PB
FERC 2105

Dear Mr. Barnes,

The following letter was approved by unanimous vote of the voting members of the Lake Almanor Watershed Group. We appreciate the opportunity to provide comments on the Draft EIR for the SWRCB water quality certification for the FERC Project 2105.

The Lake Almanor Watershed Group is a local volunteer citizen group. Our vision is, "to guarantee a healthy watershed that ensures water quality and riparian and wetland habitat for fish, wildlife, and native plants while recognizing the importance of people's economic livelihood and quality of life." LAWG has provided annual reports of the health of the lake to interested citizens, home owner associations and to governmental agencies. Our assessments of the lake have been done in cooperation with the Department of Water Resources, Northern Division, and Dr. Gina Johnston, Professor Emeritus of Biological and Geological Sciences from Chico State University. A considerable amount of this recent (2011 – 2014) data on Lake Almanor water quality monitoring does not appear to have been considered in drafting the EIR. In our opinion this is a failure to meet the standard of considering the best available science. We believe that upon consideration of this data the conclusions drawn in the EIR would be different. We are including copies of the 2011 - 2014 reports to better inform the final EIR.

We have significant specific concerns about the potential impacts of the two alternatives evaluated in the DEIR. Our concerns are as follows:

1. Recent reports and assessments strongly suggest that Lake Almanor's cold water fish habitat, especially in late summer, is declining. Our 2011 report, from one of the wettest and coldest springs, showed only 53% suitable cold water fish habitat (<20C and >5ppm DO) in the lake, a level to which the lake has only dipped to five other times in the roughly 30 year monitoring history of the lake. Even more of a concern, in 2010, less than 40% of water samples from LA-1 (Canyon Dam), LA-2 (Eastern lobe) and LA-3 (Western lobe) indicated suitable habitat for salmonids in late summer. In late summer 2014 the oxygen levels where <20C water existed were near zero, lower than in 2012 and 2013. In September of 2014, below 12 meters, the hypolimnion at both stations was essentially devoid of oxygen. These findings suggest that these periods of time are extremely stressful on salmonids. Also, trends showing increasing temperatures and decreasing dissolved oxygen levels throughout the month of November from 1990-2010 suggest that the lake is remaining warmer longer each year. We disagree with the assertion that there is sufficient cold oxygenated water to sustain a thriving salmonid fishery and we have significant concerns about any alternative that increases cold water releases out of the lake. The DEIR fails to consider the best available science by not taking these recent reports into consideration.

2. Biological and nutrient data from the lake over the past five years was not considered in the draft EIR. In 2014, warmer water temperatures resulted in higher than average algal abundance in September and November at both LA-02 and LA-03. In fact, algal abundance at LA-03 was three times higher than in previous years. The shallow nature of the western lobe and the warmer water made ideal conditions for algal growth. Blue-green algae pose a potential health risk to people and pets. Removal of additional cold water may exacerbate the increasing trends in algal blooms in the lake, reducing water clarity and effecting human health. This information has been available in reports for at least the past 3 years. It seems this should have been evaluated in the DEIR.
3. With current trends in lake inflows (PG&E data) and predicted impacts of climate change it seems less than forthright to propose thermal curtains will only be installed if other measures do not achieve water temperature objectives. Is a cold water fishery in the North Fork under predicted future climate conditions sustainable even under the thermal curtain and cold water release strategy outlined in the DEIR? Might Almanor offer the only cold water refugia in the upper north fork by the latter half of this century? Might then this proposed project be climate mal-adaptation? We see a lack of a real effort to evaluate climate change impacts including citation of some of the most important literature on the subject for the Sierra Nevada. The Climate Change section deals exclusively with climate mitigation and not at all with climate adaptation. This in our opinion is a fundamental flaw that underlies the majority of this analysis.
4. The claims under Global Climate Change on page 6.5-1 that, "Neither the Proposed UNFFR Project or the alternatives would be likely to affect the potential trends in water temperatures of Lake Almanor that may be related to climate change (i.e., global warming) because overall seasonal reservoir storage volumes would not be affected" is not based on the most current science. Our data suggests that there is a 3 month period from July – September when cold water resources in the lake are limited and likely affecting the cold water fishery (see point # 1 above). Water volume is not the key parameter here – it is the cold water resource. Further, trends in Almanor water temperatures are not the most important factor here – threshold levels of water temperatures related to DO to support the fishery are the critical component. With Almanor expected to warm under climate change, will this project result in surpassing a threshold beyond which the cold water fishery in the lake is not sustainable? In 2014 we measured the Feather River being 2 degrees Celsius warmer in July than in July 2012. Evaluations of the cold water pool and its effects in the DEIR use old data and do not consider conditions under the predicted future climate. Since this license is for 30 to 50 years it seems reasonable to evaluate the cold pool and this projects effects on it out to conditions expected through the entire license period.
5. Mitigating potential loss of cold water fishery habitat by stocking large trout is an unfortunate misguided solution. Proposing a fishery that is all but reliant on annual hatchery stocking followed by high summer mortality significantly

degrades the Almanor sports fishery and could have substantial impacts on water quality. This is not a reasonable mitigation measure.

6. We are concerned with the effects of increased summer draw-downs will have on the Aecomorphus grebe breeding colonies on the lake. The issue of water levels and rate of draw down on grebe nesting success has been well documented for Lake Almanor (Ivey 2004, Robison et al. 2009, Arsenault 2014). As of 2013, Lake Almanor represented the largest breeding colony of Western Grebe in California (Arsenault 2014). Under current reservoir operations, in many years water levels drop too rapidly resulting in mass stranding and abandonment of nests. An increase in the rate of lake level draw down during the birds breeding period from July – September, as potentially would occur under the DEIR alternatives, will almost certainly result in habitual colony failure. This could potentially lead the species towards T&E listing under state or federal law. Any project that may result in such a massive take of a migratory bird species should be fully evaluated. In Chapter 4 page 7 it states "increasing the canyon dam releases would require decreasing the Prattville intake flow commensurately to avoid lake level fluctuations or changes from the operating rules agreed to in the 2004 Settlement agreement". Then on page 4-10 it states that water would be moved from releases in the winter months to the summer months. This appears contradictory. We suggest the EIR needs to develop daily or weekly lake level curves under the different draw down scenarios and then evaluate the effects these would have on take of the grebes. We would like to see a reduction in lake level draw downs in July – September to improve grebe productivity on the lake from the existing approach. Our partners at Plumas Audubon have the data to help better manage lake level draw-downs to avoid take of these migratory birds.
7. The claim of no significant effects to cultural resources – especially Native American burial grounds in the vicinity of the thermal curtain location – seem arbitrary. Through the 2105 agreement process, PG&E stated that in order to get the cold water to the Prattville area it would require re-dredging the lake bottom. Is this not the case? If it is, it needs to be fully re-evaluated to determine effects on these cultural resources in direct consultation with local Maidu representatives. Any disturbance of the lake bottom in the vicinity of the Prattville ditch needs to involve consultation with the Maidu.

Respectfully,

Carl Felts – Chair

The Lake Almanor Watershed Group
Carl Felts, Aaron Seandel, Ryan Burnett, Charles Plopper, Lorena Gorbet, Peggy Fulder, Dr. Gina Johnston, Dick Daniel, & Jonathan Kusel

Additional references available upon request

Lake Almanor Water Quality Report, 2011

Prepared for

Plumas County Flood Control & Water Conservation District and
Almanor Basin Watershed Advisory Committee

By

K.R. Gina Johnston and John McMurtry
Butte Environmental Technologies

Submitted January 2011

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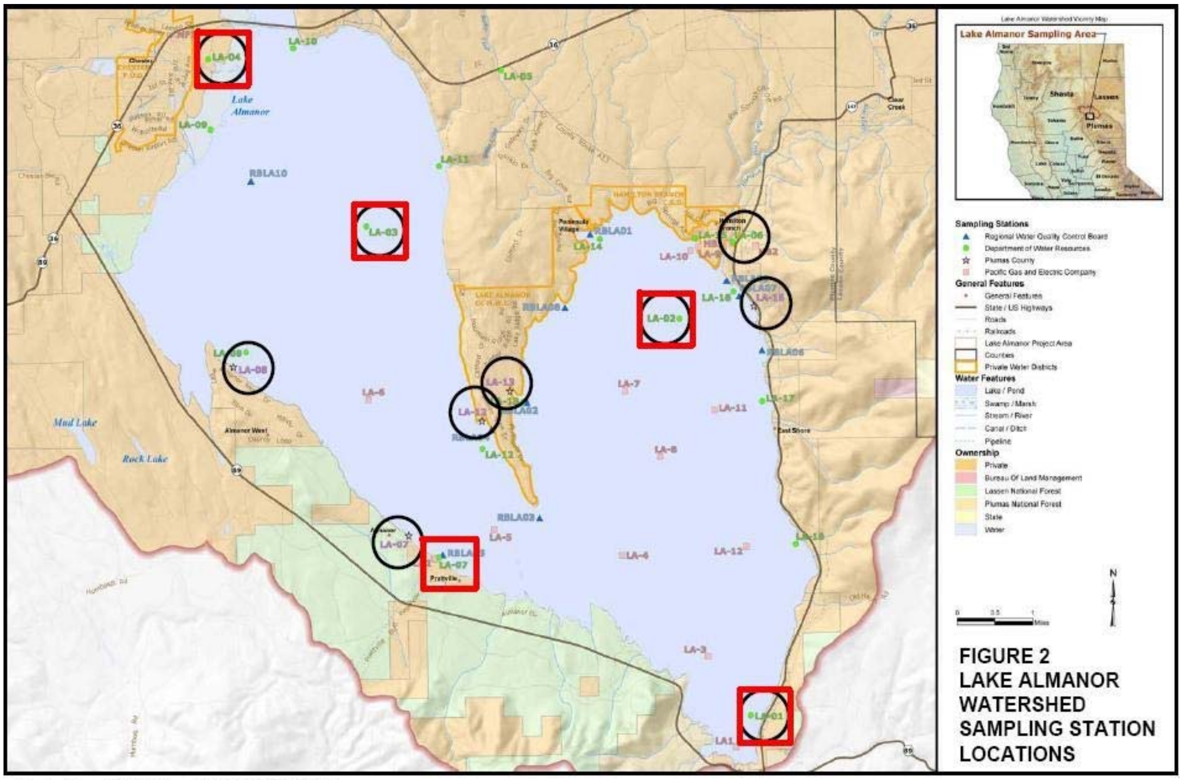
Introduction and Project Overview

A water quality monitoring program for Lake Almanor was conducted during 2011, following the same protocol used in the 2009 and 2010 study. The Plumas County Flood Control and Water Conservation District, in conjunction with the Almanor Basin Watershed Advisory Committee (ABWAC), provided oversight for the contract. Due to the limited funds available for this project, ABWAC selected some of the important parameters that had been monitored in the past by California Department of Water Resources (DWR), the County of Plumas and Pacific Gas & Electric Company. Four sampling windows were chosen for sampling to provide a look at lake health: during spring turnover (April 10-16), the period of heavy recreational use (July 10-16 and September 4-10) and fall turnover (November 13-19). Three stations in the lake were selected: LA-01, near the Canyon Dam Intake Tower; LA-02, in the east lobe; and LA-03, near the middle of the west lobe. A station in Chester (LA-04) was selected for monitoring the North Fork of the Feather River just prior to discharge into the lake. Station locations are shown in Figure 1. The parameters and sampling times are listed in Table 1, below.

Table 1. Lake Almanor Parameters Monitored in 2011

Parameter	Specific Parameters	Locations	Sampling Window
Physical	Temperature Dissolved oxygen Electrical Conductivity Secchi depth	LA-01, LA-02, LA-03 every two meters, just once at LA-04 (no Secchi)	April 10-16 July 10-16 Sept 4-10 Nov 13-19
Plankton	Zooplankton Phytoplankton	LA-02 LA-03 (vertical tow)	April 10-16 July 10-16 Sept 4-10 Nov 13-19
Nutrients	Total phosphorus Total nitrogen	LA-02, LA-03 (0.5 meter below surface and 1 meter off bottom)	Apr 10-16 Nov 13-19

Figure 1. Sampling Station Locations in Lake Almanor (Adapted from Lake Almanor Watershed Water Quality Report, CH2M HILL, April 2006). Note: LA-01, LA-02, LA-03, LA-04 (highlighted in red) were used in the 2011 investigation. LA-07, near the Prattville intake, was not used.



Adapted from: CH2M HILL and EARTHWORKS, 2006

Methods Used for Sampling and Analysis

a. Procedures for Field Measurements: Temperature, Dissolved Oxygen, Electrical Conductivity, and Secchi Depth

   Temperature, dissolved oxygen and electrical conductivity were measured with a Hydrolab Surveyor 4 water quality meter equipped with these probes. All probes were calibrated in the lab prior to each field measurement day. The probes were lowered into the water column and readings were taken at 0.5 meter below the surface and at every two meters to within one meter of the lake bottom. During periods of thermal stratification, readings were taken every meter to more accurately measure changes in temperature and dissolved oxygen with depth.

   Secchi disk transparency was measured using a standard Secchi disk which was lowered on the shady side of the boat. The disappearance and reappearance depths were recorded and averaged.

b. Procedures for Chemical Measurements: Nutrients

   Water samples for chemical analysis were collected with a Van Dorn style 2.2 liter sampler at two depths (0.5 meter below lake surface and 1.0 meter above lake bottom). They were poured into appropriate bottles provided by Basic Laboratory. All samples were stored in a styrofoam ice chest and packed in ice to maintain a temperature of 4° C and dark conditions. They were transported to the Basic Lab branch office in Chico, CA within 24 hours of collection.

   Basic Laboratory in Redding, CA, performed the nutrient (Total Kjeldahl nitrogen, nitrite plus nitrate, total nitrogen and total phosphorus) analyses. It is certified by the California Department of Public Health to conduct these analyses.

c. Procedures for Plankton Collection and Analyses

   Phytoplankton were collected with a Wisconsin type conical net (80 micron mesh) that was pulled from the bottom to the surface to produce an integrated sample. They were preserved with Lugol's solution, as well as 40% formalin solution.

   Phytoplankton were counted and were identified to division (Chlorophyta, Chrysophyta, etc.) and to genus when this would allow for comparison with previous data and when the genus would be indicative of water quality.

Zooplankton were collected with a net towed from the bottom to the lake surface to produce an integrated sample and preserved with 40% formalin solution.

Zooplankton were enumerated and identified to order (Cladocera, Copepoda, etc.) and to suborder or genus when this would allow for comparison with previous data or where the identity had water quality significance. (Again, certain genera are indicators of lake health and it would be important to know their abundance.)

Results and Discussion

1. Physical Parameters

   a. Temperature

   The temperature data are shown in graphic form for each station (See figures 2, 3, 4 and 5 as well as Table 1 in Appendix). In April 2011 three lake stations (LA-01, LA-02 and LA-03) were well-mixed with little temperature difference between surface and bottom. At LA-01 and LA-02 temperature at the surface was about 7 °C and at the bottom it was between 5 and 6 °C. LA-03 was slightly warmer with surface at 8 °C and the bottom at 7 °C.

   By July 2011 all three stations were thermally stratified. The epilimnion was about 20 °C. The thermocline (or metalimnion) at LA-01 and LA-02 was between 6 and 10 meters. At LA-03 it was 5-8 meters. LA-03 may not have stayed stratified, due to its shallow condition.

   In September surface temperatures at LA-01 and LA-02 were between 21 and 22 °C. At both stations the thermocline was a little deeper than in July (8-13 meters) and the temperature in the hypolimnion was 11-12 °C. LA-03 was well mixed, with temperature between 20 and 21 °C.

   By November 2011 the lake was no longer thermally stratified at any station. Water temperature at LA-01 and LA-02 was about 11 °C throughout. LA -03 was cooler, with a temperature between 9 and 10 °C.

   In summary, the lake warms up over the summer as it absorbs solar radiation and the heat energy gets distributed through the water column primarily by wind mixing. The wind is not strong enough to mix deeper than about 10 meters, as marked by the thermocline. Below the thermocline, the hypolimnion is stable and cool. LA-03 is only 7-9 meters deep, so water can be fully mixed by wind action. By late summer most of the lake volume is 15 °C or warmer and only the deeper parts of the eastern basin have water temperatures cooler than 12 °C.

Temperature in the North Fork of the Feather River at Station LA-04 follows a similar seasonal pattern to the lake, although it is generally cooler than the lake temperature. The highest temperature was in September. (See Figure 5, as well as Table 1 in the Appendix.)

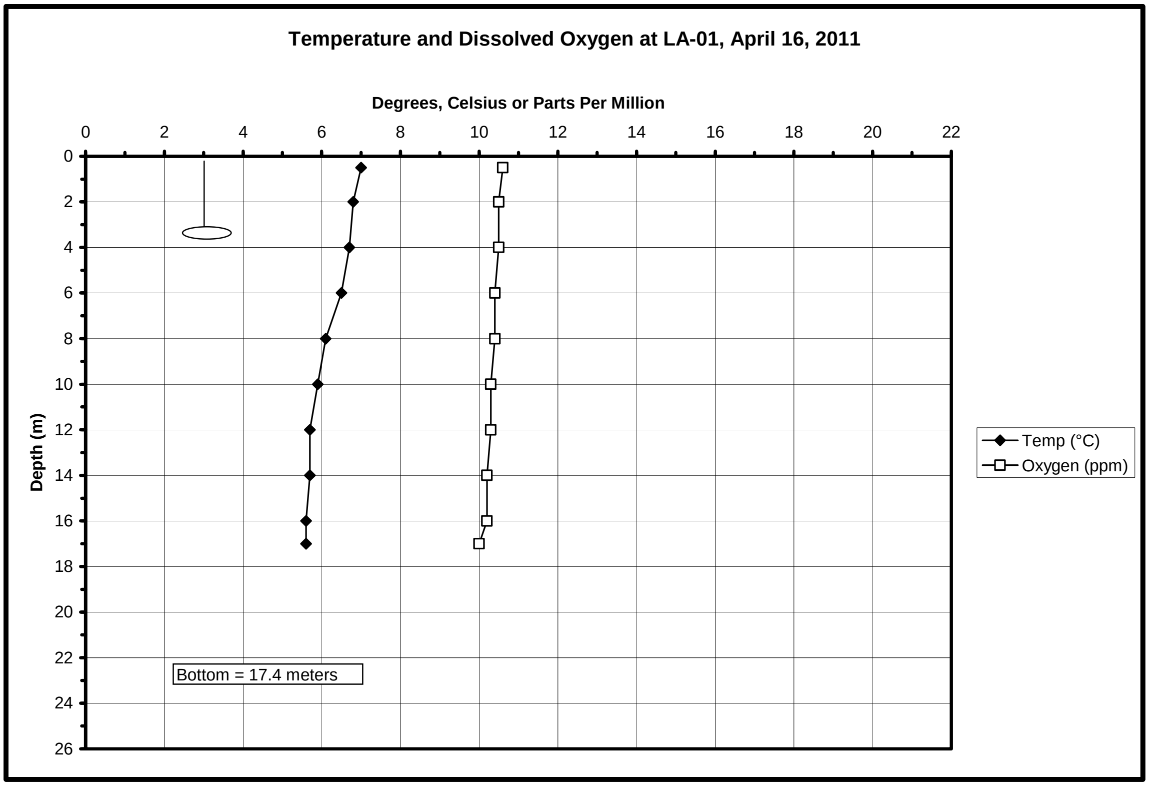
b. Oxygen

The oxygen data are shown in graphic form (Figures 2, 3, 4 and 5) along with the temperature for each station for each date, as well as in Table 1 in the Appendix. The amount of oxygen that can be dissolved in freshwater is primarily a function of temperature and atmospheric pressure. Temperature is very important, since the higher the temperature the less oxygen can be dissolved. The higher the elevation, the lower the atmospheric pressure, and the lower the pressure, the less oxygen can be dissolved. Biological processes can affect the oxygen concentration. Photosynthesis produces oxygen and respiration, including decomposition, consumes oxygen. If one of these processes exceeds the other, the oxygen concentration is affected. The amount of mixing with the atmosphere (usually due to wind action in a lake) can affect oxygen concentration. All of these factors must be considered when trying to interpret the change in oxygen concentration from the surface of a lake to the bottom or the change from season to season.

In April 2011 the oxygen concentration at all three lake stations was about 10.5 parts per million (ppm) throughout the water column. This was approximately the maximum that could be dissolved at that water temperature (7-8 ºC) and the existing atmospheric pressure.

In July 2011 oxygen concentration in the epilimnion at LA-01 and LA-02 was about 7.5 ppm, even though the water temperature was over 20 ºC. Oxygen was being maintained at a high level due to wind mixing and also photosynthesis. Due to the shallow conditions at LA-03, oxygen was between 7-8 ppm throughout. In the region of the thermocline at LA-01 and LA-02, oxygen levels increased as the temperature decreased. (Colder water can hold more dissolved oxygen.) In the hypolimnion at LA-01 and LA-02, oxygen levels dropped even though temperature continued to decrease. Once the lake was stratified, the deeper portion of the lake was isolated from the atmosphere and the effects of wind mixing.

Figure 2. Temperature and Dissolved Oxygen at Lake Almanor, Station LA-01, During 2011



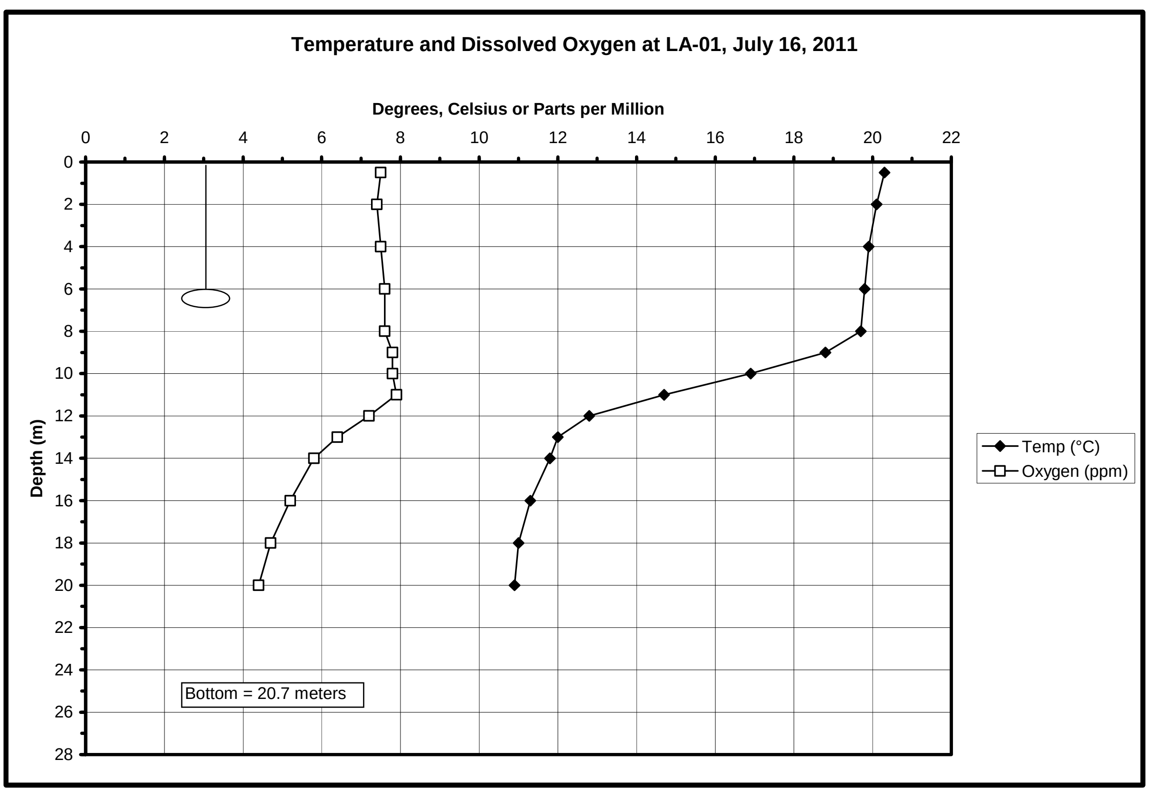
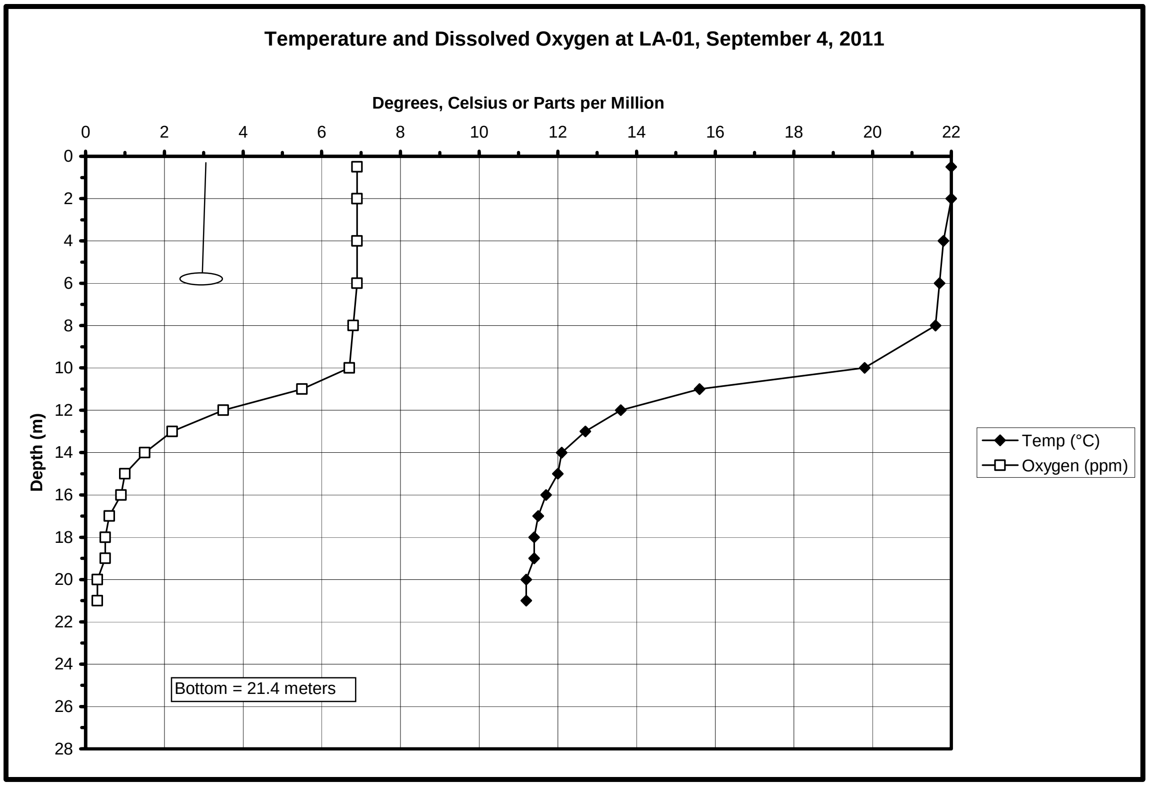


