1). This latter dose compares with a calculated average dose of 32 g Al/m^2 for Big Bear lake based upon mobile-P estimates there (Welch, unpubl.2004). Use of a buffered aluminate salt may be necessary for the higher doses, especially in shallow regions of the lake.

Additional core-flux measurements were conducted to quantify winter nutrient flux rates and assess the capacity for aeration and oxygenation techniques to slow the release of nutrients from the sediments of Canyon Lake. Nutrient analyses have not yet been completed however, so these results will be described in the draft final report expected later this month.

Conclusions

Water quality conditions in Canyon Lake were generally quite improved from those found in the prior quarter. Dissolved oxygen levels were generally high through most of the water column, at least until stratification commenced in March. Nutrient concentrations were slightly lower, with total N:total P ratios considerably lower (having declined from ~8 in the summer to ~2 this winter). Thus the lake may become limited by N, although sufficient dissolved N remained available to support algal growth through March. Sequential extractions of sediments indicate that almost two-thirds of the P in the sediments of the lake is associated with reducible Fe phases, with smaller amounts of Al-P and Ca-P present. Preliminary alum dose calculations suggest that 50-125 g Al/m^2 would be needed to sequester mobile P within the surface sediments. Such a treatment would move the lake away from N-limitation and to a P-limited condition.

References

Lewandowski, J., Schauser, I., and Hupfer, M. (2003) Long term effects of phosphorus precipitations with alum in hypereutrophic Lake Süsser See (Germany). Water Research. **37**:3194-3204.

Men, S. and M.A. Anderson. 2007. *Sediment Nutrient Flux and Oxygen Demand Study for Canyon Lake with Nutrient Monitoring and Assessment of In-Lake Alternatives: October-December,2006.* Draft 2nd Quarterly Report. San Jacinto River Watershed Council and Santa Ana Regional Water Quality Control Board. 18 pp.