Figure 2 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-01, During 2011



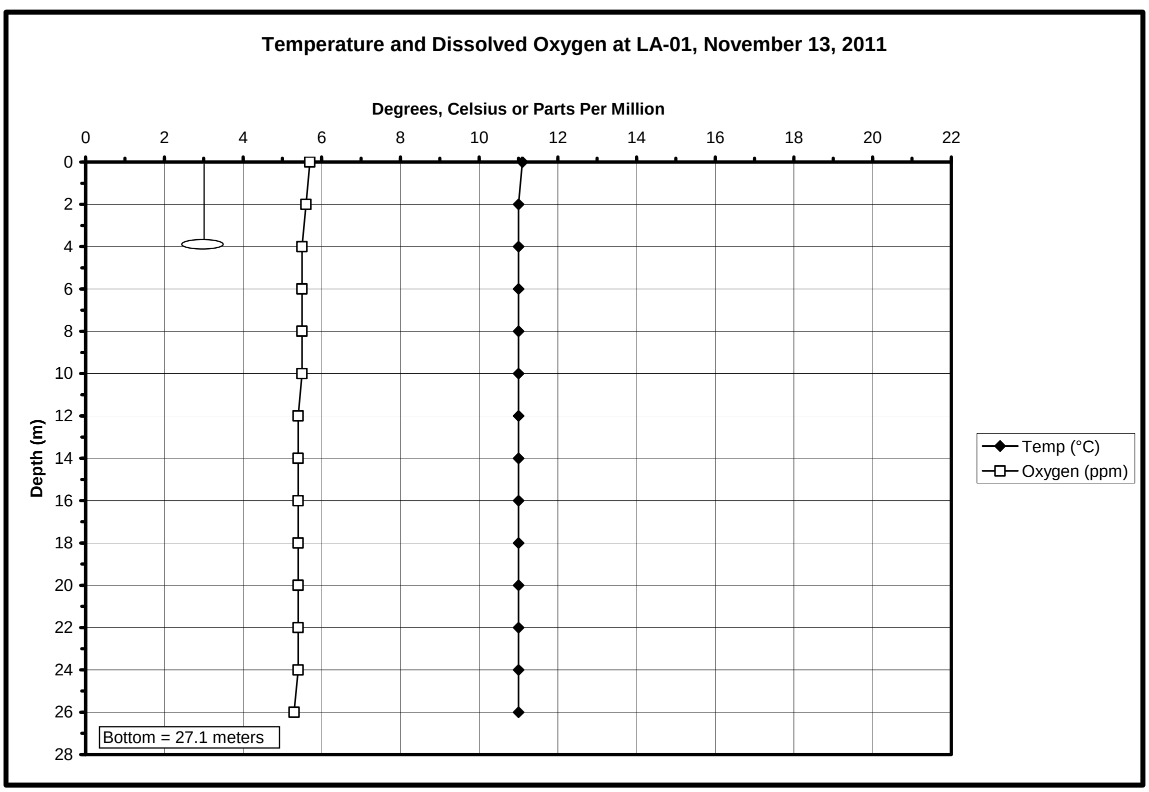
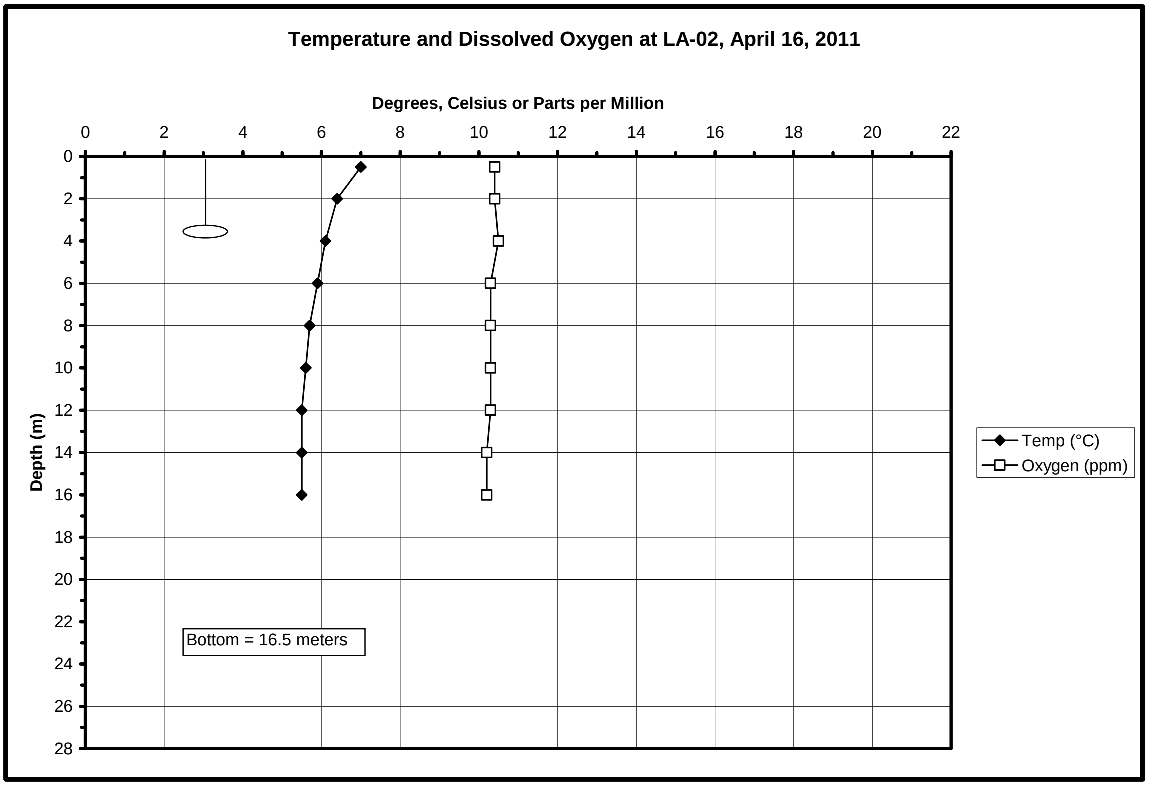


Figure 3. Temperature and Dissolved Oxygen at Lake Almanor, Station LA-02, During 2011



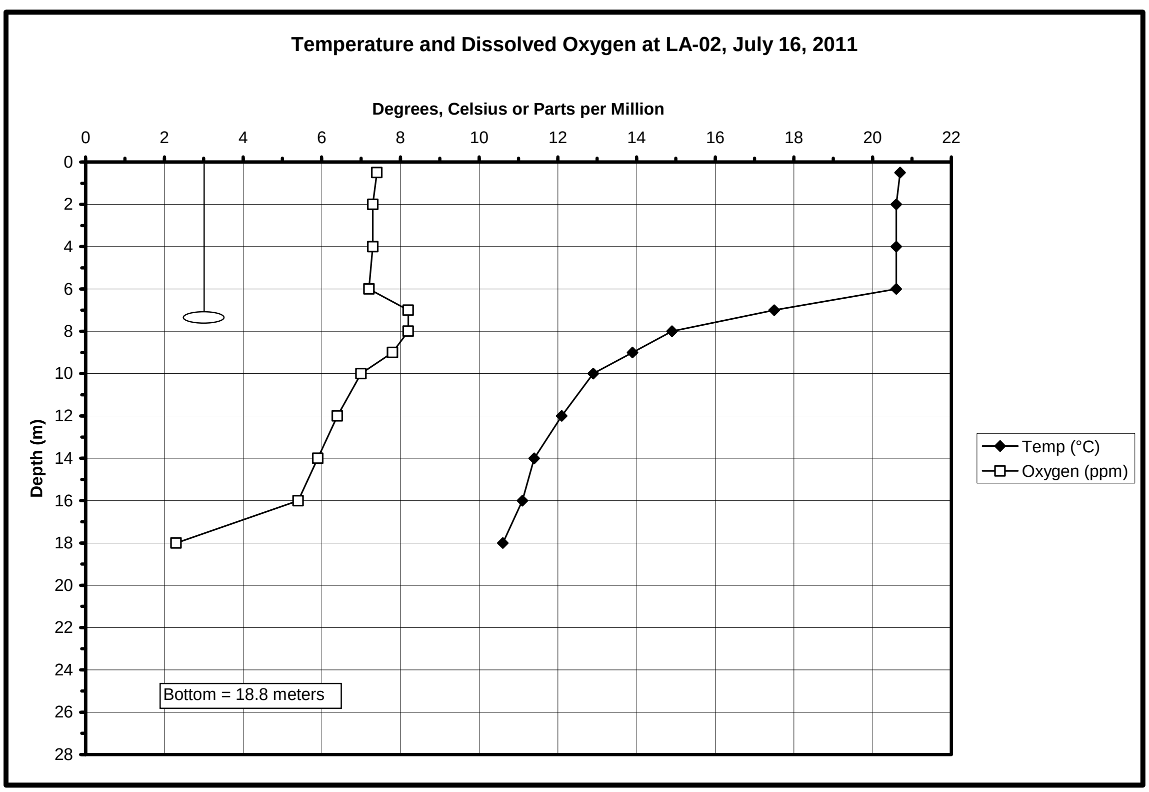
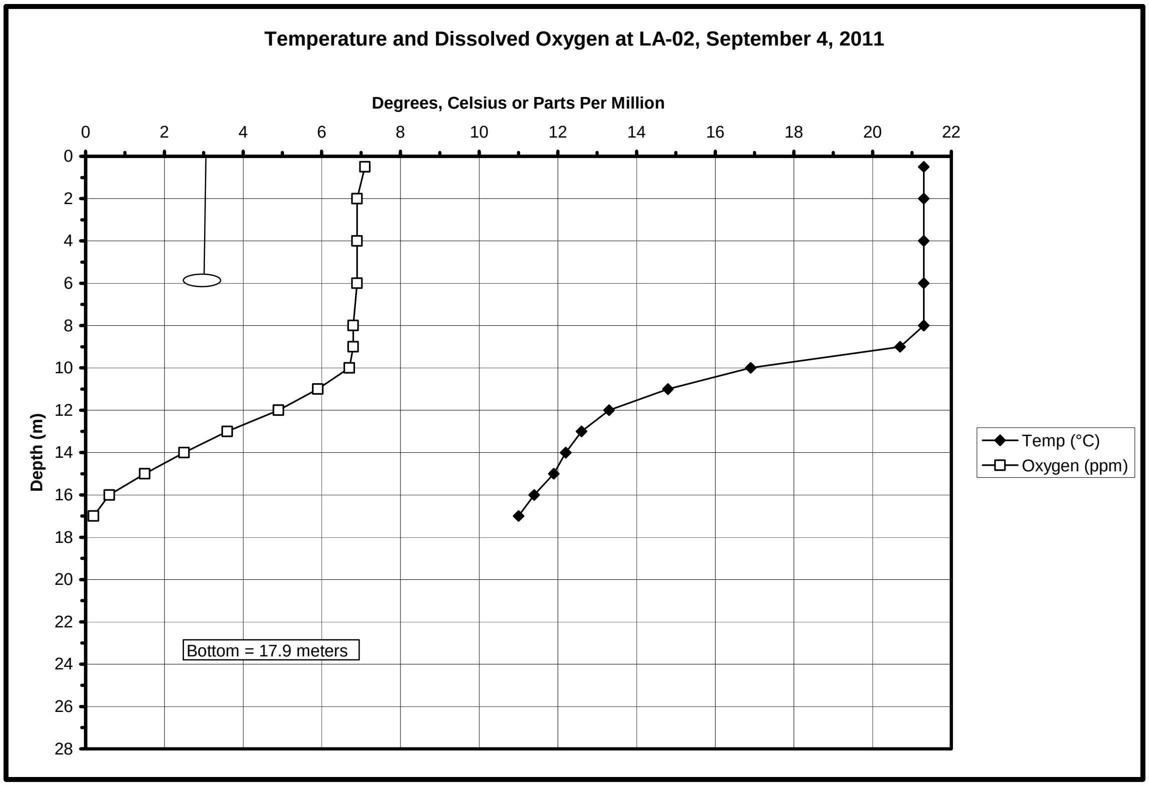


Figure 3 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-02, During 2011



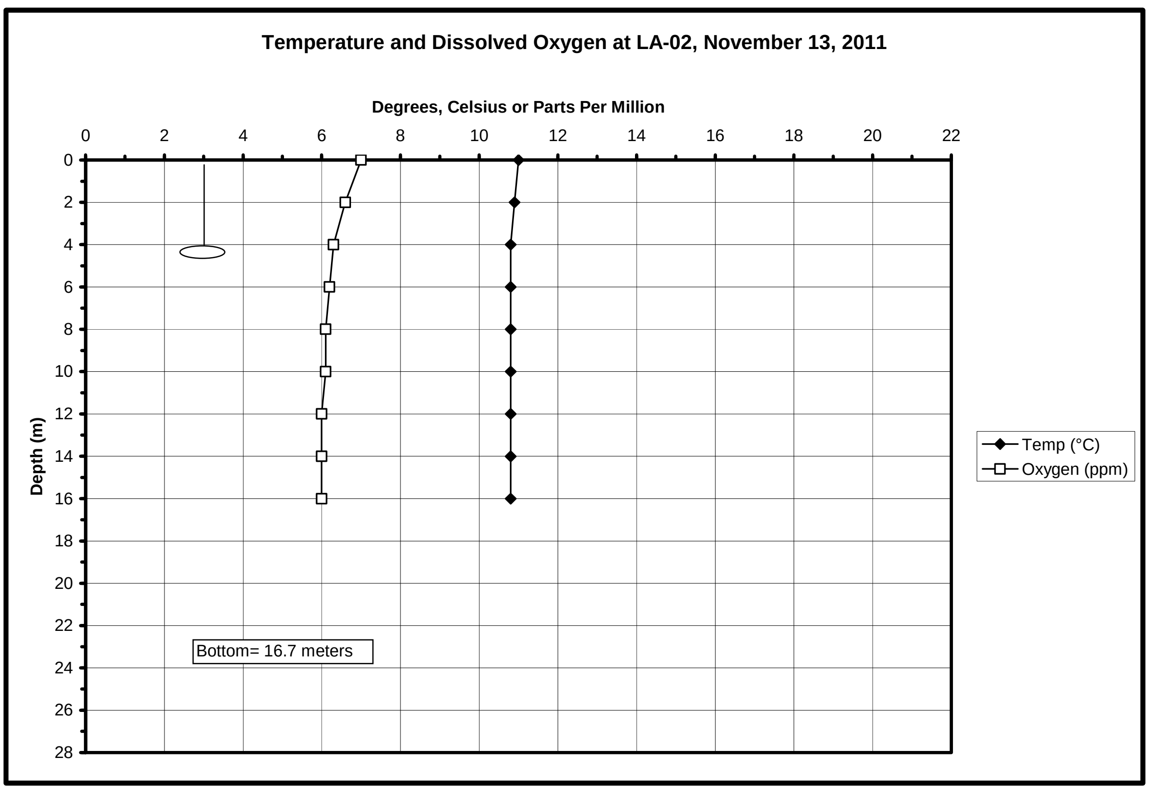
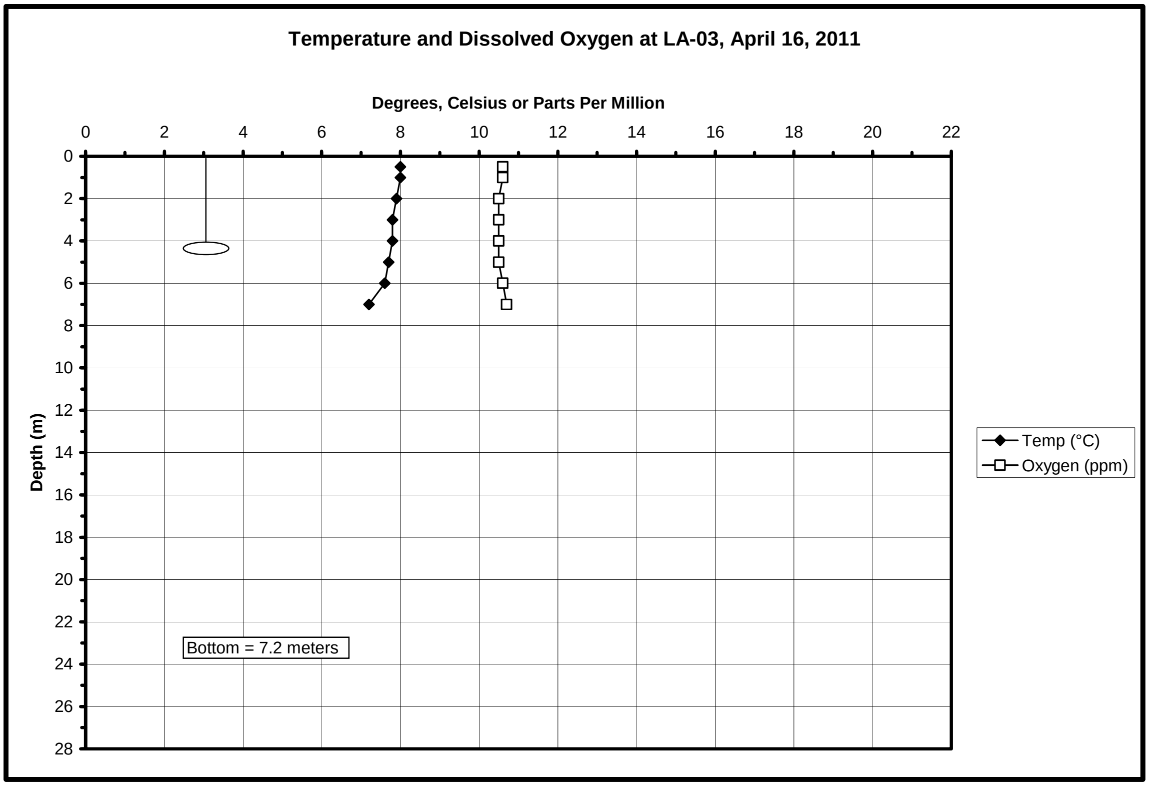


Figure 4. Temperature and Dissolved Oxygen at Lake Almanor, Station LA-03, During 2011



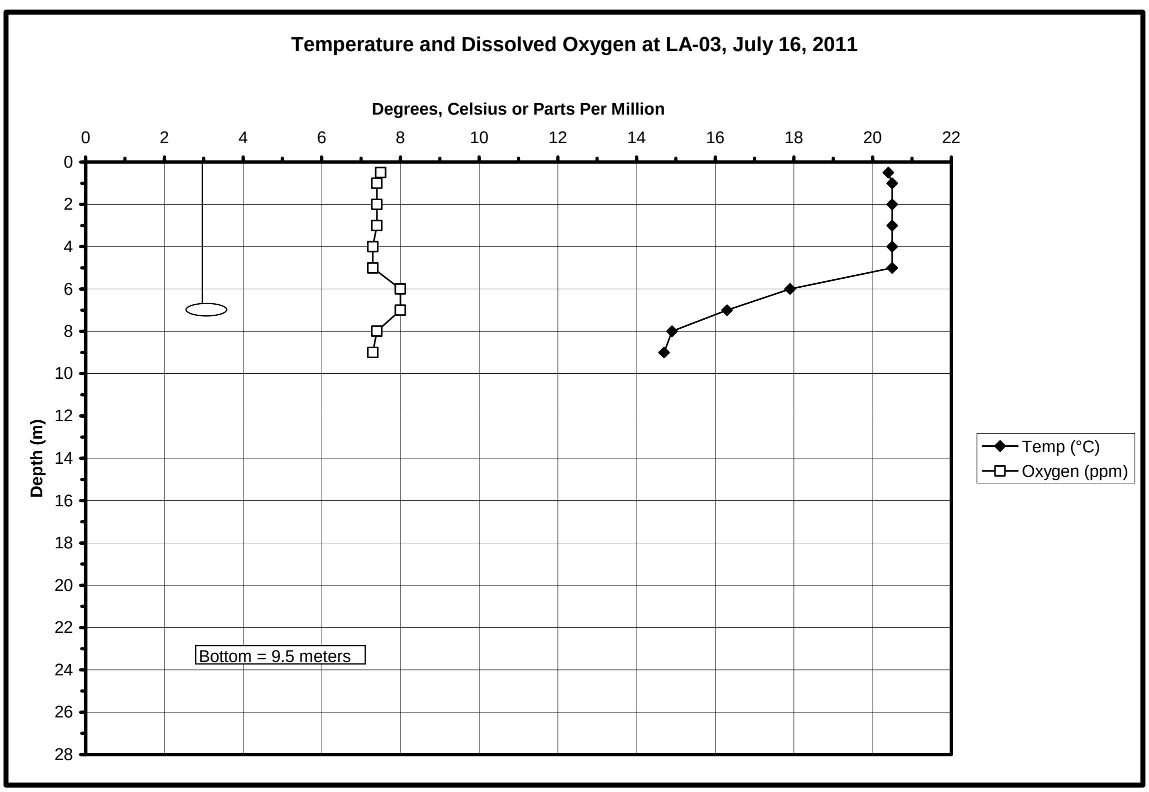
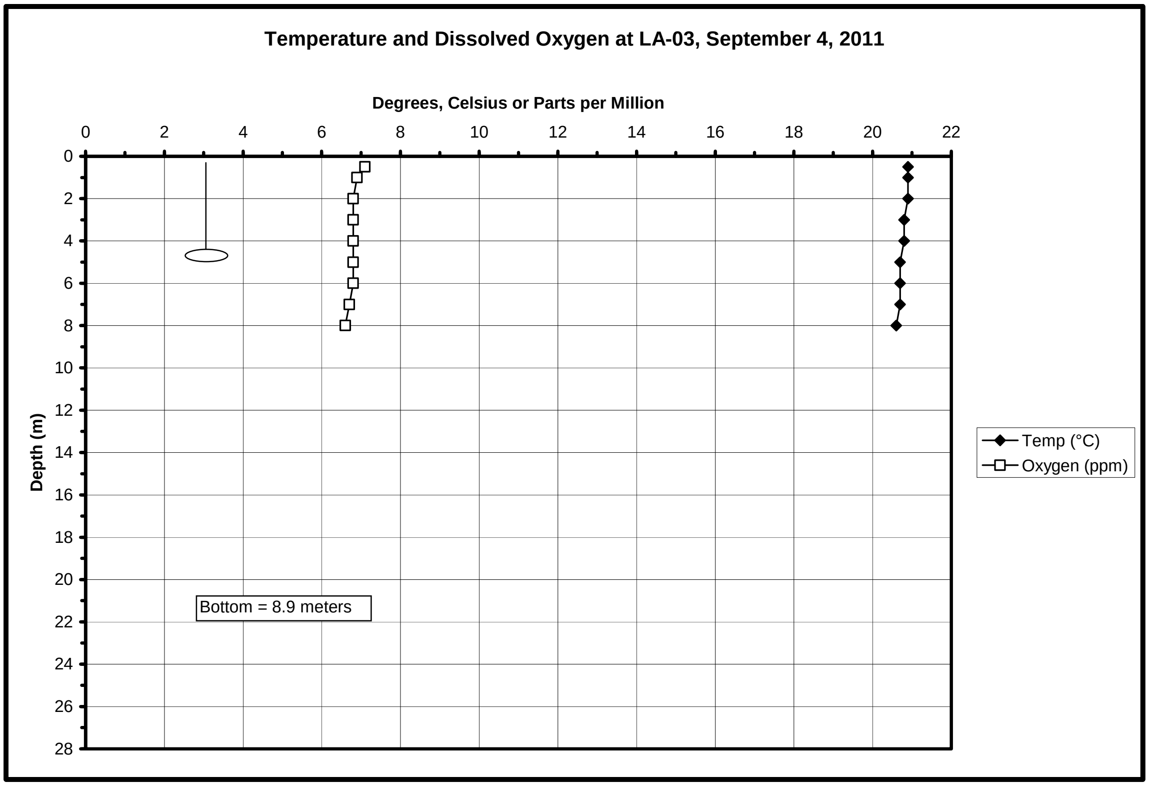
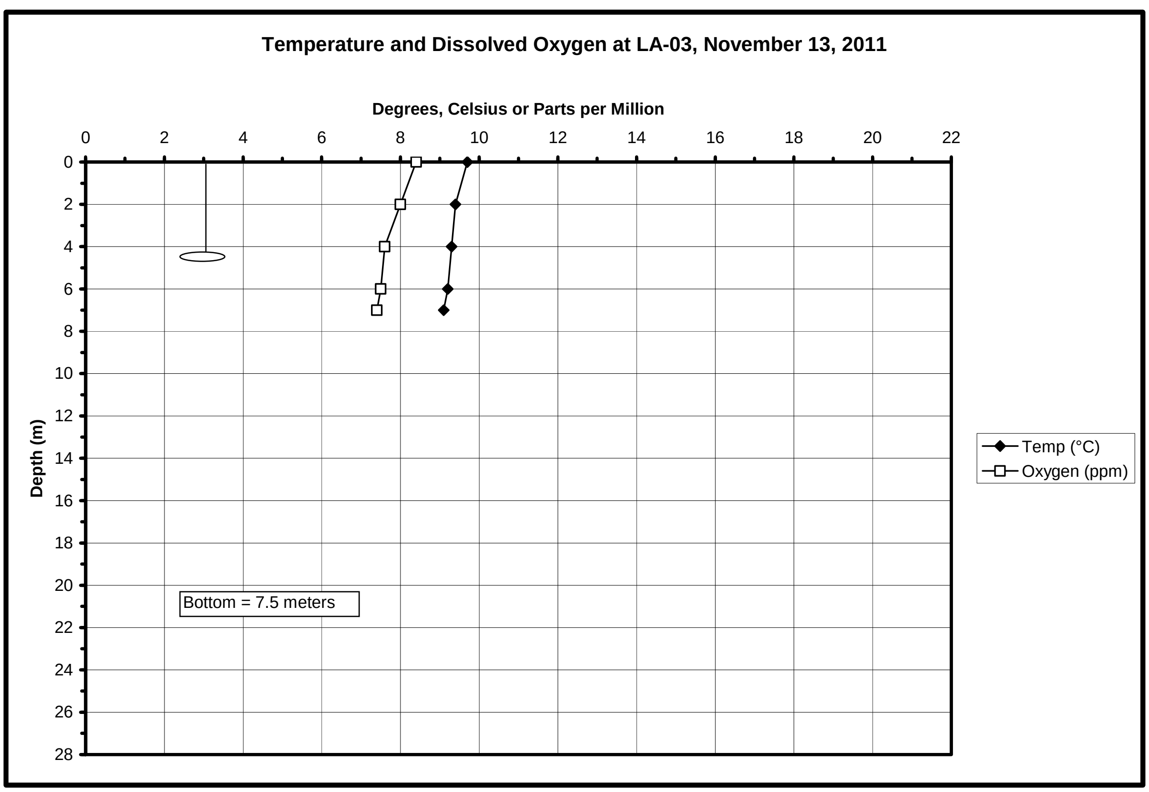


Figure 4 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-03, During 2011





Decomposition consumed oxygen at a faster rate than photosynthesis could produce it, so levels dropped. In the deepest part of the hypolimnion at LA-01, oxygen was at 4-5 ppm and at LA-02 oxygen was at 2-5 ppm.

By September 2011, oxygen was still near 7 ppm in the epilimnion of LA-01 and LA-02, and throughout the water column at LA-03. In the region of the thermocline at LA-01 and LA-02, oxygen levels dropped off very abruptly to less than 5 ppm. The hypolimnion at LA-01 was essentially devoid of oxygen.

As the lake cooled in the autumn, the thermal stratification broke up. By November, all stations were again well-mixed and oxygen levels were between 5 and 7 ppm throughout.

An examination of the DWR data base (1989-2004) for Lake Almanor showed that the annual pattern for temperature and oxygen has been about the same since their records began. Low levels of oxygen in the hypolimnion are the “norm”. Data for the lake prior to 1989 is patchy, so it is difficult to determine when oxygen depletion in the hypolimnion began.

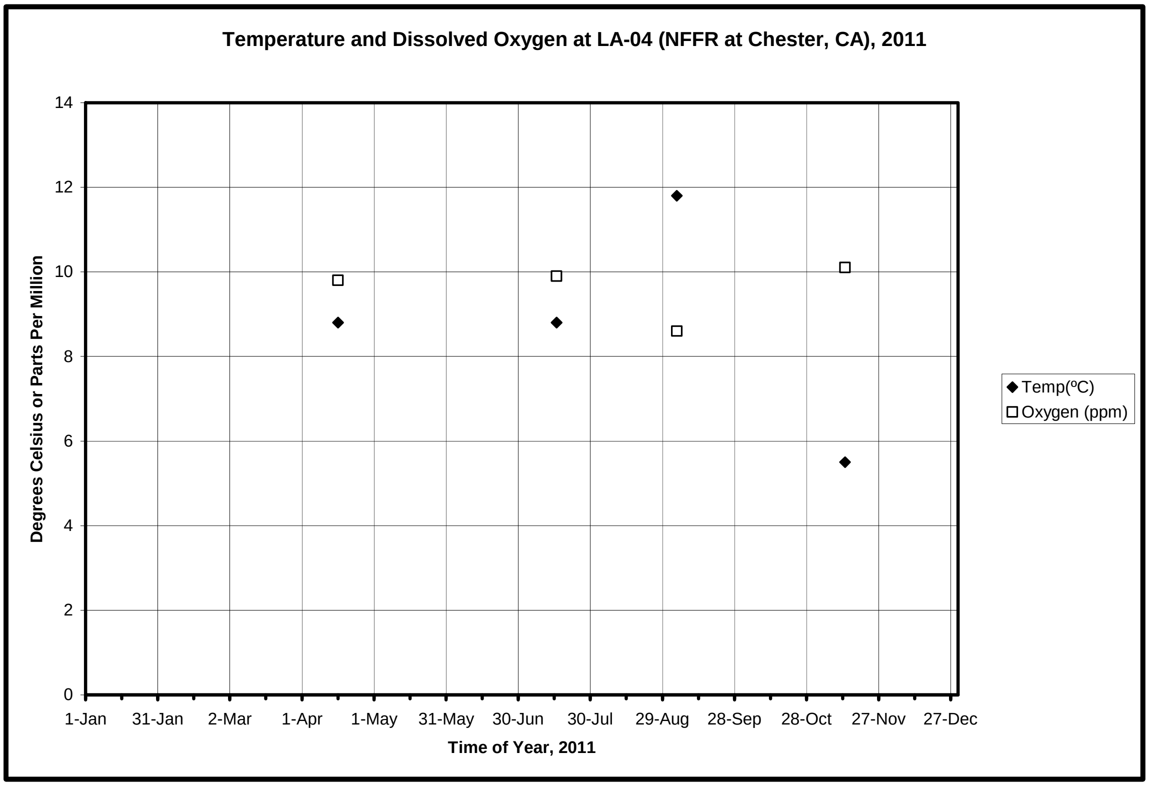
As discussed in earlier reports, the low levels of oxygen stress the cold-water fish species in the lake, since the regions where both temperature and oxygen preferences are met become scarce.

Oxygen levels in the Feather River are always higher than in the lake, primarily because of the colder water temperature and the turbulence of the water (See Figure 5).

c. Electrical Conductivity

Electrical conductivity is a measure of the dissolved salts in water. The data for this report is presented in Table 1 in the Appendix. Values ranged from 54-58 micro-Siemens/cm at all lake stations and from 31-46 micro-Siemens/cm in the Feather River. There was little difference between lake stations, although LA-03 tended to be lower, due to the influence of the river. The range of data is similar to that in the DWR data base for 1989-2004. The values are lower than in 2011 due to the greater precipitation received throughout the spring of 2011.

Figure 5. Temperature and Dissolved Oxygen at LA-04 (NFFR at Chester, CA) 2011



d. Secchi Depth

Secchi depth is an indication of suspended particles in the water column. Data for Secchi depth is presented on all graphs by a line and disk on the left-hand side, as well as in Table 1 in the Appendix. For LA-01 and LA-02, Secchi depth was about 3 meters and at LA-03 it was 4 meters in April. It increased to 6-7 meters at all stations in July. In September it was still 5.5 -6 meters at LA-01 and LA-02, but only 4 meters at LA-03. It then decreased in November to about 4 meters at all stations. Variation is probably related to sediment carried by inflowing streams, as well as phytoplankton. Values were in agreement with those in the DWR data base and with the 2009 and 2010 studies.

2. Chemical Parameters: Nutrients

These tests were performed to get an estimate of the amount of nitrogen and phosphorus available to phytoplankton at the time of lake turnover. Total nitrogen, nitrite plus nitrate and total phosphorus were analyzed in April and November 2011 at LA-02 and LA-03. Data are presented in Table 2 below.

Table 2. Nutrient Concentrations at LA-02 and LA-03 in 2011

Date	Station	Total Kjeldahl Nitrogen	Nitrite plus Nitrate	Total Nitrogen	Total Phosphorus
16 April	LA-02 surface	0.2	ND	ND	ND
16 April	LA-02 bottom	0.2	ND	ND	0.02
16 April	LA-03 surface	0.2	ND	ND	ND
16 April	LA-03 bottom	0.2	ND	ND	ND
13 November	LA-02 surface	0.2	ND	0.2	ND
13 November	LA-02 bottom	0.2	ND	0.2	ND
13 November	LA-03 surface	0.2	ND	0.2	ND
13 November	LA-03 bottom	0.2	ND	0.2	ND

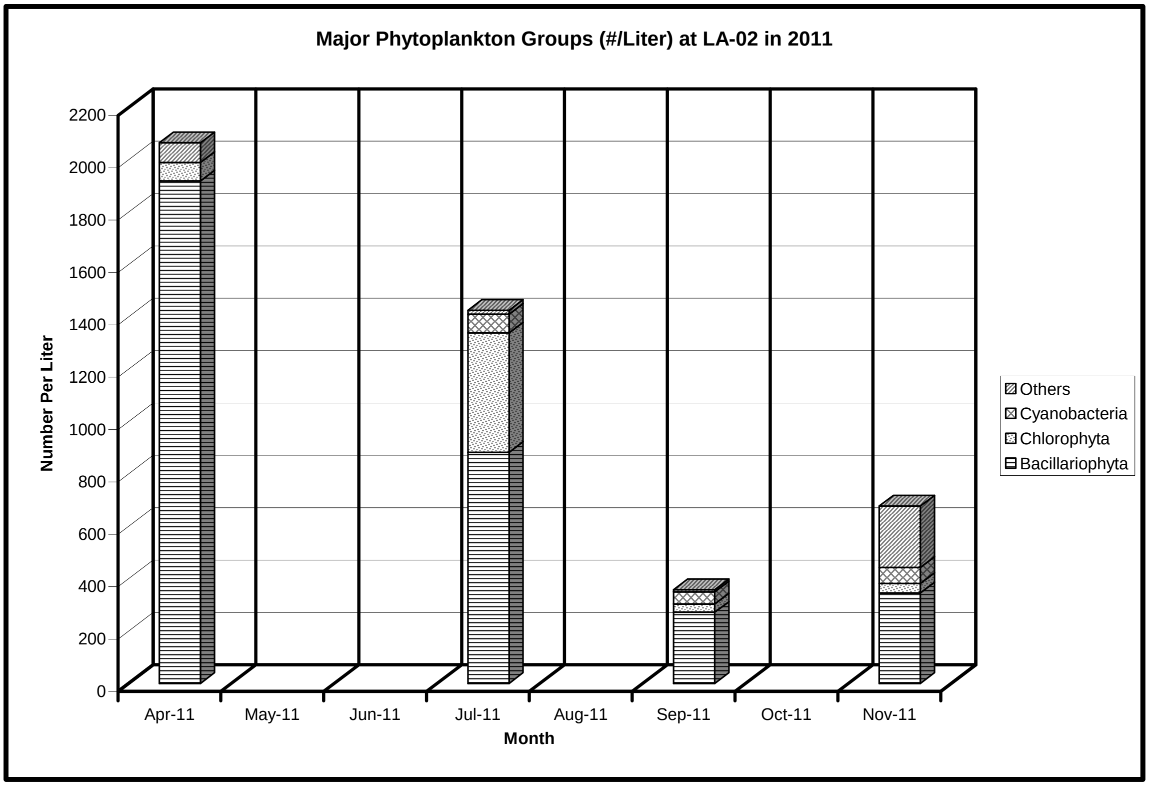
(Note: ND= Not Detected at the detection limit for the test)

Nitrite plus nitrate and total phosphorus were below detection limits for all samples except LA-02 bottom in April. Total Kjeldahl and total nitrogen were close to the minimum detection limit. The concentrations may have been low because there were already large populations of phytoplankton present in the lake in April and November. If these tests are repeated, samples should be collected in September, before turnover. That might indicate if nutrients are being released from sediments.

3. Phytoplankton and Zooplankton

Phytoplankton samples were collected at LA-02 and LA-03 on all four sampling dates. Data for the major groups of phytoplankton are presented in graphic form in Figures 6 and 7. More detailed data are in the Appendix. The data are presented in two different graphs for each station. The first graph shows the number of algal cells or colonies per liter of lake water. The second graph shows the volume of algal cells per milliliter of lake water (cubic microns per milliliter). This way of showing the data is important where the number of colonies is low but the size of each colony is large. It is a more accurate way of expressing the total amount of algae present.

Figure 6. Major Phytoplankton Groups at Lake Almanor, By Number/Liter and By Volume (cubic microns/milliliter), Station LA-02 in 2011



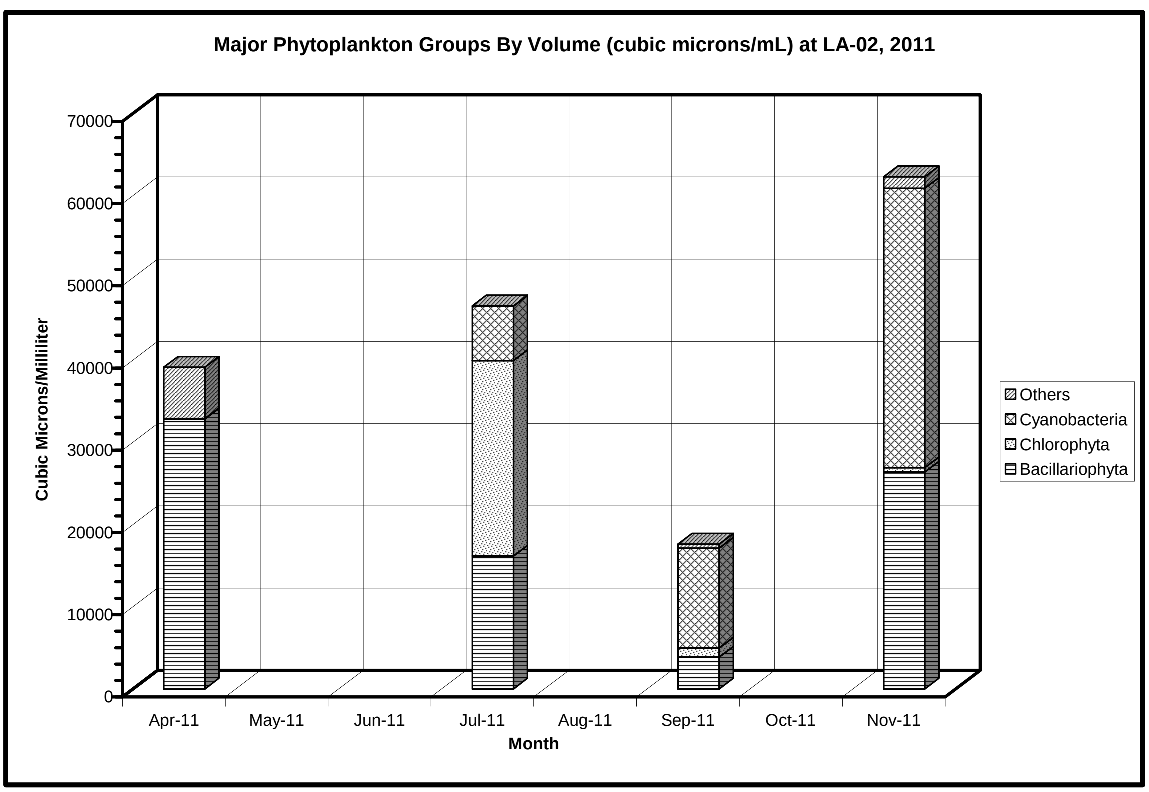
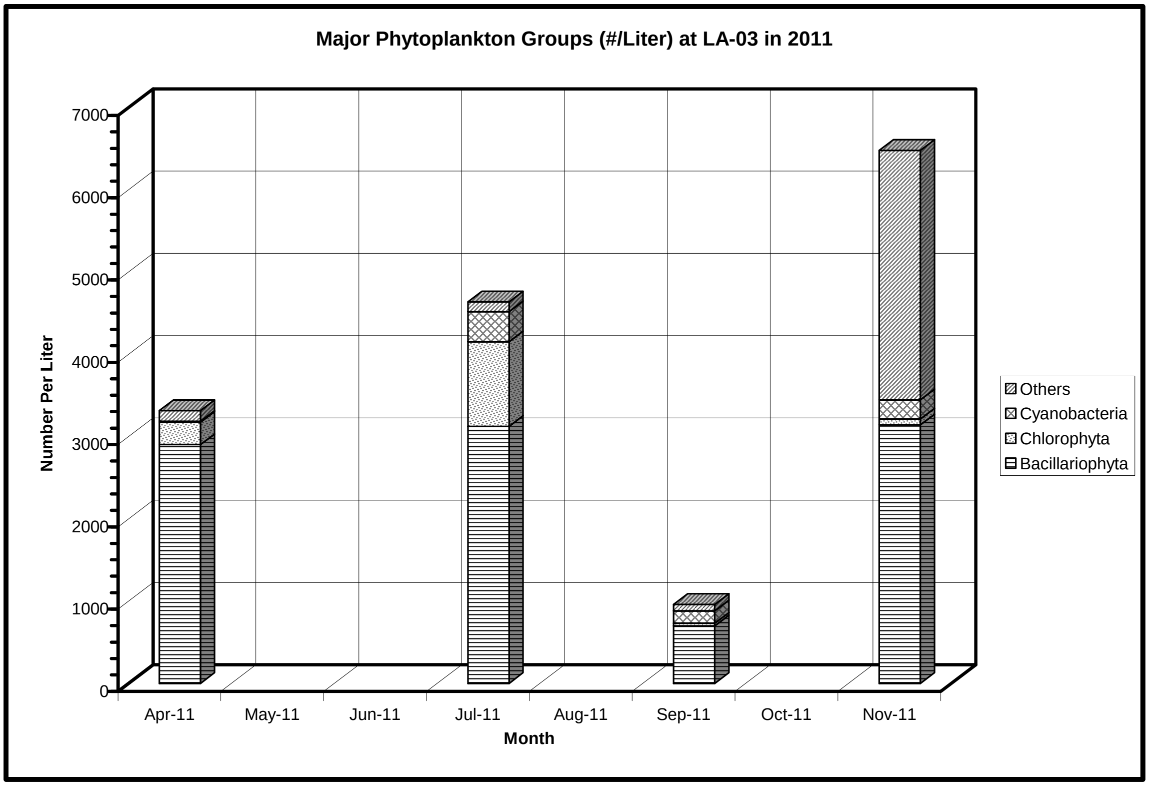
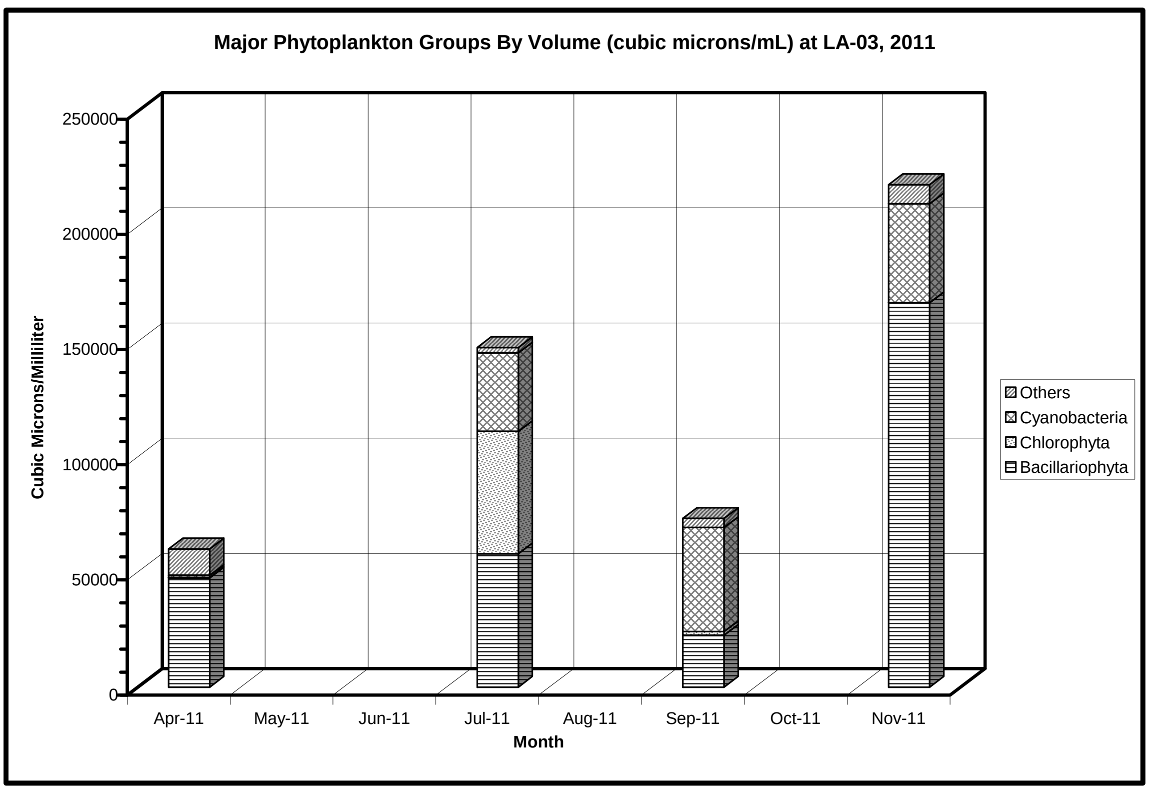


Figure 7. Major Phytoplankton Groups at Lake Almanor, By Number/Liter and By Volume (cubic microns/milliliter), Station LA-03 in 2011





In April diatoms (Bacillariophyta) were the dominant form at both LA-02 and LA-03, particularly *Fragilaria, Asterionella* and *Stephanodiscus.* By July some bluegreen algae appeared, primarily *Anabaena*. Colonial green algae (Chlorophyta) were also abundant, primarily *Eudorina*. In September and November these genera were joined by more bluegreens, *Lyngbya* and *Microcystis*. At LA-03 a yellow-brown algae, *Dinobryon*, was very abundant. It constituted most of the "Others" category on the graphs.

Although the species present were similar to those in previous years, the total amount of phytoplankton was considerably less than in 2010. At LA-02 the greatest volume was in November but the amount in 2011 was less than half of the greatest amount in 2010. At LA -03 the greatest volume was also in November, but was less than one third of the greatest amount in 2010. Bluegreen algae continued to be numerous in the late summer and fall, but the lower amounts of algae overall was probably due to the higher precipitation and cooler air temperatures during Spring 2011. This delayed the warming of the lake and also produced higher lake levels.

There are no recent data from DWR concerning the phytoplankton, but some tables from the 1970's show that some of the same species were present then. The assemblage of genera is characteristic of meso-trophic lakes.

Zooplankton were collected along with the phytoplankton and results are presented in Figures 8 and 9. More detailed data are in the Appendix.
The most abundant group at both stations were the Rotifera, with few Copepoda and Cladocera present. Most likely, their small size limits predation by small fish, whereas Copepoda and Cladocera are readily eaten. The most common genera were *Keratella* and *Polyarthra* at both stations. The cooler spring weather and lower phytoplankton populations resulted in much lower zooplankton populations. Their abundance was generally half of the 2010 values.

Conclusion

Lake Almanor is a fairly rich reservoir capable of supporting a diverse assemblage of plants and animals. Large populations of phytoplankton can develop during lake overturn in the spring and fall. Nutrients that collect in the hypolimnion during the period of thermal stratification in the summer are distributed throughout the water column during periods of overturn or mixing. When there is an abundance of precipitation and cool weather in the spring, this can slow population growth and favor green algae or diatoms over bluegreen algae.

A more extensive study of the nutrient budget of the lake might reveal major sources of nutrients. Loss of oxygen in the hypolimnion does result in release of

Figure 8. Major Zooplankton Groups (#/Liter) at Lake Almanor, Station LA- 02, 2011

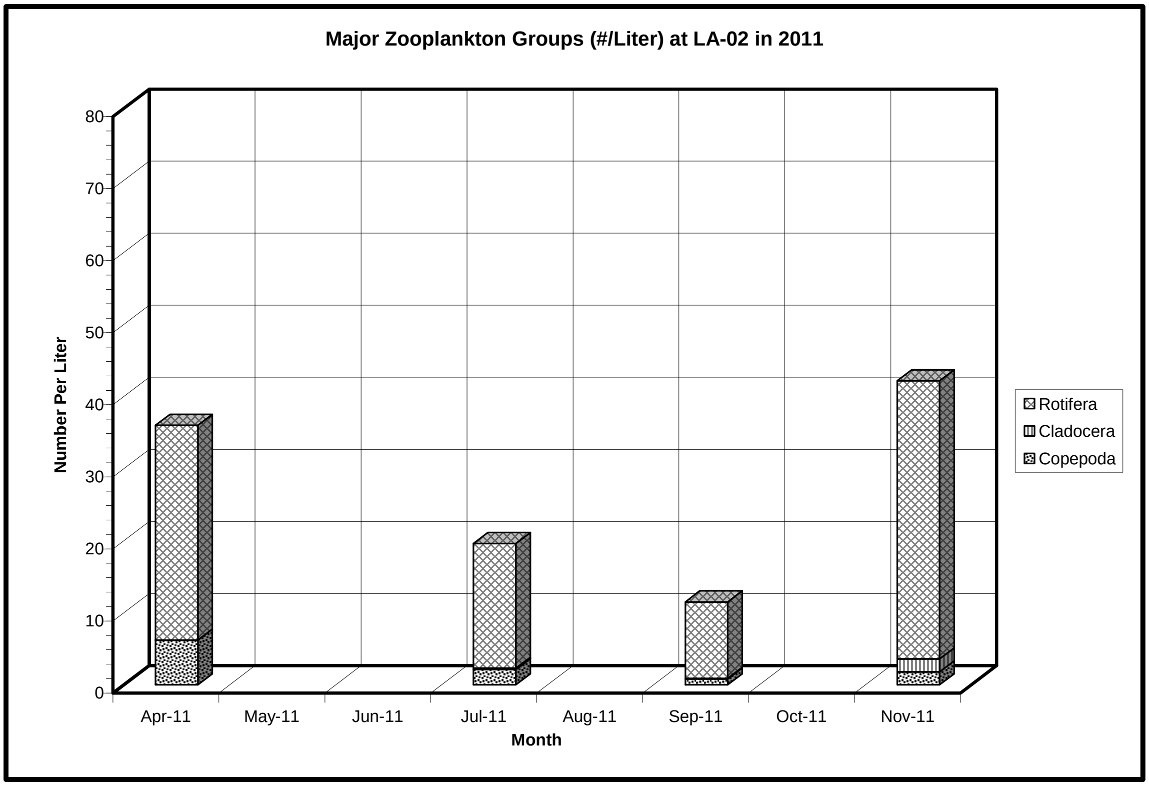
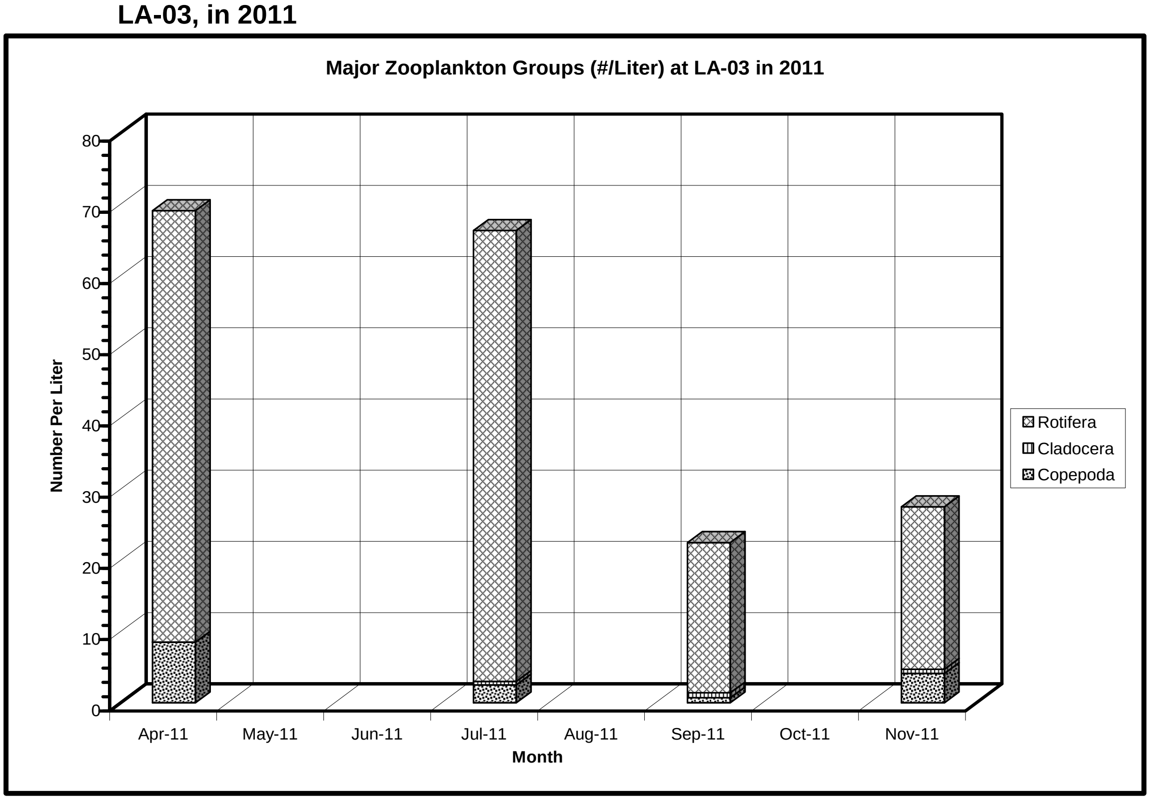


Figure 9. Major Zooplankton Groups (#/Liter) at Lake Almanor, Station LA-03, in 2011



nutrients from lake sediments, but other sources could be septic tanks, golf courses or lawn fertilizer.

This year the nuisance species of algae were present in low numbers due to the cool, wetter weather. We can expect that dry years will be accompanied by larger populations.

General Discussion of Lake Conditions and the Importance of Monitoring

Lakes and reservoirs are often pristine right after they are created. However, when rivers, groundwater and human activities bring nutrients (phosphorus, nitrogen and other chemicals needed for plant and animal growth), sediments and other substances into them, they begin to change. The rate at which these substances enter can affect how quickly the system changes. Over time the lake or reservoir begins to accumulate sediment and nutrient concentration increases. Eventually, the nutrients are sufficient to support a large population of phytoplankton or other plants. If the growing conditions are suitable, certain nuisance species of phytoplankton (blue-greens) or rooted aquatic plants may become numerous to the point that they interfere with the use of the water for recreation or drinking. As more plant material is produced, only a portion of it is consumed by fish and other animals. This “extra” organic material settles out of the water and accumulates near the bottom. Bacteria will decompose the material and use up the dissolved oxygen in the deeper portion of the lake or reservoir. The loss of dissolved oxygen can become so severe that some fish species, such as trout, can’t survive. Tolerant species, such as catfish or carp, may become more abundant. The system continues to change physically and biologically until it becomes dominated by algae and aquatic plants, with a limited number of fish species that can tolerate these conditions.

Lake Almanor is a reservoir that is already undergoing many changes. Because of the lake’s high elevation, the cooler water temperature and the short growing season limit some plant growth. However, the western basin is shallow and the water is warm in the summer. Phytoplankton and larger aquatic plants can become very numerous at this time of year. There are enough nutrients coming in from the river, streams or from human activities (septic tanks, golf courses, lawns) to support abundant plant growth. As more homes are built in the watershed, the nutrient input will increase.

In the eastern basin, the water is deep enough to become thermally stratified in the summer. The warm, well-oxygenated water at the surface does not mix with the colder water deep in the lake. Over the summer, the deep water’s oxygen supply gets depleted by bacterial decomposition and oxygen levels drop to zero. This is a stressful time for those fish species that need both cold water and sufficient oxygen, such as trout. The warm, nutrient-rich water near the surface may support large populations of phytoplankton, especially blue-green species. As these algae become more numerous, they will detract from the lake’s appearance and may limit recreational use. Even though climatic variations from year to year may temporarily affect population size, nuisance species of algae will most likely increase in abundance as more development occurs in the watershed.

Data collected by California DWR and others show that oxygen depletion in some parts of the lake has been occurring at least since the 1970's. Since only a few locations have long-term data, we don't know if a change in the percentage of affected lake area has occurred. The data on algal composition and abundance has been more sporadic. There have been some bluegreen algae at least since the 1970's, but we don't know if the number of species and total amount have increased. A long-term data base of reservoir conditions is vital to any land or water use management decisions. Historical data and the current monitoring program data suggest that the water quality is deteriorating, since the oxygen depletion in the summer seems to be wide spread and the amount of bluegreen algae may be increasing. The lake is undergoing changes that will affect its esthetic appearance and our ability to use it for recreation. We need to continue a monitoring program that will provide the data to inform our land and water use decisions.

Suggestions for Future Monitoring

For the last three years we have collected physical and biological data and some nutrient data. While there have been variations due to weather, especially precipitation, the pattern of the physical data has been similar from year to year: mixing from fall to spring and thermal stratification at the deep stations (LA-01 and LA-02) during the summer. The biological data have been less predictable. In November 2009, algal populations were over one million cubic microns/milliliter of lake water at LA-03 (mostly green algae). In November 2010, the population was nearly 900,000 (mostly bluegreen algae). In November 2011, the population was about 240,000 (mostly diatoms). The biological component seems to respond very quickly to annual differences in temperature, precipitation and runoff.

Future monitoring of Lake Almanor must continue to include the collection of physical data as long as the construction of a thermal curtain remains a possible lake modification. It is important to document how limited the pool of cool water is in the lake during the summer months and to show that oxygen levels are low during this time. If funding permits, a fourth station, possibly near the Prattville intake (LA-07) should be added. This would give a more complete picture of both lobes of the lake.

It is also important to monitor the phytoplankton/zooplankton so that we know whether bluegreen algae are increasing and whether there are changes to the foodchain base in the lake. The diversity of the phytoplankton and zooplankton indicate the biological health of the lake and its ability to support other life forms. At least two stations (LA-02 and LA-03) should be included.

If more funds become available, nutrients should be monitored at inflowing streams and springs. This would allow us to determine if there are identifiable point sources of nutrients. Additional sampling along the reservoir perimeter would be needed to determine if there are nonpoint sources. Possibly, chloride monitoring should be included as an indicator of septic tank inputs. The timing of such monitoring would be dependent on the annual precipitation pattern. Because of the expense involved for sample collection and analysis, this may have to be postponed until the monitoring budget is larger.

The monitoring program of the last three years should be viewed as the minimum for understanding lake conditions. It should be continued as long as funds are available.

References

1. California Department of Water Resources data base for Lake Almanor, obtained from Almanor Basin Watershed Advisory Committee records.
2. Lake Almanor Watershed Water Quality Report. April 2006. CH2MHILL, Redding, CA
3. Raleigh, Robert F., Terry Hickman, R. Charles Solomon and Patrick C. Nelson. 1984. Habitat Suitability Information: Rainbow Trout. U.S Fish and Wildlife Service, U.S. Department of the Interior. http/www.nwrc.usgs.gov/wdb/pub/hsi/hsi-060.pdf
4. Lake Almanor Water Quality Report, 2009 and 2010. K.R. Gina Johnston and John McMurtry.

Lake Almanor Water Quality Report, 2012

Prepared for

Plumas County Flood Control & Water Conservation District and
Almanor Basin Watershed Advisory Committee

By

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Butte Environmental Technologies

Submitted January 2013

Table of Contents

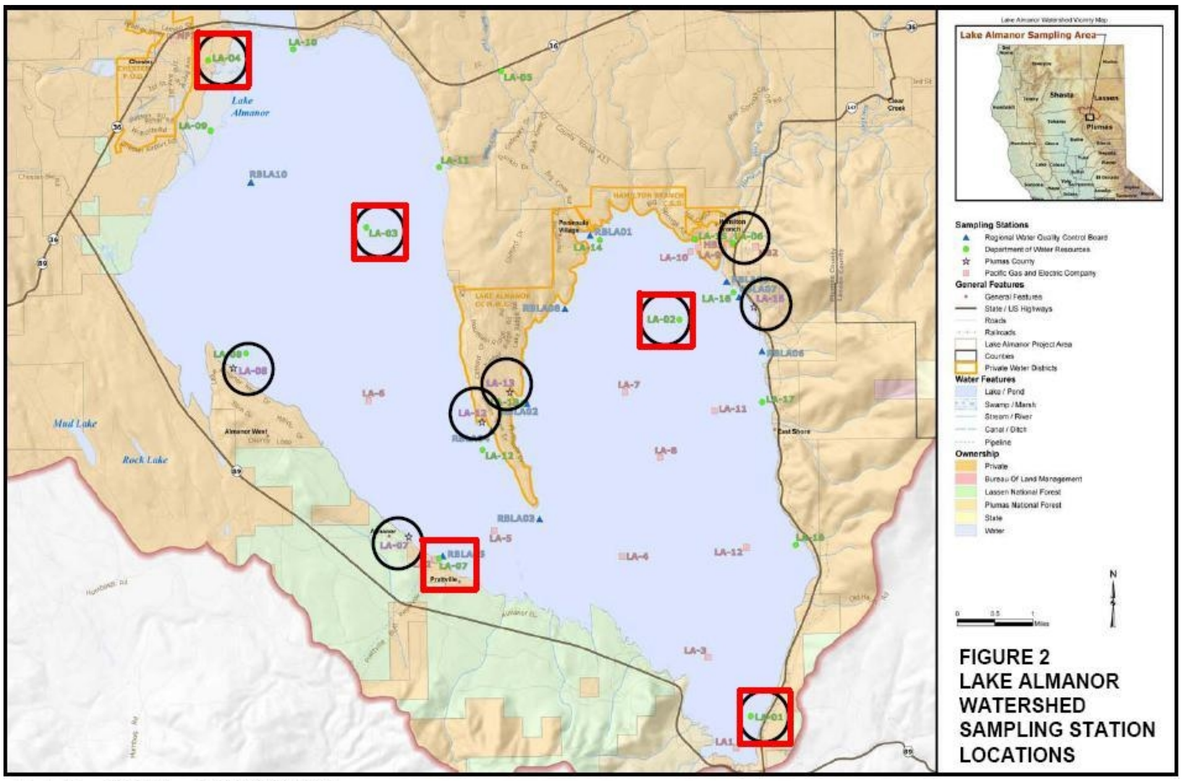
Introduction and Project Overview

A water quality monitoring program for Lake Almanor was conducted during 2012, following the same protocol used in the 2009, 2010 and 2011 studies. The Plumas County Flood Control and Water Conservation District and the Almanor Basin Watershed Advisory Committee (ABWAC) provided oversight for the contract. Due to the limited funds available for this project, ABWAC selected some of the important parameters that had been monitored in the past by California Department of Water Resources (DWR), the County of Plumas and Pacific Gas & Electric Company. Four sampling windows were chosen to provide a look at lake health: during spring turnover (April 15-22), the period of heavy recreational use (July 7-14 and September 4-10) and fall turnover (November 11-17). Four stations in the lake were selected: LA-01, near the Canyon Dam Intake Tower; LA-02, in the east lobe; LA-03, near the middle of the west lobe; and LA-07, near the Prattville Intake. A station in Chester (LA-04) was selected for monitoring the North Fork of the Feather River just prior to discharge into the lake. Station locations are shown in Figure 1. In addition to the regular sampling, PG&E covered the cost of analysis of water samples for inorganic silver. The parameters and sampling times are listed in Table 1.

Table 1. Lake Almanor Parameters Monitored in 2012

Parameter	Specific Parameters	Locations	Sampling Window
Physical	Temperature Dissolved oxygen Electrical Conductivity Secchi depth	LA-01, LA-02, LA-03 and LA-07 every two meters, just once at LA-04 (no Secchi)	April 15-22 July 7-14 Sept 4-10 Nov 11-17
Plankton	Zooplankton Phytoplankton	LA-02 LA-03 (vertical tow)	April 15-22 July 7-14 Sept 4-10 Nov 11-17
Nutrients	Total phosphorus Total nitrogen	LA-02, LA-03 (0.5 meter below surface and 1 meter off bottom)	Apr 15-22 Nov 11-17
Silver	Inorganic silver ion	LA-01, LA-02, LA-03 and LA-04; Bailey Creek, Hamilton Branch	April 15-22

Figure 1. Sampling Station Locations in Lake Almanor used in 2012 study. (Adapted from Lake Almanor Watershed Water Quality Report, CH2M HILL, April 2006). Note: LA-01, LA-02, LA-03, LA-04 and LA-07 (highlighted in red) were used in the 2012 investigation.



Adapted from: CH2M HILL and EARTHWORKS, 2006

Methods Used for Sampling and Analysis

1. Procedures for Field Measurements: Temperature, Dissolved Oxygen, Electical Conductivity, and Secchi Depth

   Temperature, dissolved oxygen and electrical conductivity were measured with a Hydrolab Surveyor 4 water quality meter equipped with these probes. All probes were calibrated in the lab prior to each field measurement day. The probes were lowered into the water column and readings were taken at 0.5 meter below the surface and at every two meters to within one meter of the lake bottom. During periods of thermal stratification, readings were taken every meter through the metalimnion to more accurately measure changes in temperature and dissolved oxygen with depth.

   Secchi disk transparency was measured using a standard Secchi disk which was lowered on the shady side of the boat. The disappearance and reappearance depths were recorded and averaged.

2. Procedures for Chemical Measurements: Nutrients

   Water samples for chemical analysis were collected with a Van Dorn style 2.2 liter sampler at two depths (0.5 meter below lake surface and 1.0 meter above lake bottom). They were poured into appropriate bottles provided by Basic Laboratory. All samples were stored in a Styrofoam ice chest and packed in ice to maintain a temperature of 4° C and dark conditions. They were transported to the Basic Lab branch office in Chico, CA within 24 hours of collection. They were immediately fixed with preservative to stabilize them until analysis.

   Basic Laboratory in Redding, CA, performed the nutrient (Total Kjeldahl nitrogen, nitrite plus nitrate, total nitrogen and total phosphorus) analyses. It is certified by the California Department of Public Health to conduct these analyses.

3. Procedures for Plankton Collection and Analyses

   Phytoplankton were collected with a Wisconsin type conical net (80 micron mesh) that was pulled from the bottom to the surface to produce an integrated sample. They were preserved with Lugol's solution, as well as 40% formalin solution.

   Phytoplankton were counted and were identified to division (Chlorophyta, Chrysophyta, etc.) and to genus when this would allow for comparison with previous data and when the genus would be indicative of water quality.

Zooplankton were collected with a net towed from the bottom to the lake surface to produce an integrated sample and preserved with 40% formalin solution.

Zooplankton were enumerated and identified to order (Cladocera, Copepoda, etc.) and to suborder or genus when this would allow for comparison with previous data or where the identity had water quality significance. (Again, certain genera are indicators of lake health and it would be important to know their abundance.)

4. Procedures for Silver Analyses

Water samples were collected at surface and near bottom at LA-01, LA-02 and LA-03, at the North Fork Feather River (LA-04), at the mouth of Bailey Creek and at the mouth of Hamilton Branch on April 22, 2012, using the methodology and materials for low-level metal sampling. The samples were packed in ice and shipped to Brooks Rand Labs in Seattle, WA, which specializes in the analysis of low-level metals.

Results and Discussion

1. Physical Parameters

a. Temperature

The temperature data are shown in graphic form for each station (See figures 2, 3, 4, 5 and 6 as well as Table 1 in Appendix). The Secchi depth is also shown on each graph as a line and disk on the left side. In April 2012 all four lake stations (LA-01, LA-02, LA-03 and LA-07) were well-mixed with little temperature difference between surface and bottom. At LA-01 and LA-02 temperature at the surface was about 13-15 °C, but dropped quickly in the first two meters and at the bottom it was around 6 °C. LA-07 was similar to LA-01 and LA-02. LA-03 was slightly cooler with surface at 12 °C and the bottom at 7 °C.

By July 2012 stations LA-01, LA-02 and LA-07 were thermally stratified. The epilimnion was about 20-22 °C. The thermocline (or metalimnion) was between 8 and 14 meters. At LA-03 the temperature difference from top to bottom was less than 3 degrees, so it was not stratified.

In September surface temperatures at LA-01 and LA-02 were between 21 and 22 °C and LA-07 was at 20 °C. At all three stations the thermocline was a little deeper than in July (10-14 meters) and the temperature in the hypolimnion was 10-12 °C. LA-03 was well mixed, with temperature between 19 and 20 °C.

By November 2012 the lake was no longer thermally stratified at any station. Water temperature at LA-01, LA-02 and LA-07 was 10-11 °C throughout. LA -03 was cooler, with a temperature around 9 °C.

In summary, the lake warms up over the summer as it absorbs solar radiation and the heat energy gets distributed through the water column primarily by wind mixing. The wind is not strong enough to mix deeper than about 10 meters, as marked by the thermocline. Below the thermocline, the hypolimnion is stable and cool. LA-03 is only 7-9 meters deep, so water can be fully mixed by wind action. By late summer most of the lake volume is 15 °C or warmer and only the deeper parts of the eastern basin have water temperatures cooler than 12 °C.

Temperature in the North Fork of the Feather River at Station LA-04 follows a similar seasonal pattern to the lake, although it is generally cooler than the lake temperature. The highest temperature was in September. (See Figure 6, as well as Table 1 in the Appendix.)

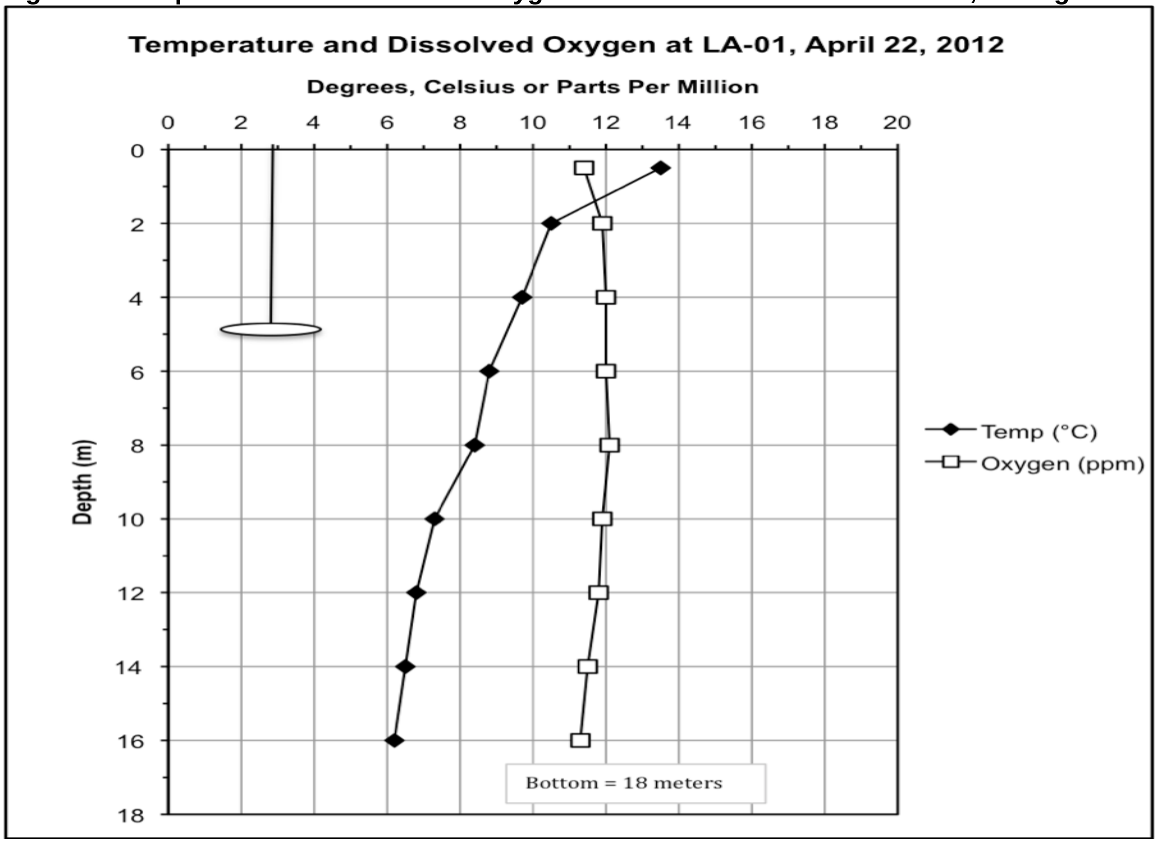
b. Oxygen

The oxygen data are shown in graphic form (Figures 2, 3, 4, 5 and 6) along with the temperature for each station for each date, as well as in Table 1 in the Appendix. The amount of oxygen that can be dissolved in freshwater is primarily a function of temperature and atmospheric pressure. Temperature is very important, since the higher the temperature the less oxygen can be dissolved. The higher the elevation, the lower the atmospheric pressure, and the lower the pressure, the less oxygen can be dissolved. Biological processes also affect the oxygen concentration. Photosynthesis produces oxygen and respiration, including decomposition, consumes oxygen. If one of these processes exceeds the other, the oxygen concentration is affected. The amount of mixing with the atmosphere (usually due to wind action in a lake) can affect oxygen concentration. All of these factors must be considered when trying to interpret the change in oxygen concentration from the surface of a lake to the bottom or the change from season to season.

In April 2012 the oxygen concentration at all four lake stations was between 11-13 parts per million (ppm) throughout the water column. This was approximately the maximum that could be dissolved at that water temperature (6-9 ºC) and the existing atmospheric pressure.

In July 2012 oxygen concentration in the epilimnion at all stations was 8-9 ppm, even though the water temperature was over 20 ºC. Oxygen was being maintained at a high level due to wind mixing and also photosynthesis. Due to the shallow conditions at LA-03, oxygen was between 8-9 ppm throughout. In the region of the thermocline at LA-01, LA-02 and LA-07, oxygen levels increased as the temperature decreased. (Colder water can hold more dissolved oxygen.) In the hypolimnion at these three stations, oxygen levels dropped even though temperature continued to decrease. Once the lake was stratified, the deeper portion of the lake was isolated from the atmosphere and the effects of wind mixing.

Figure 2. Temperature and Dissolved Oxygen at Lake Almanor Station LA-01, During 2012



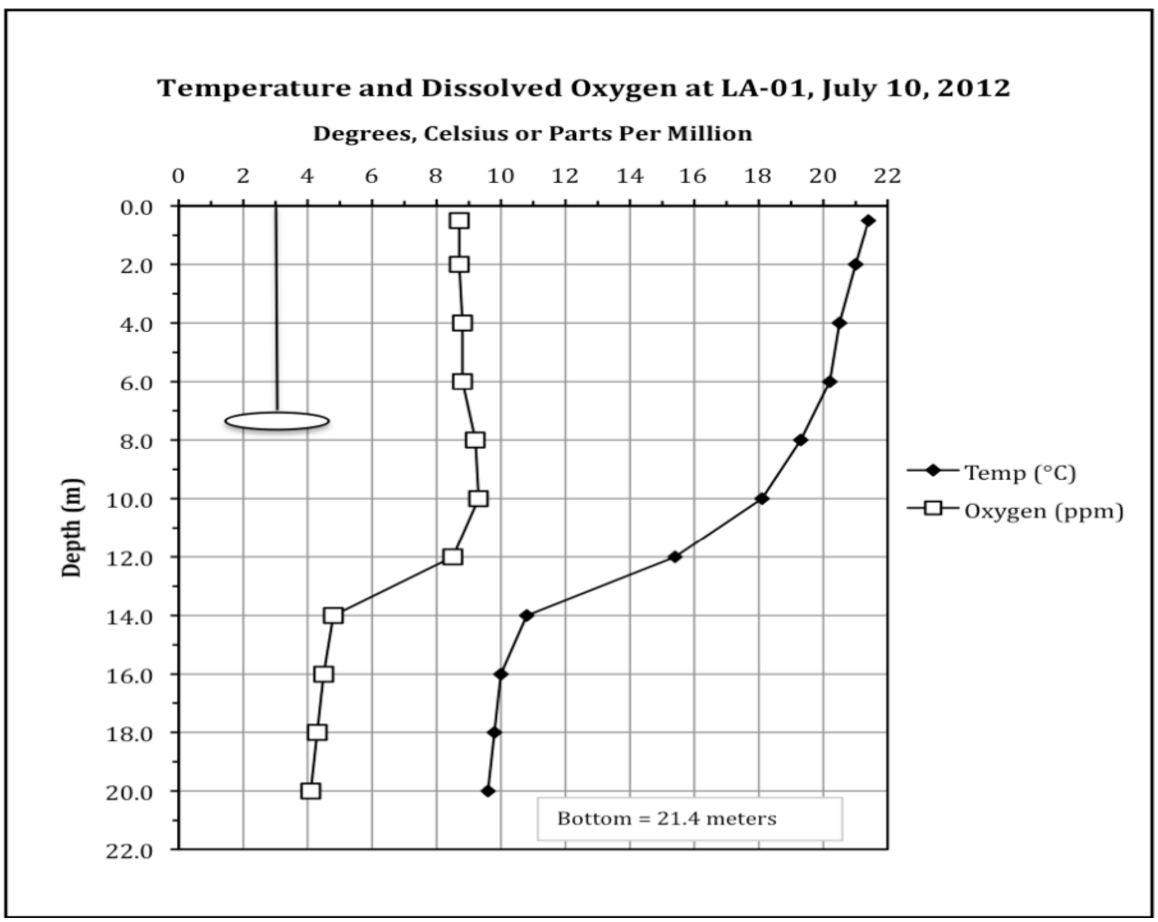
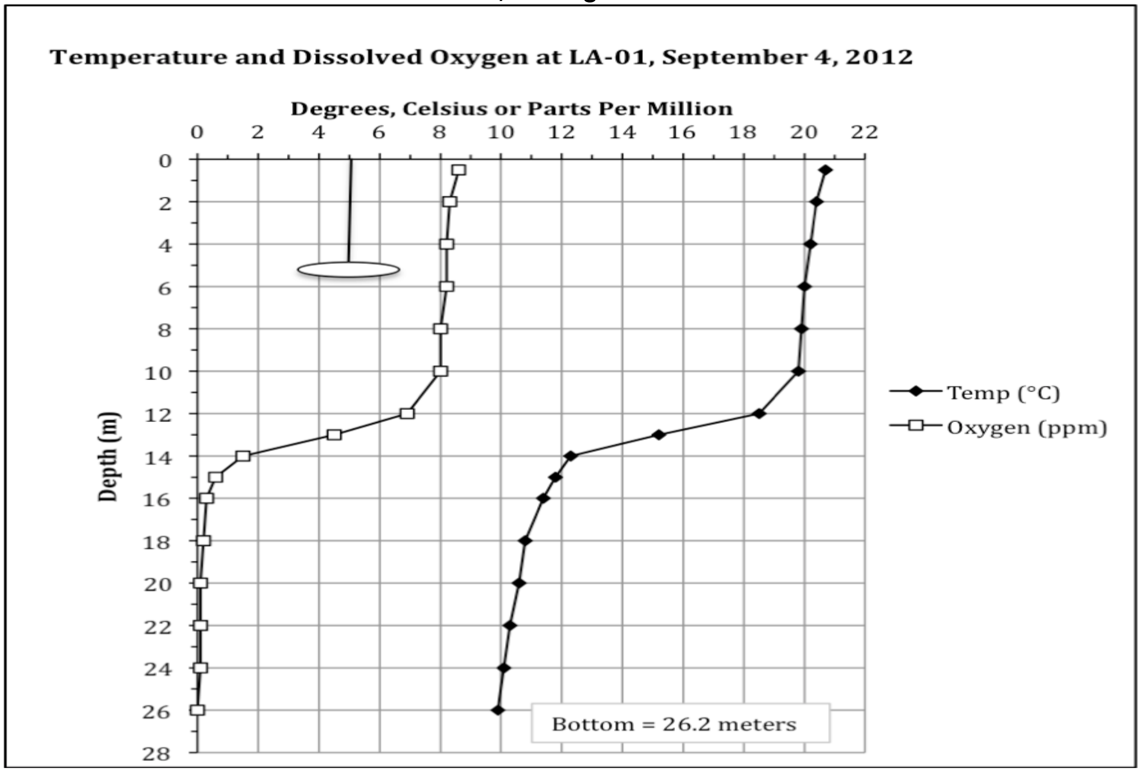


Figure 2 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-01, During 2012



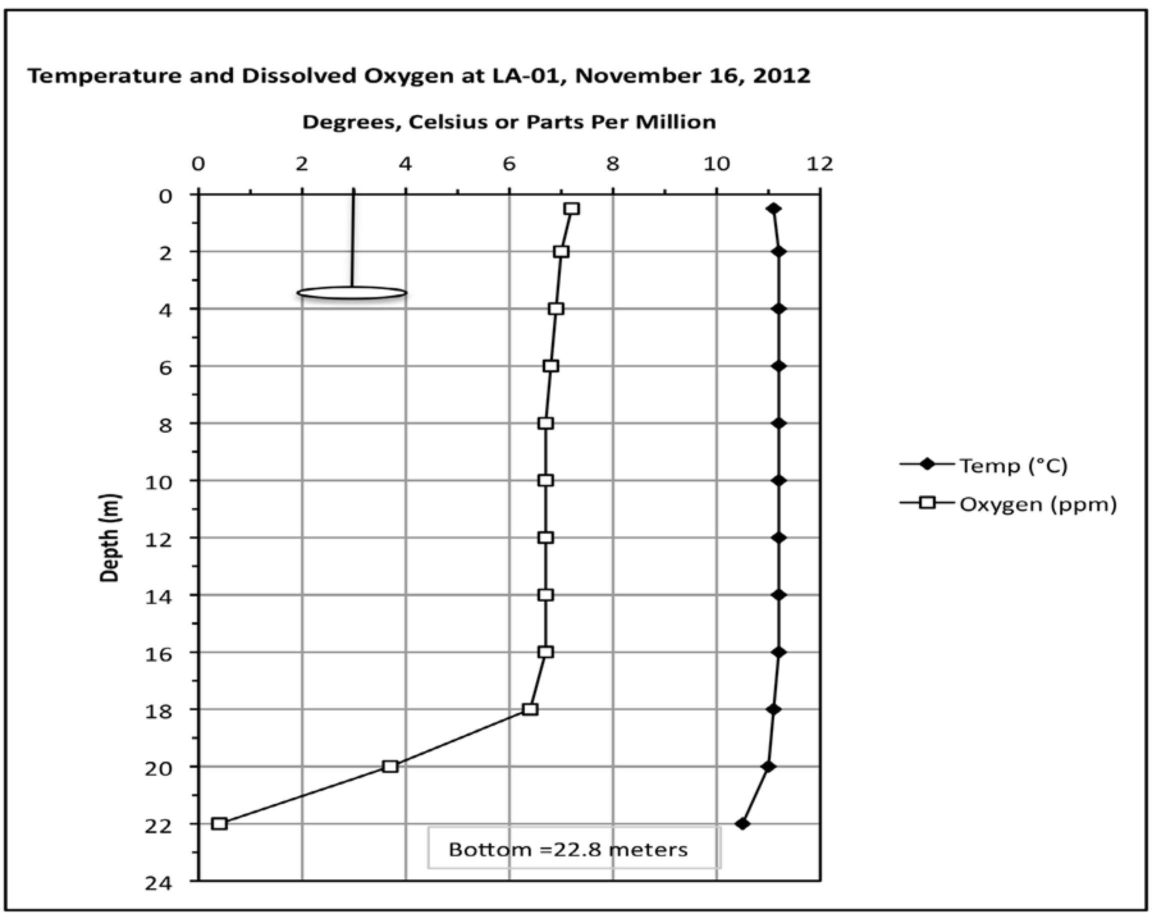
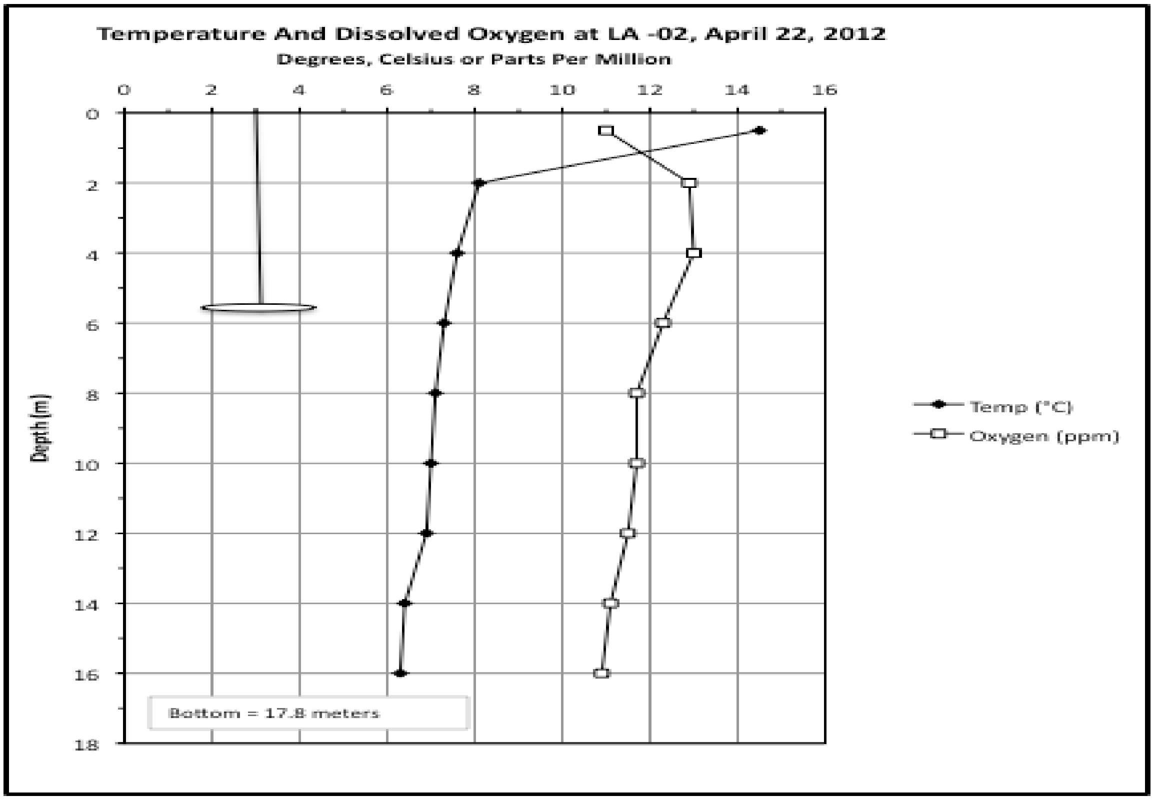


Figure 3. Temperature and Dissolved Oxygen at Lake Almanor, Station LA-02, During 2012



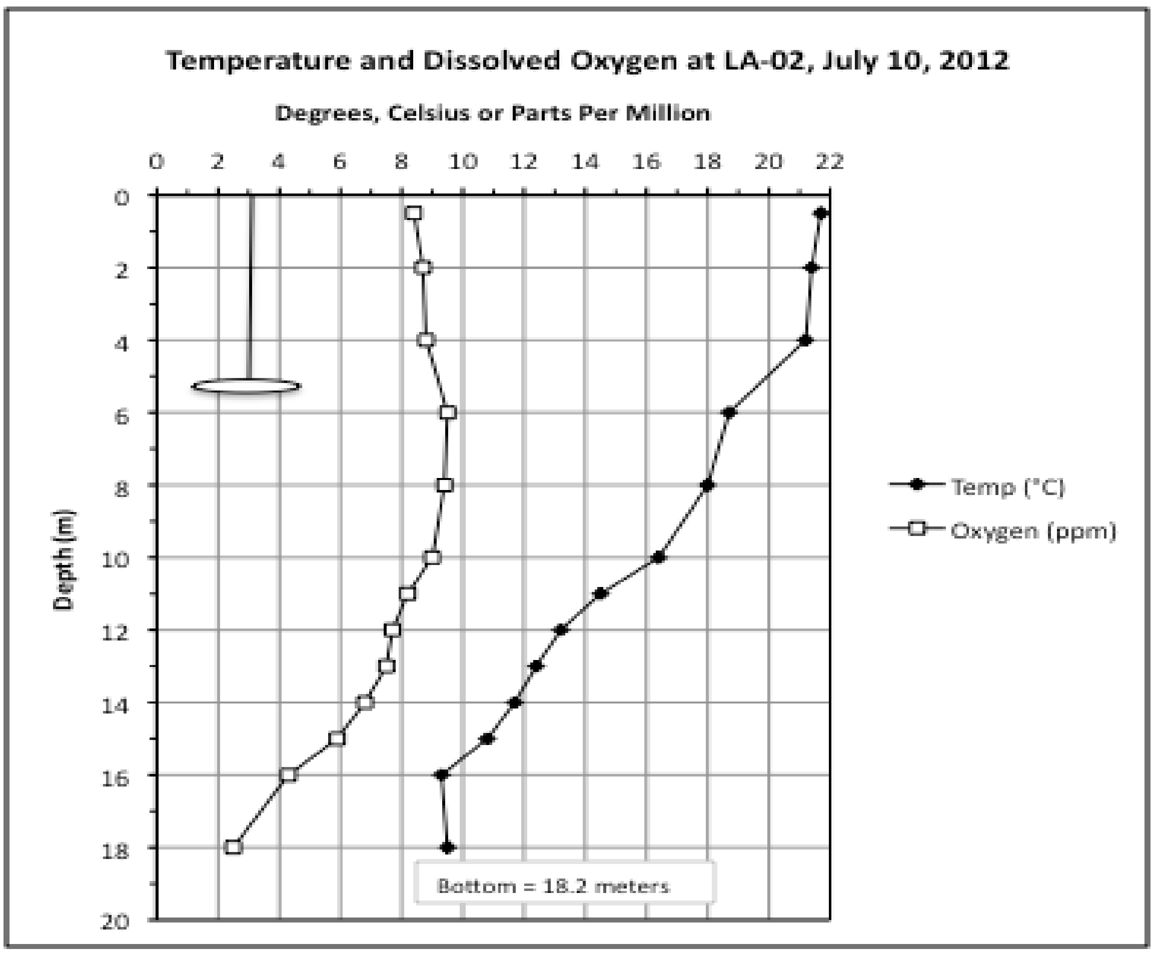
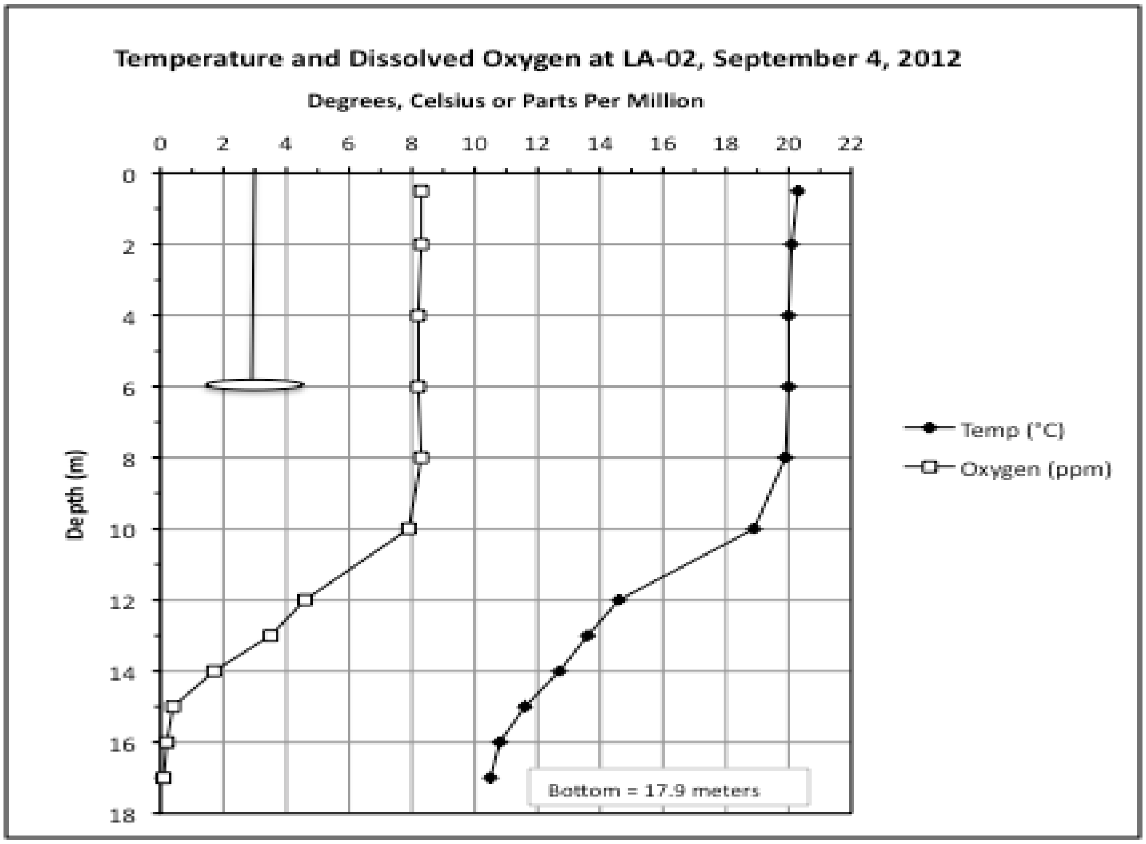


Figure 3 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-02, During 2012



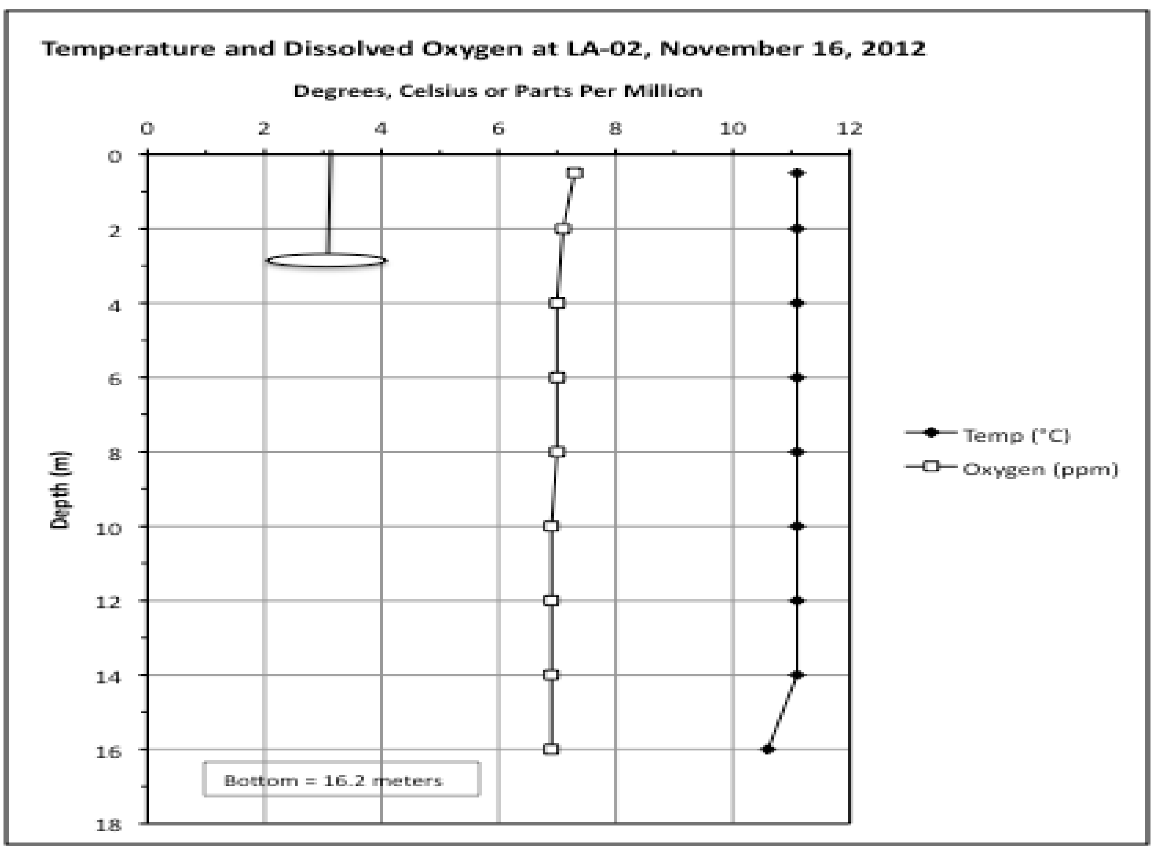
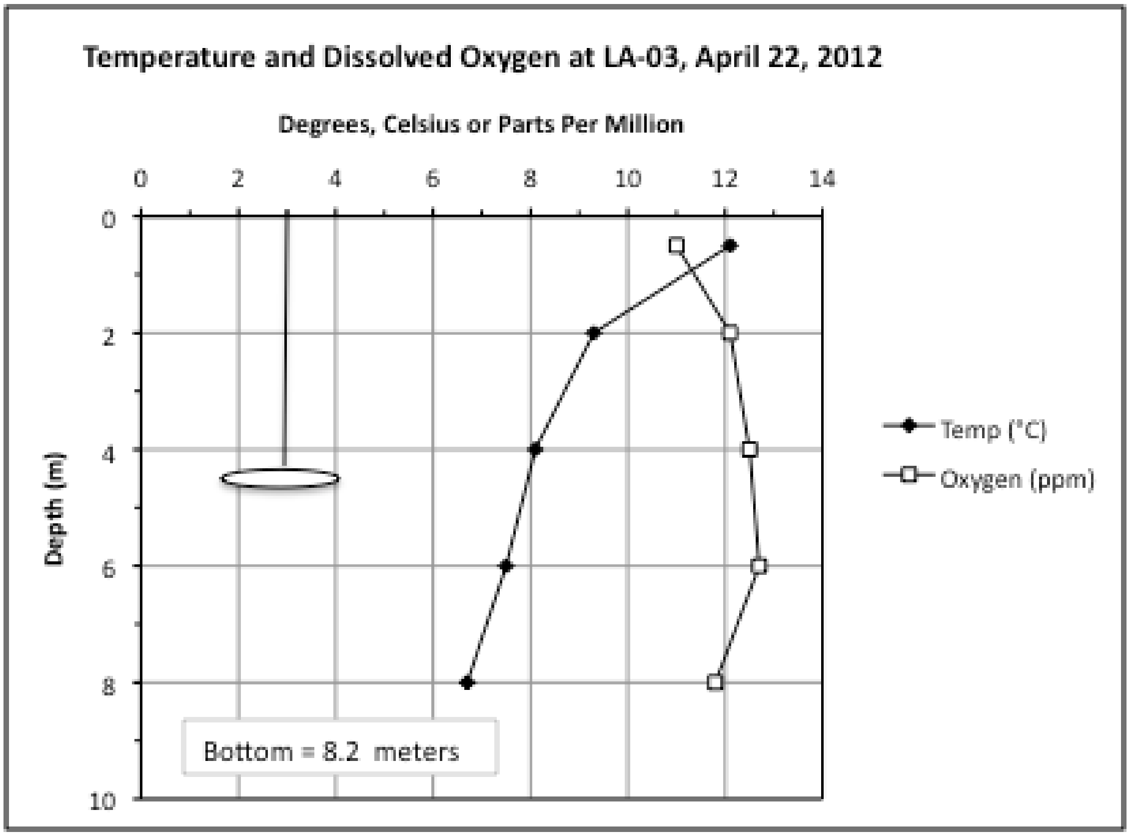


Figure 4. Temperature and Dissolved Oxygen at Lake Almanor, Station LA-03, During 2012



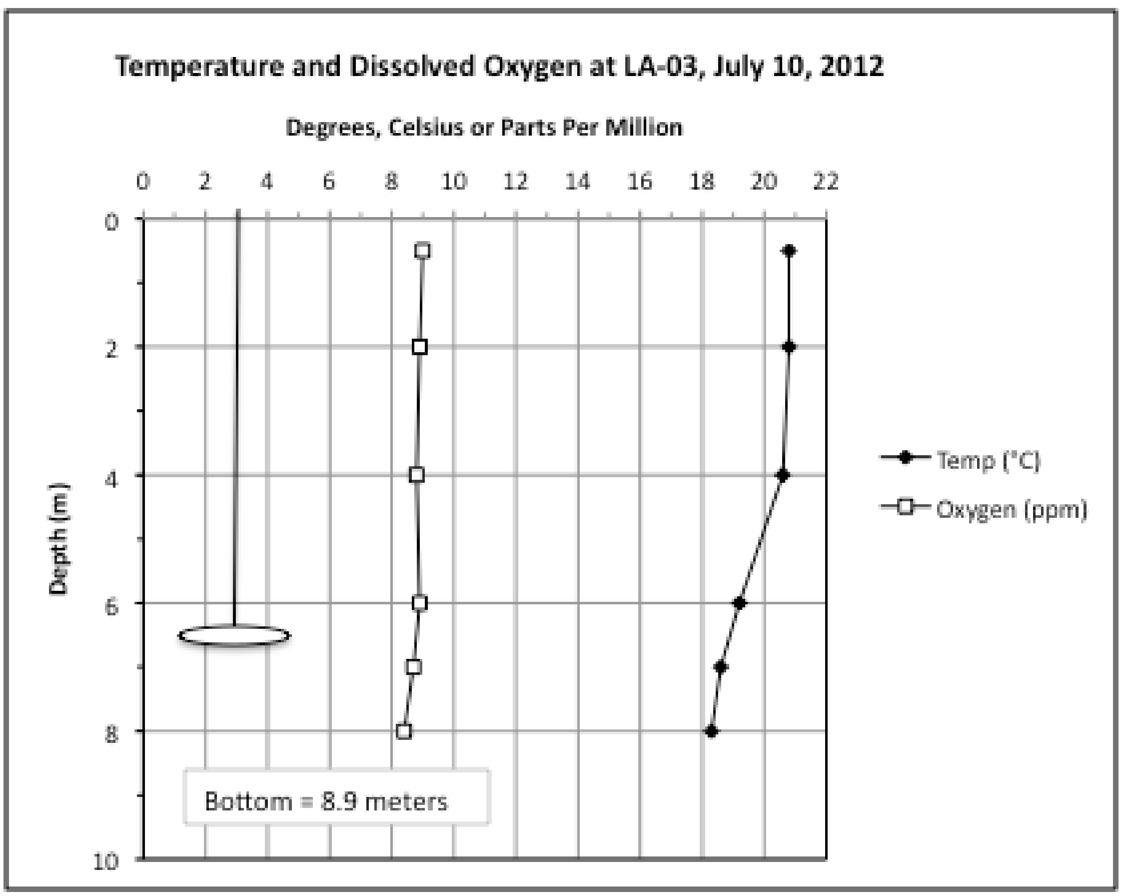
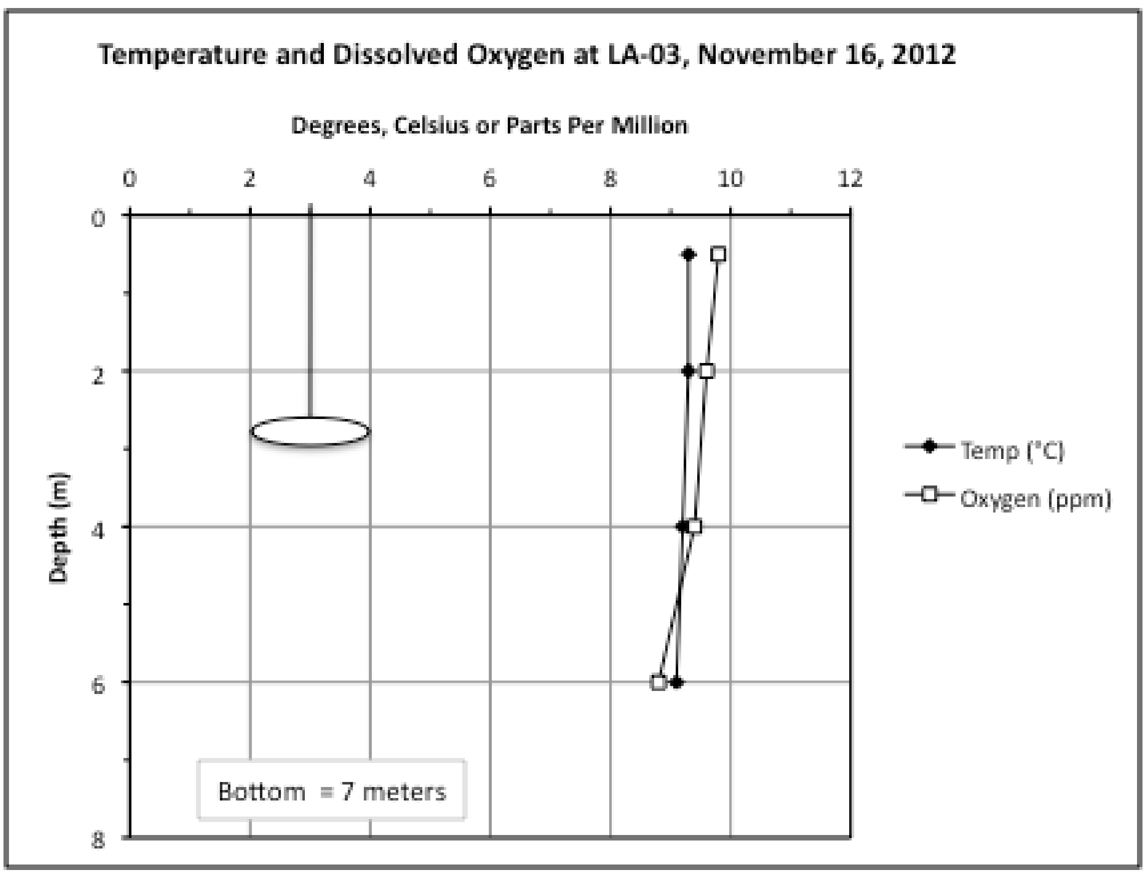


Figure 4 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-03, During 2012



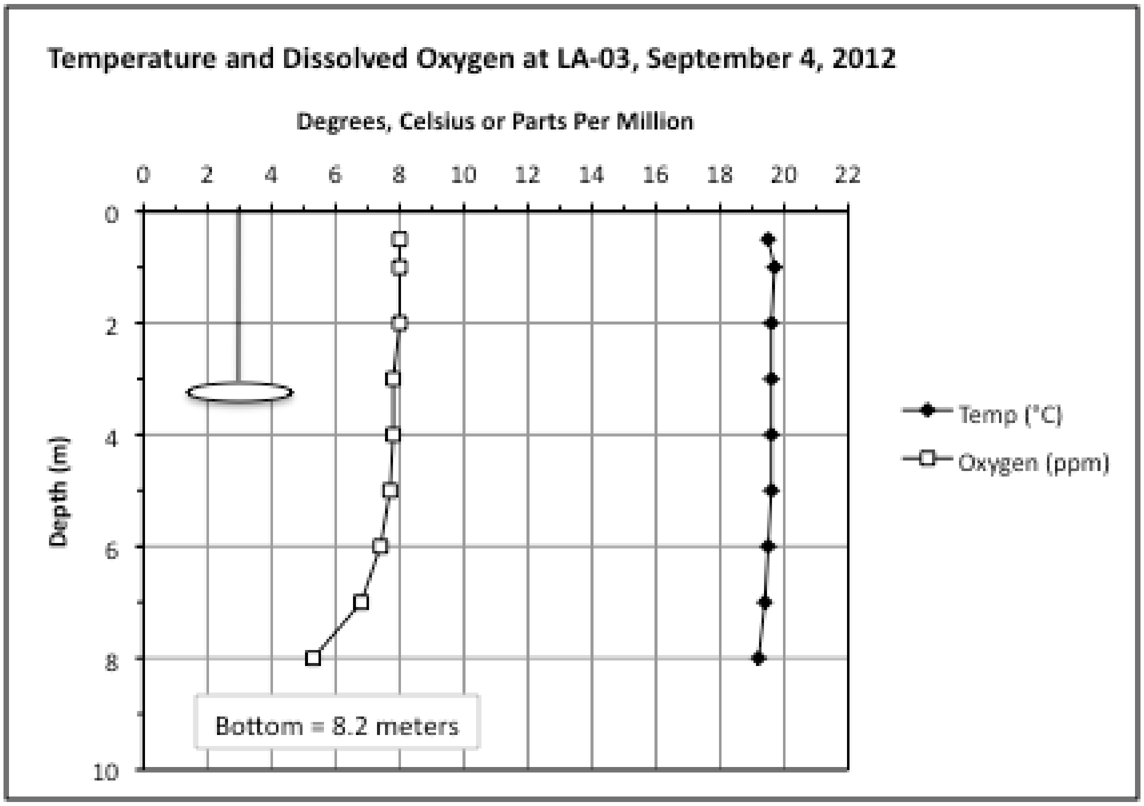


Figure 5. Temperature and Dissolved Oxygen at Lake Almanor, Station LA-07, During 2012

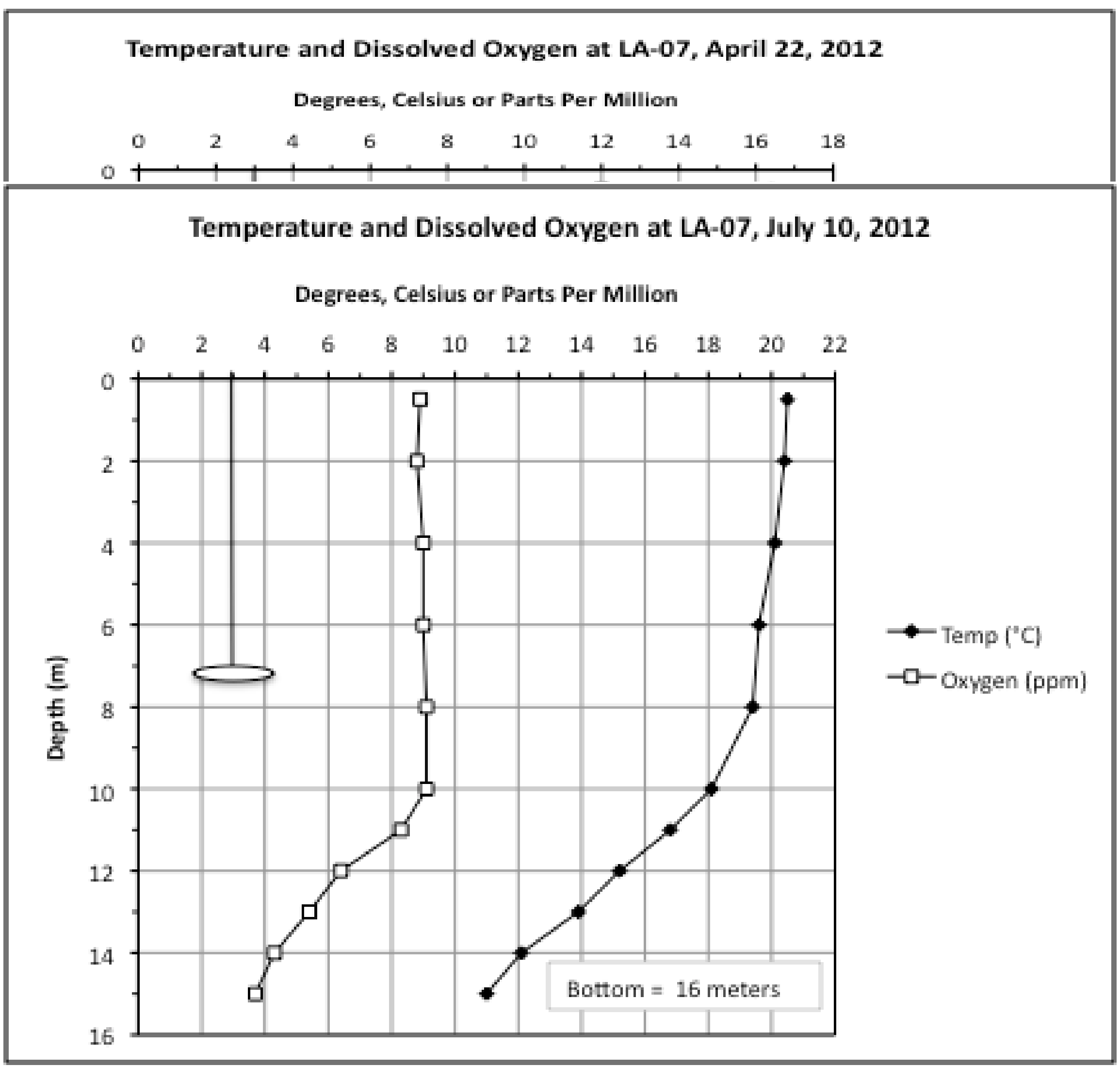
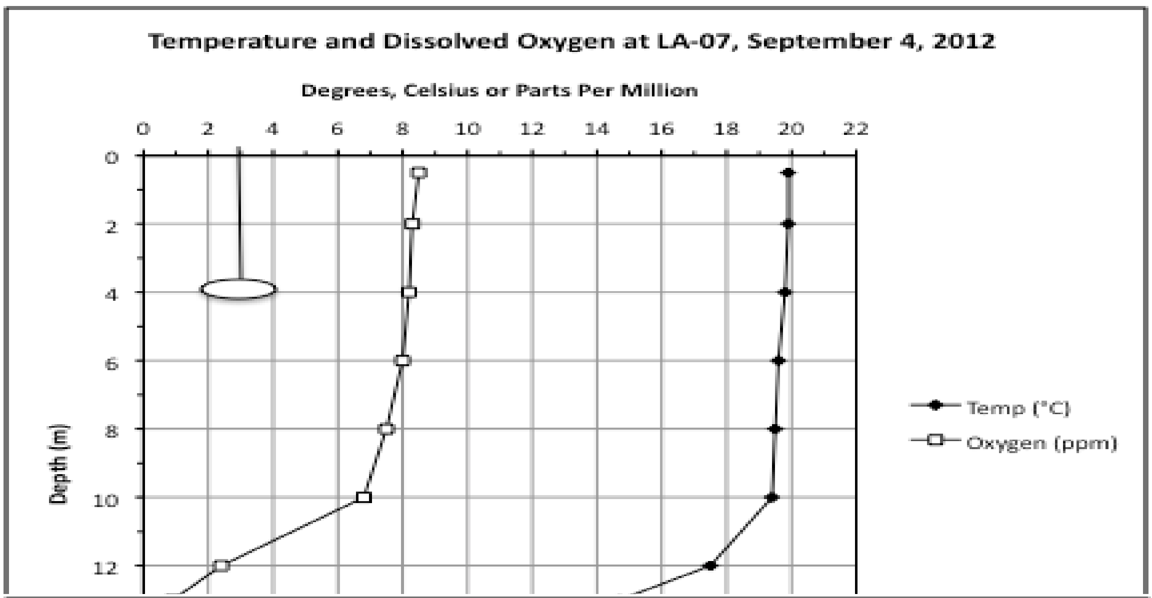


Figure 5 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-07, During 2012



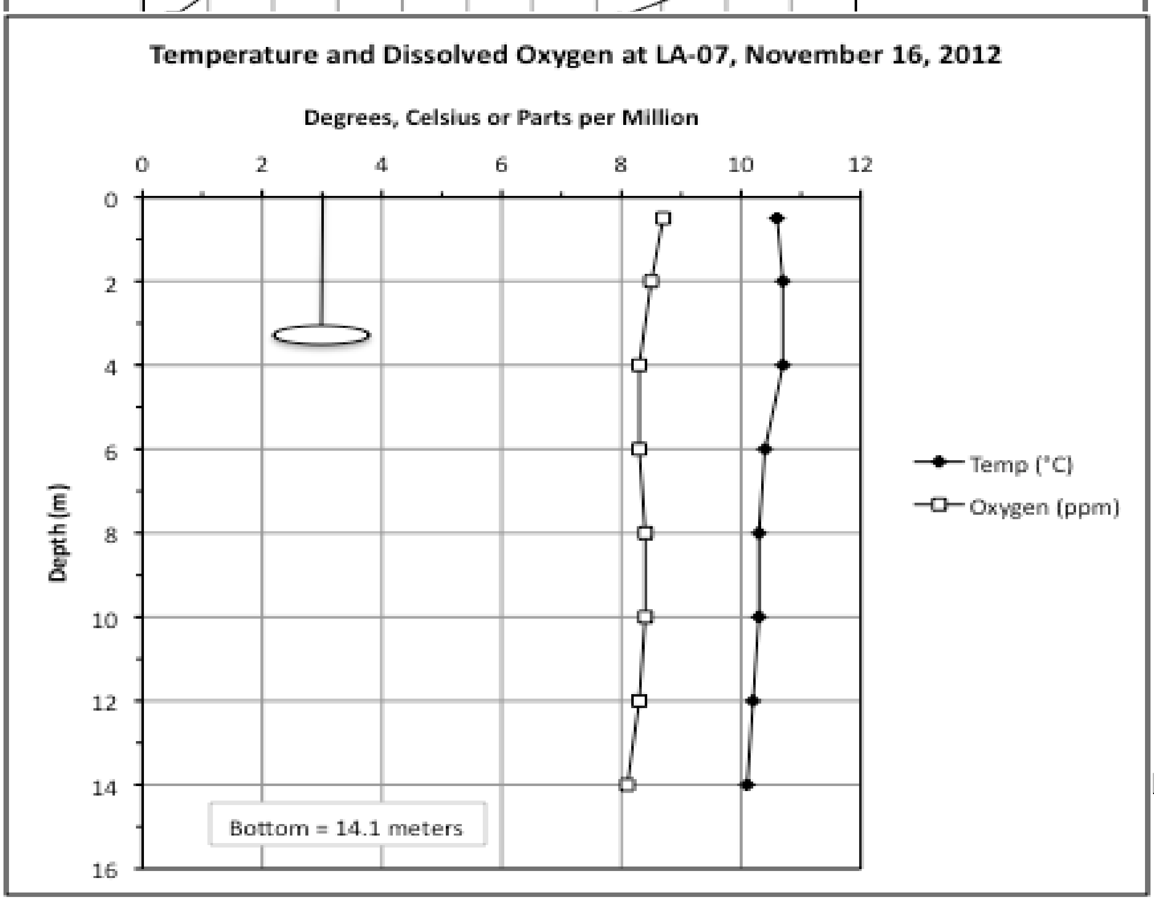
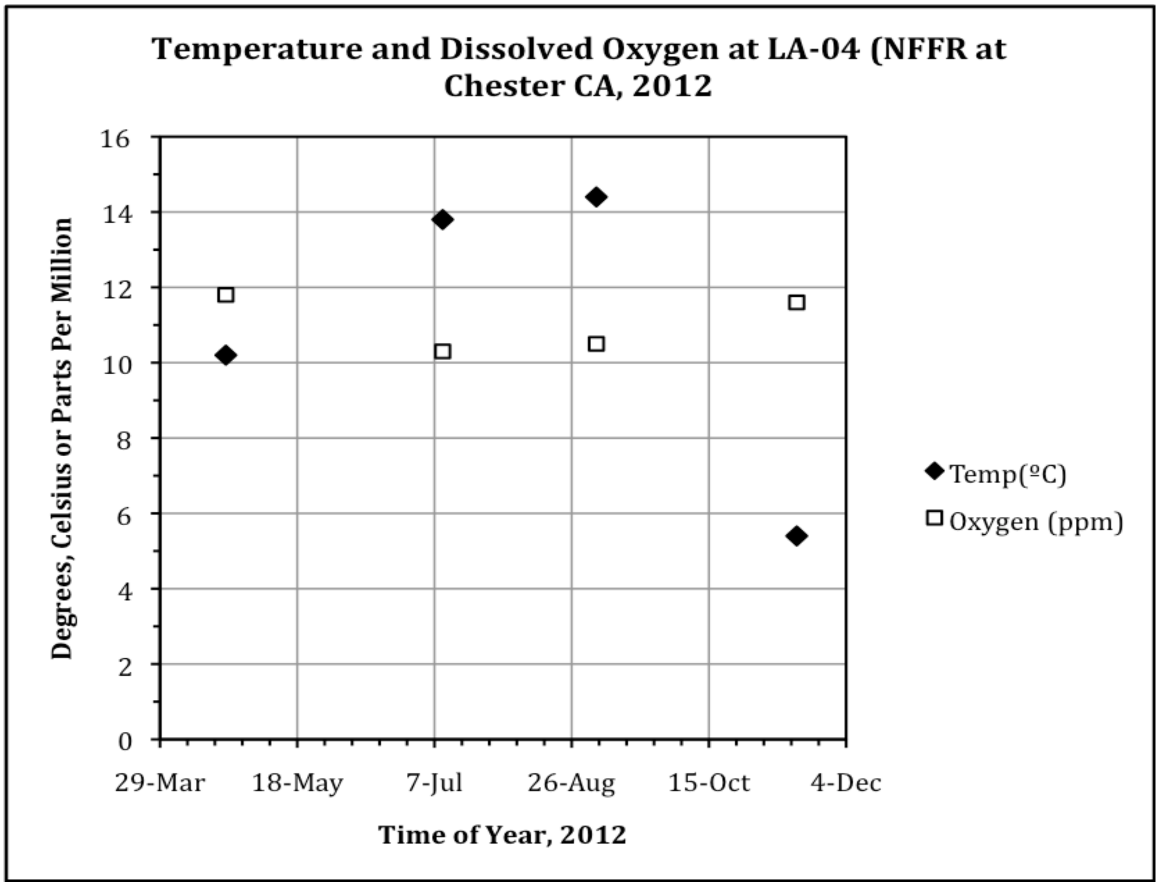


Figure 6. Temperature and Dissolved Oxygen at Lake Almanor, Station LA-04, During 2012



In the hypolimnion decomposition consumed oxygen at a faster rate than photosynthesis could produce it, so oxygen levels dropped. In the deepest part of the hypolimnion at LA-01 and LA-07, oxygen was at 4-5 ppm and at LA-02 oxygen was at 2-5 ppm.

By September 2011, oxygen was still near 8 ppm in the epilimnion of LA-01 and LA-02, and LA-07, and throughout the water column at LA-03. In the region of the thermocline at LA-01 and LA-02, oxygen levels dropped off very abruptly to less than 5 ppm. The hypolimnion at all three deep-water stations was essentially devoid of oxygen.

As the lake cooled in the autumn, the thermal stratification broke up. By November, all stations were again well-mixed and oxygen levels were between 7 and 9 ppm throughout.

An examination of the DWR data base (1989-2004) for Lake Almanor showed that the annual pattern for temperature and oxygen has been about the same since their records began. Low levels of oxygen in the hypolimnion are the “norm” for most of summer. Data for the lake prior to

1989 is patchy, so it is difficult to determine when oxygen depletion in the hypolimnion began.

As discussed in earlier reports, the low levels of oxygen stress the cold-water fish species in the lake, since the regions where both temperature and oxygen preferences are met become scarce.

Oxygen levels in the Feather River are always higher than in the lake, primarily because of the colder water temperature and the turbulence of the water (See Figure 6).

c. Electrical Conductivity

Electrical conductivity is a measure of the dissolved salts in water. The data for this report is presented in Table 1 in the Appendix. Values ranged from 54-67 micro-Siemens/cm at the lake stations and from 31-50 micro-Siemens/cm in the Feather River. There was little difference between lake stations, although LA-03 tended to be lower, due to the influence of the river. The range of data is similar to that in the DWR data base for 1989-2004. The values are slightly higher than in 2011 due to the greater precipitation received throughout the spring of 2011.

d. Secchi Depth

Secchi depth is an indication of suspended particles in the water column. Data for Secchi depth is presented by a line and disk on the left-hand side of each graph, as well as in Table 1 in the Appendix. For LA-01, LA-02 and LA-07, Secchi depth was about 5.7 meters and at LA-03 it was 4.5 meters in April. It increased to 6-7 meters at all stations in July. In September it was still 5-6 meters at LA-01 and LA-02, but only 4 meters at LA-07 and 3.3 meters at LA-03. It then decreased in November to 3-3.5 meters at all stations. Variation is probably related to sediment carried by inflowing streams (lower values in April), as well as phytoplankton (lower values in November). Values were in agreement with those in the DWR data base and with the 2009 - 2011 studies.

2. Chemical Parameters: Nutrients

These tests were performed to get an estimate of the amount of nitrogen and phosphorus available to phytoplankton at the time of lake turnover in the spring and at the end of thermal stratification in September when nutrients in the hypolimnion would be at their highest concentration. Total nitrogen, nitrite plus nitrate, ortho-phosphate and total phosphorus were analyzed in April and September 2012 at LA-02 and LA-03. Data are presented in Table 2 below.

Table 2. Nutrient Concentrations at LA-02 and LA-03 in 2012

Date	Station	Total Kjeldahl Nitrogen (mg/L)	Nitrite plus Nitrate (mg/L)	Total Nitrogen (mg/L)	Ortho-phosphate (mg/L)	Total Phosphorus (mg/L)
22 April	LA-02 surface	0.1	0.02	0.1	ND	ND
22 April	LA-02 bottom	0.1	0.03	0.2	ND	ND
22 April	LA-03 surface	0.3	0.03	0.3	ND	ND
22 April	LA-03 bottom	0.1	0.03	0.2	ND	ND
4 September	LA-02 surface	0.2	ND	0.2	ND	ND
4 September	LA-02 bottom	0.3	ND	0.3	0.02	0.06
4 September	LA-03 surface	0.3	ND	0.3	ND	ND
4 September	LA-03 bottom	0.2	ND	0.2	ND	0.02

(Note: ND= Not Detected at the detection limit for the test)

Nitrite plus nitrate and total nitrogen were detected in all samples in April, but values were low, close to the minimum detection limit. Phosphorus was not detected. The concentrations may have been low because there were already large populations of phytoplankton present in the lake in April. The September data do show higher amounts, especially for total phosphorus near the bottom of LA-02.

3. Inorganic Silver

This test was performed because of public concern about the effects of cloud seeding and the potential for accumulation of silver in the Lake Almanor watershed. Table 3 shows the location of sampling stations and the results of the analyses. The North Fork Feather River, Bailey Creek and Hamilton Branch were all sampled near where they enter Lake Almanor. Samples were collected on April 22, 2012, when inflows were at their peak.

All samples were at or below the minimum detection level for this test and indistinguishable from the field blank, which was de-ionized water. The unit of measure is one millionth of a gram per liter of water.

Table 3. Inorganic Silver Ion Analyses, April 2012

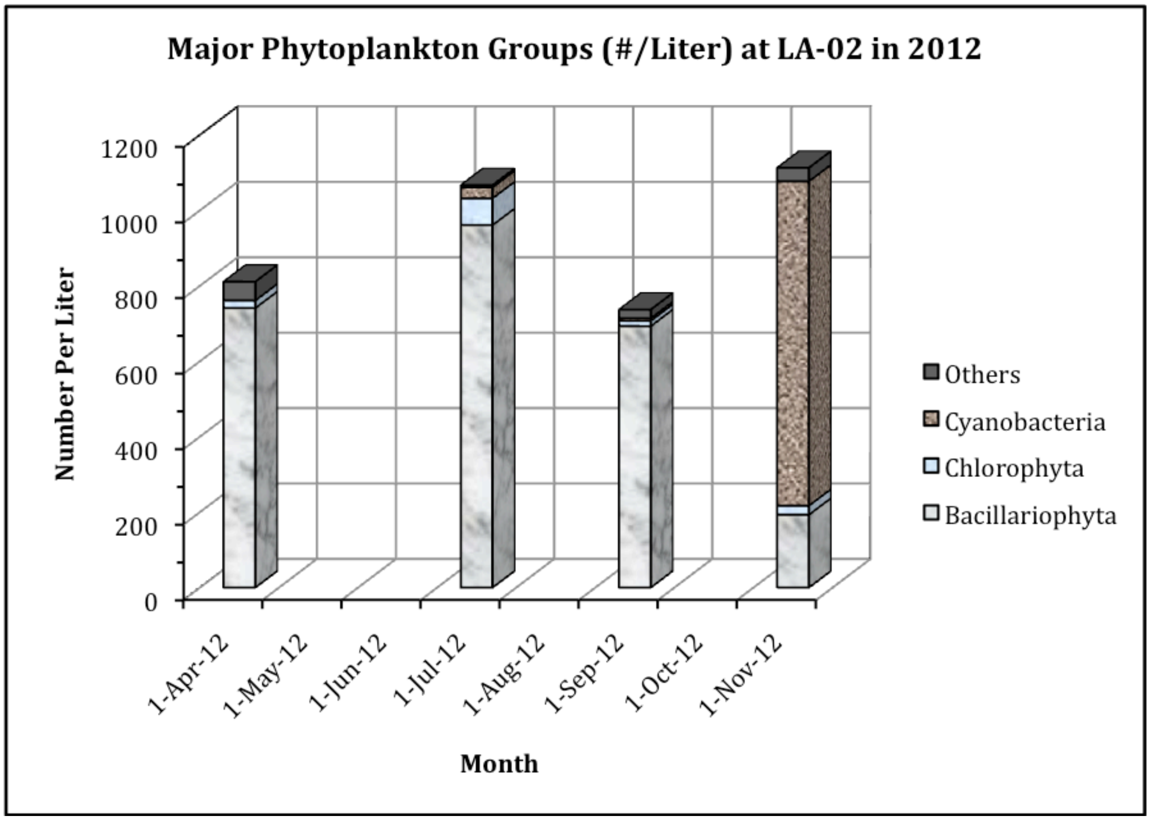
Sample	Result	Minimum Detection Limit	Unit
Bailey Creek	0.005	0.005	μg/L
NF Feather River	0.005	0.005	μg/L
Hamilton Branch	0.005	0.005	μg/L
LA-01 surface	0.005	0.005	μg/L
LA-01 bottom	0.005	0.005	μg/L
LA-02 surface	0.005	0.005	μg/L
LA-02 bottom	0.005	0.005	μg/L
LA-03 surface	0.005	0.005	μg/L
LA-03 bottom	0.005	0.005	μg/L
Field blank	0.005	0.005	μg/L

4. Phytoplankton and Zooplankton

Phytoplankton samples were collected at LA-02 and LA-03 on all four sampling dates. Data for the major groups of phytoplankton are presented in graphic form in Figures 7 and 8. More detailed data are in the Appendix. The data are presented in two different graphs for each station. The first graph shows the number of algal cells or colonies per liter of lake water. The second graph shows the volume of algal cells per milliliter of lake water (cubic microns per milliliter). This way of showing the data is important where the number of colonies is low but the size of each colony is large. It is a more accurate way of expressing the total amount of algae present.

In April diatoms (Bacillariophyta) were the dominant form at both LA-02 and LA-03, particularly *Fragilaria, Asterionella* and *Stephanodiscus.* By July some bluegreen algae appeared, primarily *Anabaena*. Colonial green algae (Chlorophyta) were also abundant, primarily *Pleodorina and Volvox*. In September and November these genera were joined by more bluegreens, *Lyngbya* and *Microcystis*. A dinoflagellate, *Sphaerodinium*, was very abundant at both stations. It constituted most of the “Others” category on the graphs.

Figure 7. Major Phytoplankton Groups at Lake Almanor, By Number/Liter and By Volume (cubic microns/milliliter), Station LA-02 in 2012



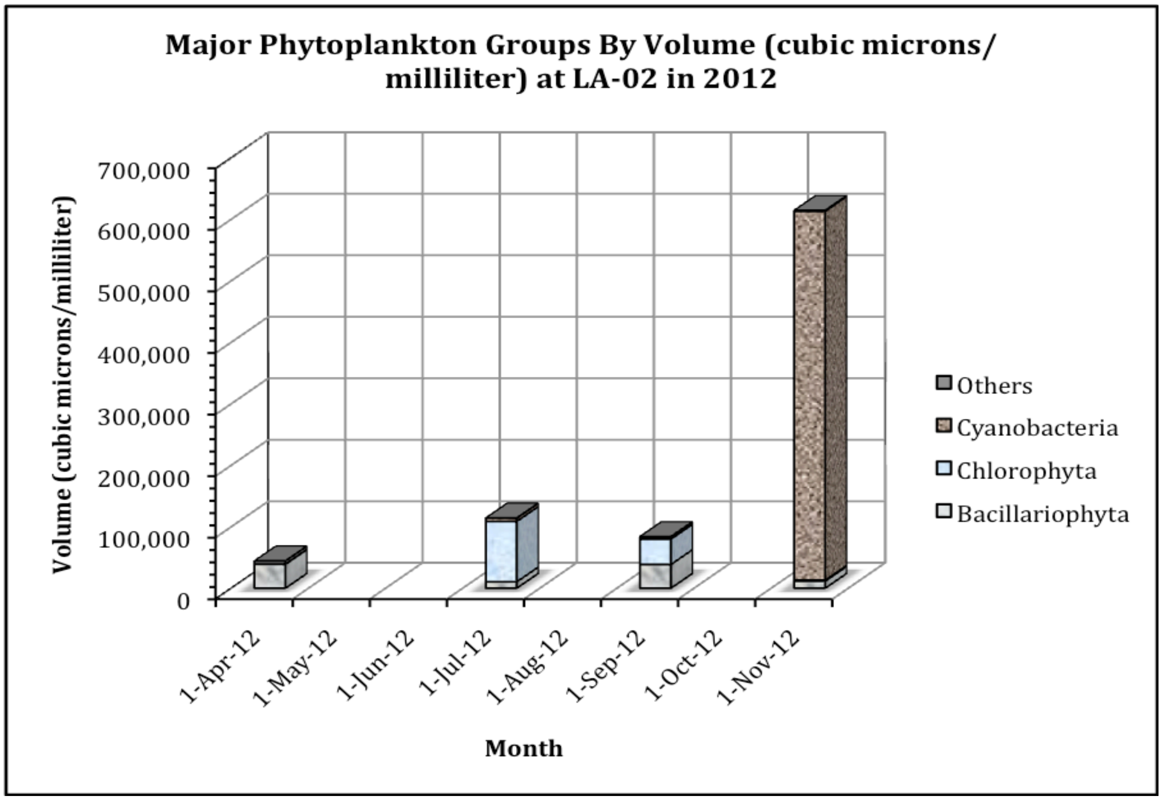
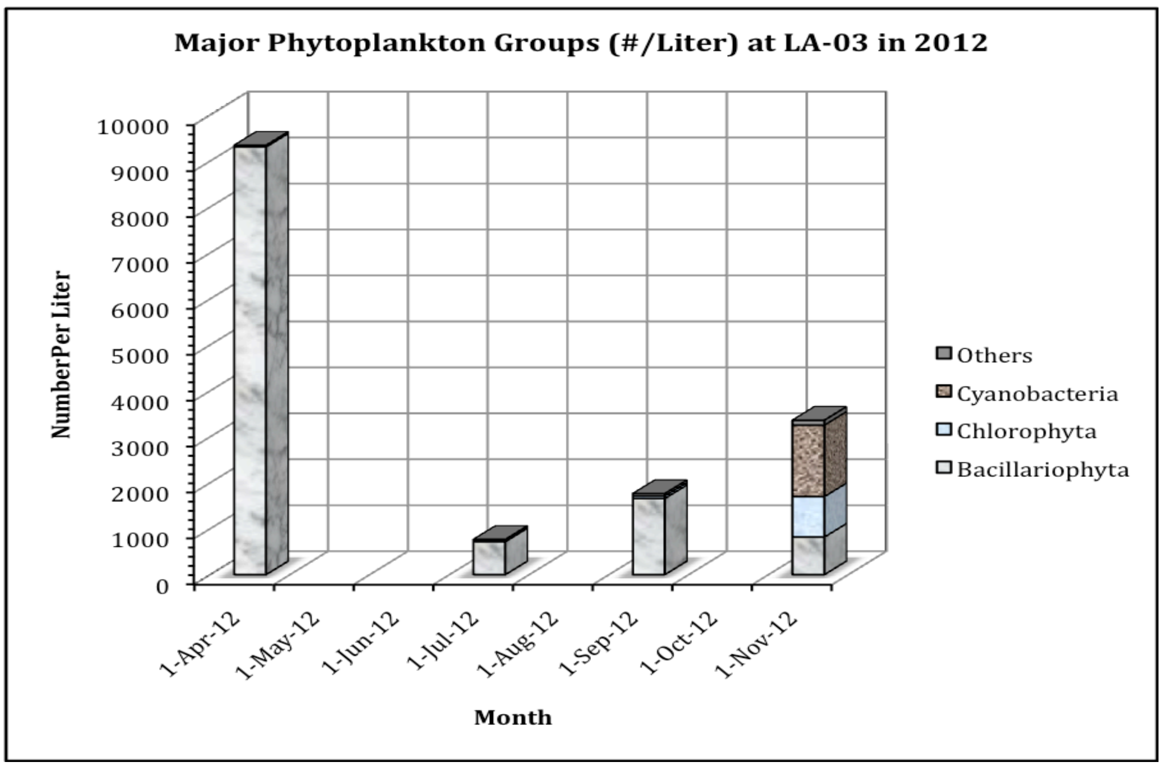
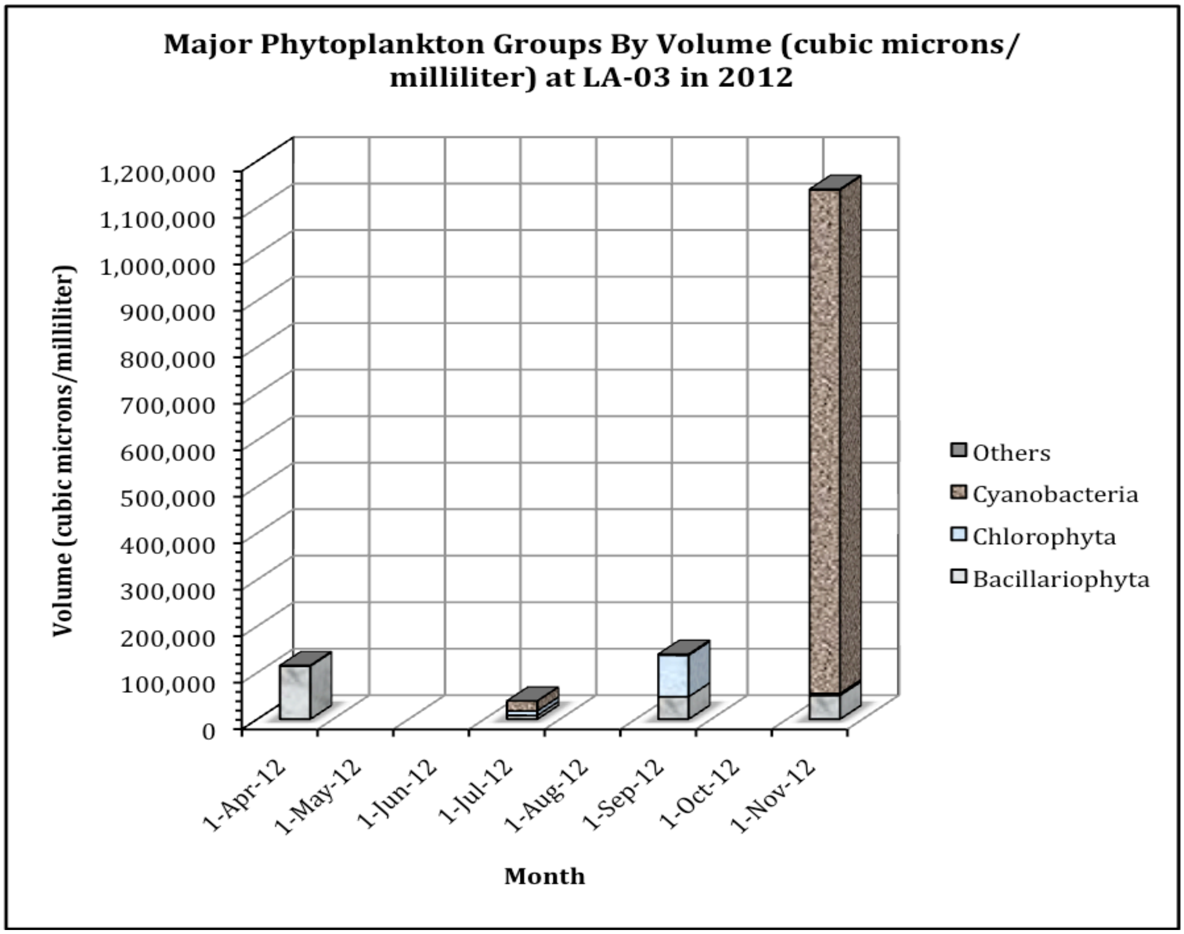


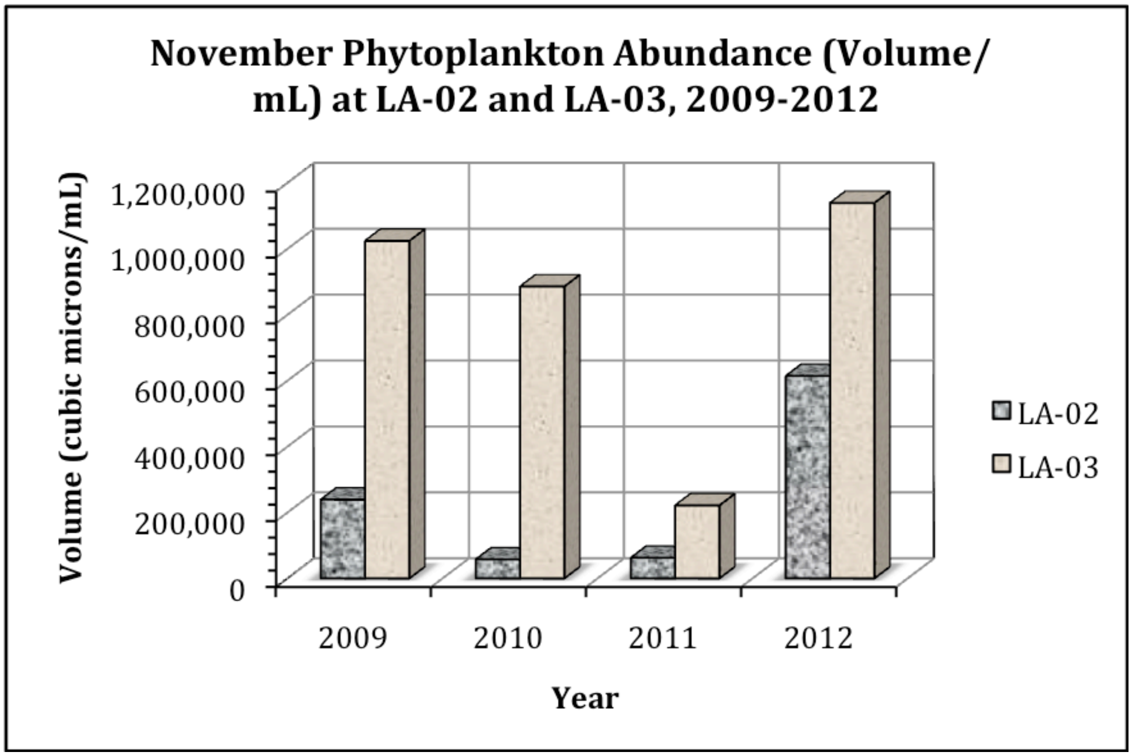
Figure 8. Major Phytoplankton Groups at Lake Almanor, By Number/Liter and By Volume (cubic microns/milliliter), Station LA-03 in 2011





Although the species present were similar to those in previous years, the total amount of phytoplankton was considerably more than in 2011. Figure 9 shows the maximum amount of phytoplankton by volume at LA-02 and LA-03. The maximum was generally in November. At LA-02 the amount in 2012 was 10 times more than in 2010 or 2011. At LA -03 the greatest volume was five times the highest level in 2011. The highest level was similar to 2009 and 2010. Bluegreen algae continued to be numerous in the late summer and fall, especially the genus *Microcystis* . The higher amounts of algae overall were probably due to the lower precipitation and warmer air temperatures during 2012. These values are more like 2009 and 2010, but somewhat higher, especially at LA-02.

Figure 9. Maximum Phytoplankton at LA-02 and LA-03



There are no recent data from DWR concerning the phytoplankton, but some tables from the 1970's show that some of the same species were present then. The assemblage of genera is characteristic of meso-trophic lakes.

Zooplankton were collected along with the phytoplankton and results are presented in Figures 9 and 10. More detailed data are in the Appendix.
The most abundant group at both stations was the Rotifera, with few Copepoda and Cladocera present. Most likely, their small size limits predation by small fish, whereas Copepoda and Cladocera are readily eaten. The most common genera were *Keratella* and *Polyarthra* at both stations. Their abundance was generally higher than in 2011, but populations were low in November. Perhaps this was because the phytoplankton was dominated by *Microcystis*, which is not a food source.

Figure 10. Major Zooplankton Groups (#/Liter) at Lake Almanor, Station LA- 02, 2012

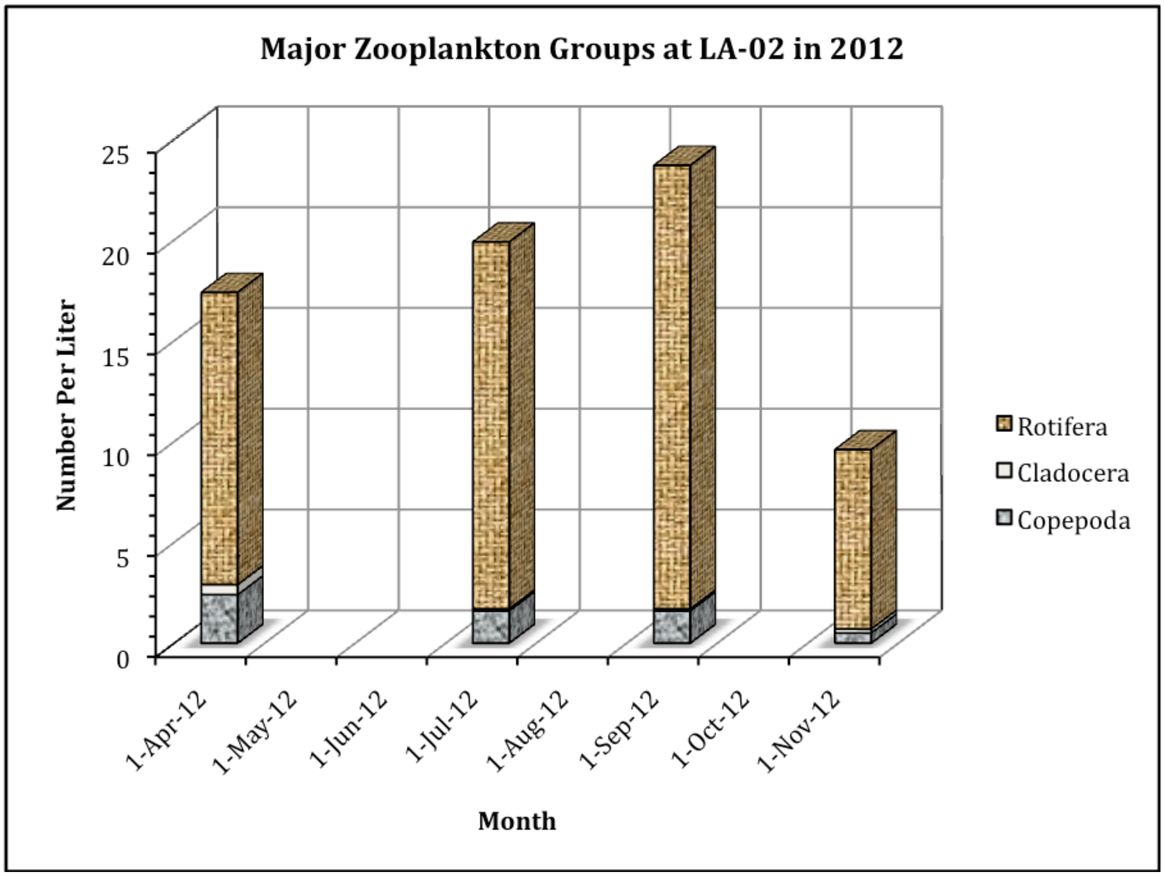
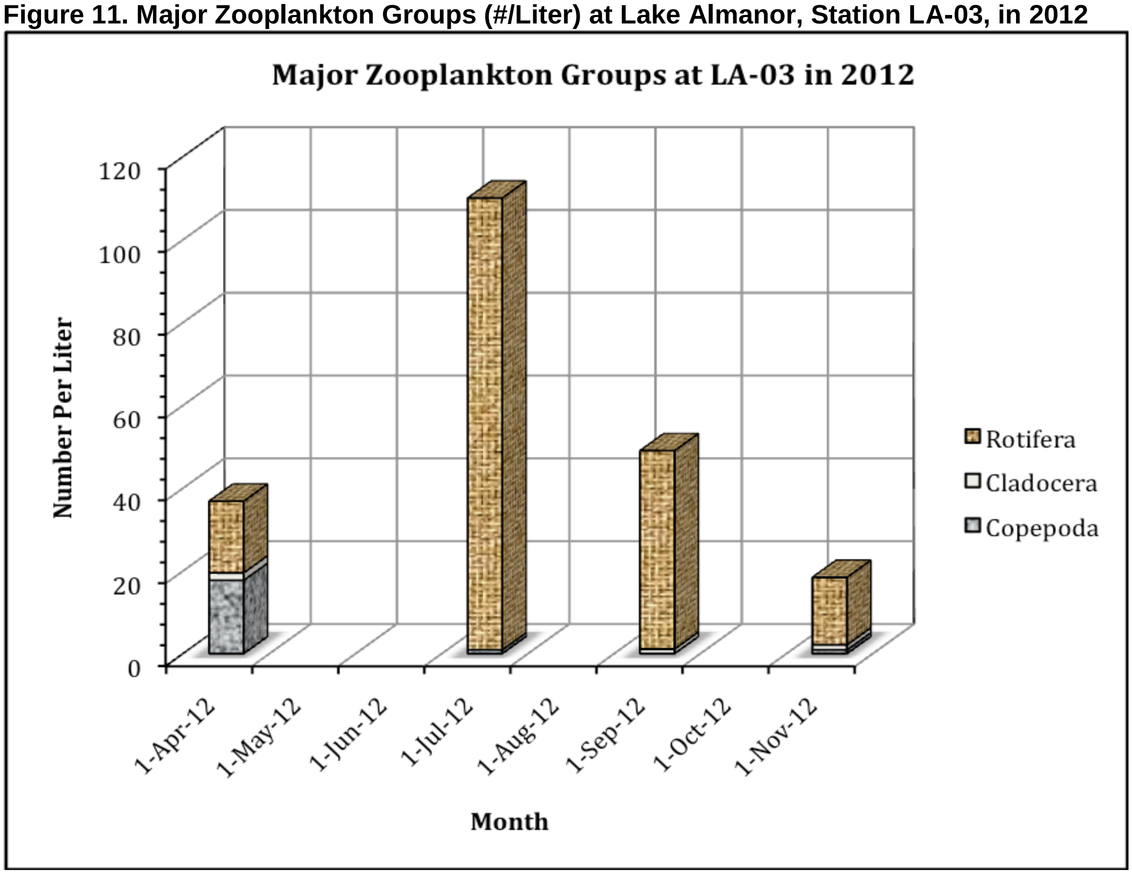


Figure 11. Major Zooplankton Groups (#/Liter) at Lake Almanor, Station LA-03, in 2012



Conclusion

Lake Almanor is a fairly rich reservoir capable of supporting a diverse assemblage of plants and animals. Large populations of phytoplankton can develop during lake overturn in the spring and fall. Nutrients that collect in the hypolimnion during the period of thermal stratification in the summer are distributed throughout the water column during periods of overturn or mixing. When there is an abundance of precipitation and cool weather in the spring, this can slow population growth and favor green algae or diatoms over bluegreen algae. If summer and fall are warm, this favors blue-green algae. This year the nuisance species of algae were much higher than in 2011 due to the warm, dry weather. We can expect that dry years will be accompanied by larger populations.

A more extensive study of the nutrient budget of the lake might reveal major sources of nutrients. Loss of oxygen in the hypolimnion does result in release of nutrients from lake sediments, but other sources could be septic tanks, golf courses or lawn fertilizer.

General Discussion of Lake Conditions and the Importance of Monitoring

Lakes and reservoirs are often pristine right after they are created. However, when rivers, groundwater and human activities bring nutrients (phosphorus, nitrogen and other chemicals needed for plant and animal growth), sediments and other substances into them, they begin to change. The rate at which these substances enter can affect how quickly the system changes. Over time the lake or reservoir begins to accumulate sediment and nutrient concentration increases. Eventually, the nutrients are sufficient to support a large population of phytoplankton or other plants. If the growing conditions are suitable, certain nuisance species of phytoplankton (blue-greens) or rooted aquatic plants may become numerous to the point that they interfere with the use of the water for recreation or drinking. As more plant material is produced, only a portion of it is consumed by fish and other animals. This “extra” organic material settles out of the water and accumulates near the bottom. Bacteria will decompose the material and use up the dissolved oxygen in the deeper portion of the lake or reservoir. The loss of dissolved oxygen can become so severe that some fish species, such as trout, can’t survive. Tolerant species, such as catfish or carp, may become more abundant. The system continues to change physically and biologically until it becomes dominated by algae and aquatic plants, with a limited number of fish species that can tolerate these conditions.

Lake Almanor is a reservoir that is already undergoing many changes. Because of the lake’s high elevation, the cooler water temperature and the short growing season limit some plant growth. However, the western basin is shallow and the water is warm in the summer. Phytoplankton and larger aquatic plants can become very numerous at this time of year. There are enough nutrients coming in from the river, streams or from human activities (septic tanks, golf courses, lawns) to support abundant plant growth. As more homes are built in the watershed, the nutrient input will increase.

In the eastern basin, the water is deep enough to become thermally stratified in the summer. The warm, well-oxygenated water at the surface does not mix with the colder water deep in the lake. Over the summer, the deep water's oxygen supply gets depleted by bacterial decomposition and oxygen levels drop to zero. This is a stressful time for those fish species that need both cold water and sufficient oxygen, such as trout (Raleigh *et al*, 1984). The warm, nutrient-rich water near the surface may support large populations of phytoplankton, especially blue-green species. As these algae become more numerous, they will detract from the lake's appearance and may limit recreational use. Even though climatic variations from year to year may temporarily affect population size, nuisance species of algae will most likely increase in abundance as more development occurs in the watershed.

Data collected by California DWR and others show that oxygen depletion in some parts of the lake has been occurring at least since the 1970's. Since only a few locations have long-term data, we don't know if a change in the percentage of affected lake area has occurred. The data on algal composition and abundance has been more sporadic. There have been some bluegreen algae at least since the 1970's, but we don't know if the number of species and total amount of algae have increased. A long-term data base of reservoir conditions is vital to any land or water use management decisions. Historical data and the current monitoring program data suggest that the water quality is deteriorating, since the oxygen depletion in the summer seems to be widespread and the amount of bluegreen algae may be increasing. The lake is undergoing changes that will affect its esthetic appearance and our ability to use it for recreation. We need to continue a monitoring program that will provide the data to inform our land and water use decisions.

Suggestions for Future Monitoring

For the last four years we have collected physical and biological data and some nutrient data. While there have been variations due to weather, especially precipitation, the pattern of the physical data has been similar from year to year: mixing from fall to spring and thermal stratification at the deep stations (LA-01, LA-02 and LA-07) during the summer. The biological data have been less predictable. In November 2009, algal populations were over one million cubic microns/milliliter of lake water at LA-03 (mostly diatoms). In November 2010, the population was nearly 900,000 (mostly bluegreen algae). In November 2011, the population was about 240,000 (mostly diatoms). In November 2012, it was over one million again, but mostly bluegreen algae. The biological component seems to respond very quickly to annual differences in temperature, precipitation and runoff.

Future monitoring of Lake Almanor must continue to include the collection of physical data as long as the construction of a thermal curtain remains a possible lake modification. It is important to document how limited the pool of cool water is in the lake during the summer months and to show that oxygen levels are low during this time. The inclusion of LA-07 this year allowed us to see that there is a limited pool of deep cool water in the western lobe that also becomes depleted of oxygen in the late summer.

It is also important to monitor the phytoplankton and zooplankton so that we know the degree to which bluegreen algae are increasing and whether there are permanent changes to the foodchain base in the lake. The diversity of the phytoplankton and zooplankton indicate the biological health of the lake and its ability to support other life forms. At least two stations (LA-02 and LA-03) should be included because conditions in the two lake lobes are so different.

If more funds become available, nutrients should be monitored at inflowing streams and springs. This would allow us to determine if there are identifiable point sources of nutrients. Additional sampling along the reservoir perimeter would be needed to determine if there are nonpoint sources. Possibly, chloride monitoring should be included as an indicator of septic tank inputs. The timing of such monitoring would be dependent on the annual precipitation pattern. Because of the expense involved for sample collection and analysis, this may have to be postponed until the monitoring budget is larger.

The monitoring program of the last four years should be viewed as the minimum for understanding lake conditions. It should be continued as long as funds are available.

References

1. California Department of Water Resources data base for Lake Almanor, obtained from Almanor Basin Watershed Advisory Committee records.
2. Lake Almanor Watershed Water Quality Report. April 2006. CH2MHILL, Redding, CA
3. Raleigh, Robert F., Terry Hickman, R. Charles Solomon and Patrick C. Nelson. 1984. Habitat Suitability Information: Rainbow Trout. U.S Fish and Wildlife Service, U.S. Department of the Interior. http/www.nwrc.usgs.gov/wdb/pub/hsi/hsi-060.pdf
4. Lake Almanor Water Quality Report, 2009, 2010 and 2011. K.R. Gina Johnston and John McMurtry.

Lake Almanor Water Quality Report, 2013

Prepared for

Plumas County Flood Control & Water Conservation District and
Almanor Basin Watershed Advisory Committee

By

K.R. Gina Johnston and John McMurtry
Butte Environmental Technologies

Submitted January 2014

Table of Contents

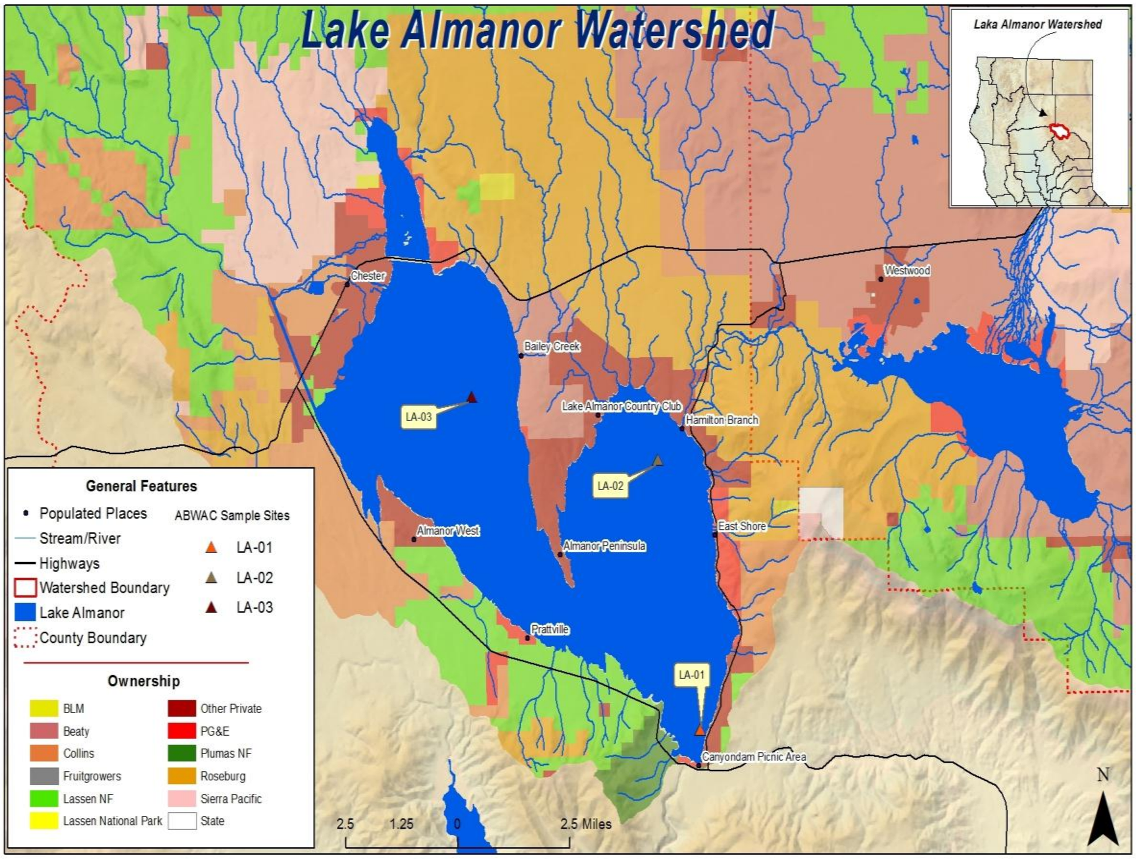
Introduction and Project Overview

A water quality monitoring program for Lake Almanor was conducted during 2013, following the same protocol used in the previous studies. The Plumas County Flood Control and Water Conservation District and the Almanor Basin Watershed Advisory Committee (ABWAC) provided oversight for the contract. Due to the limited funds available for this project, ABWAC selected some of the important parameters that had been monitored in the past by California Department of Water Resources (DWR), the County of Plumas and Pacific Gas & Electric Company. Four sampling windows were chosen to provide a look at lake health: during spring turnover (April 13-21), the period of heavy recreational use (July 6-14 and September 2-15) and fall turnover (November 3-10). Three stations in the lake were selected: LA-01, near the Canyon Dam Intake Tower; LA-02, in the east lobe; and LA-03, near the middle of the west lobe. A station in Chester (LA-04) was selected for monitoring the North Fork of the Feather River just prior to discharge into the lake. Station locations are shown in Figure 1. Certain inflows were also selected for nutrient analyses. The parameters and sampling times are listed in Table 1.

Table 1. Lake Almanor Parameters Monitored in 2013

Parameter	Specific Parameters	Locations	Sampling Window
Physical	Temperature Dissolved oxygen Electrical Conductivity Secchi depth	LA-01, LA-02, LA-03 every two meters, just once at LA-04 (no Secchi)	April 13-21 July 6-14 Sept 2-15 Nov 3-10
Plankton	Zooplankton Phytoplankton	LA-02 LA-03 (vertical tow)	April 13-21 July 6-14 Sept 2-15 Nov 3-10
Nutrients	Total phosphorus Ortho-phosphate Nitrate Total nitrogen	LA-02, LA-03 (0.5 meter below surface and 1 meter off bottom) Bailey Creek, Hamilton Branch, NFFR, North Shore Campground	April 13-21 Sept 2-15 April 13-21
		LA-01, LA-02, LA-03 and LA-04;	

Figure 1. Sampling Station Locations in Lake Almanor used in 2013 study. (Map provided by Emily Creely, Sierra Institute)



Methods Used for Sampling and Analysis

1. Procedures for Field Measurements: Temperature, Dissolved Oxygen, Electrical Conductivity, and Secchi Depth

    Temperature, dissolved oxygen and electrical conductivity were measured with a Hydrolab Surveyor 4 water quality meter equipped with these probes. All probes were calibrated in the lab prior to each field measurement day. The probes were lowered into the water column and readings were taken at 0.5 meter below the surface and at every two meters to within one meter of the lake bottom. During periods of thermal stratification, readings were taken every meter through the metalimnion to more accurately measure changes in temperature and dissolved oxygen with depth.

    Secchi disk transparency was measured using a standard Secchi disk which was lowered on the shady side of the boat. The disappearance and reappearance depths were recorded and averaged.

2. Procedures for Chemical Measurements: Nutrients

    Water samples for chemical analysis were collected with a Van Dorn style 2.2 liter sampler at two depths (0.5 meter below lake surface and 1.0 meter above lake bottom). They were poured into appropriate bottles provided by Basic Laboratory. All samples were stored in a Styrofoam ice chest and packed in ice to maintain a temperature of 4° C and dark conditions. They were transported to the Basic Lab branch office in Chico, CA within 24 hours of collection. They were immediately fixed with preservative to stabilize them until analysis.

    Basic Laboratory in Redding, CA, performed the nutrient (Total Kjeldahl nitrogen, nitrite plus nitrate, total nitrogen, ortho-phosphate and total phosphorus) analyses. This lab is certified by the California Department of Public Health to conduct these analyses.

3. Procedures for Plankton Collection and Analyses

    Phytoplankton were collected with a Wisconsin type conical net (80 micron mesh) that was pulled from the bottom to the surface to produce an integrated sample. They were preserved with Lugol's solution, as well as 40% formalin solution.

    Phytoplankton were counted and were identified to division (Chlorophyta, Chrysophyta, etc.) and to genus when this would allow for comparison with previous data and when the genus would be indicative of water quality.

Zooplankton were collected with a net towed from the bottom to the lake surface to produce an integrated sample and preserved with 40% formalin solution.

Zooplankton were enumerated and identified to order (Cladocera, Copepoda, etc.) and to suborder or genus when this would allow for comparison with previous data or where the identity had water quality significance. (Again, certain genera are indicators of lake health and it would be important to know their abundance.)

Results and Discussion

1. Physical Parameters

a. Temperature

The temperature data are shown in graphic form for each station (See figures 2, 3, 4 and 5) as well as Table 1 in Appendix). The Secchi depth is also shown on each graph as a line and disk on the left side. In April 2013 all three lake stations (LA-01, LA-02 and LA-03) were well-mixed with little temperature difference between surface and bottom. At LA-01 temperature at the surface was about 11 °C, and dropped gradually to the bottom where it was around 8 °C. LA-02 and LA-03 were slightly cooler with surface about 10 °C and the bottom at 8 °C.

By July 2013 stations LA-01 and LA-02 were thermally stratified. The epilimnion was about 22-23 °C. The metalimnion was between 5 and 14 meters. At LA-03 the temperature difference from top to bottom was less than 4 degrees, so it was not stratified.

In September surface temperature at LA-01 and LA-02 was about 20 °C. At both stations the thermocline was deeper than in July (10 meters) and the temperature in the hypolimnion was 12-13 °C. LA-03 was well mixed, with temperature of 20 °C throughout.

By November 2013 the lake was no longer thermally stratified at any station. Water temperature at LA-01 and LA-02 was about 12 °C throughout. LA -03 was about 11 °C.

Water temperatures were generally higher than in 2012. This was probably due to the lack of spring precipitation and decreased snow pack.

In summary, the lake warms up over the summer as it absorbs solar radiation and the heat energy gets distributed through the water column primarily by wind mixing. The wind is not strong enough to mix deeper than about 10 meters, as marked by the depth of thermocline (top of the metalimnion). Below the metalimnion, the hypolimnion is stable and cool. LA-03 is only 7-9 meters deep, so water can be fully mixed by wind action. By late summer most of the lake volume is 15 °C or warmer and only the deeper parts of the eastern basin have water temperatures cooler than

12 °C.
Temperature in the North Fork of the Feather River at Station LA-04 follows a similar seasonal pattern to the lake, although it is generally cooler than the lake temperature. The highest temperature was in July. (See Figure 5, as well as Table 1 in the Appendix.) The river temperature also showed the effect of decreased snow pack, with the July temperature being almost two degrees warmer than in 2012.

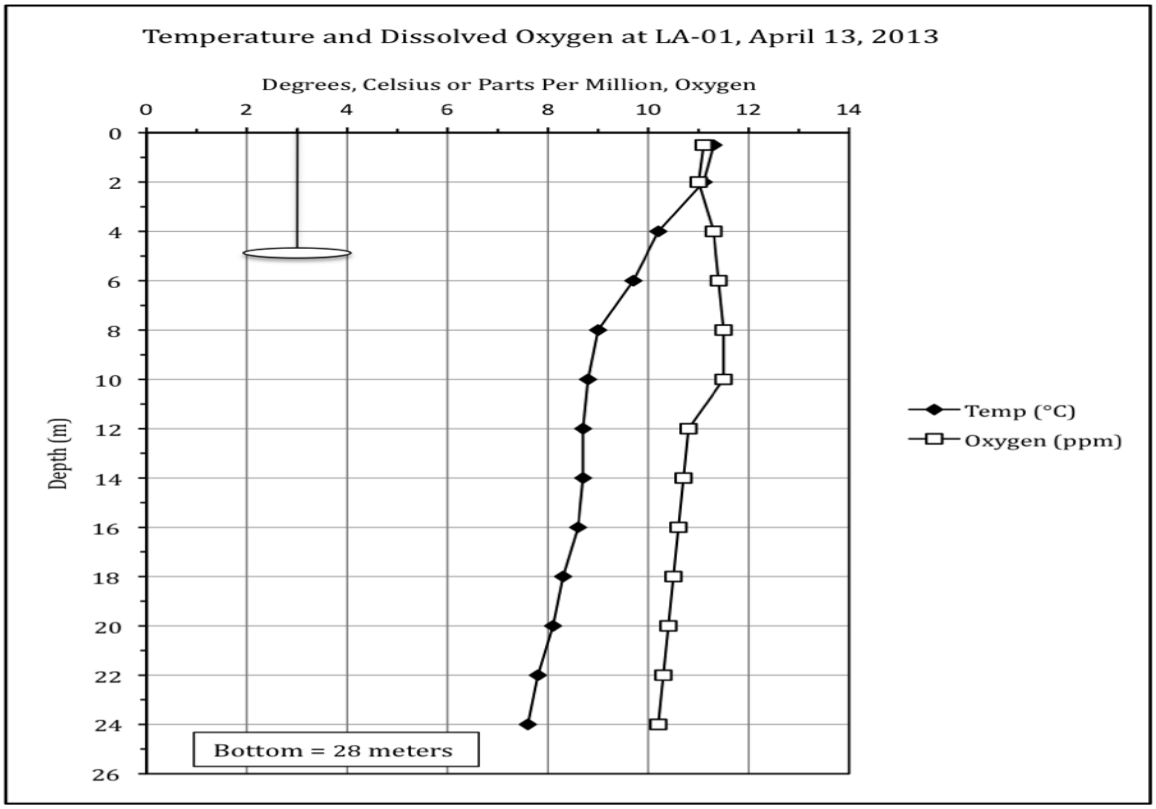
b. Oxygen

The oxygen data are shown in graphic form (Figures 2, 3, 4 and 5) along with the temperature for each station for each date, as well as in Table 1 in the Appendix. The amount of oxygen that can be dissolved in freshwater is primarily a function of temperature and atmospheric pressure. Temperature is very important, since the higher the temperature the less oxygen can be dissolved. The higher the elevation, the lower the atmospheric pressure, and the lower the pressure, the less oxygen can be dissolved. Biological processes also affect the oxygen concentration. Photosynthesis produces oxygen and respiration, including decomposition, consumes oxygen. If one of these processes exceeds the other, the oxygen concentration is affected. The amount of mixing with the atmosphere (usually due to wind action in a lake or turbulence in a stream) can affect oxygen concentration. All of these factors must be considered when trying to interpret the change in oxygen concentration from the surface of a lake to the bottom or the change from season to season.

In April 2013 the oxygen concentration at all four lake stations was between 10-12 parts per million (ppm) throughout the water column. This was approximately the maximum that could be dissolved at that water temperature (8-10 ºC) and the existing atmospheric pressure.

In July 2013 oxygen concentration in the epilimnion at all stations was 8-9 ppm, even though the water temperature was over 20 ºC. Oxygen was being maintained at a high level due to wind mixing and also photosynthesis. Due to the shallow conditions at LA-03, oxygen was between 6-9 ppm throughout. In the upper metalimnion at LA-01 and LA-02, oxygen levels increased as the temperature decreased. (Colder water can hold more dissolved oxygen.) However, below 9 meters the oxygen decreased even though temperature continued to decrease. In the hypolimnion at these two stations, oxygen levels dropped to near zero. Once the lake was stratified, the deeper portion of the lake was isolated from the atmosphere and the effects of wind mixing.

Figure 2. Temperature and Dissolved Oxygen at Lake Almanor Station LA-01, During 2013



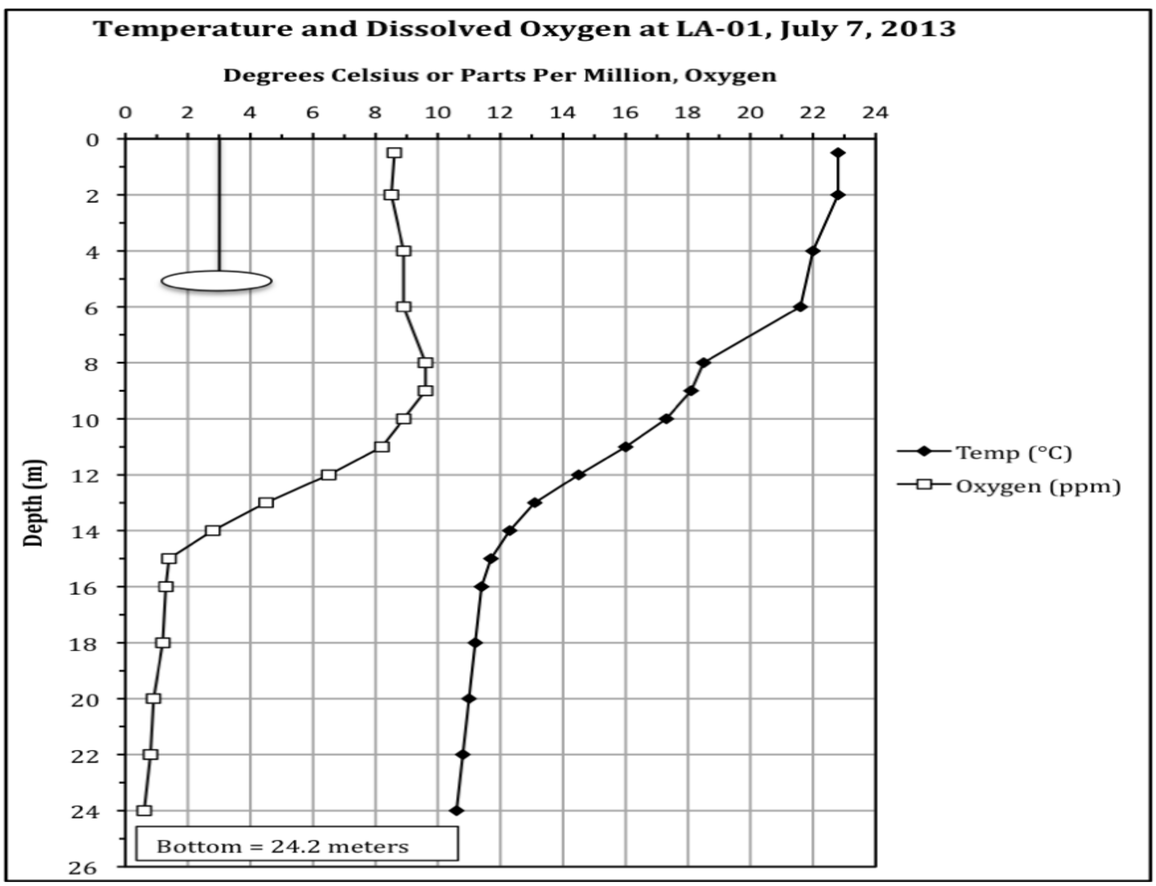
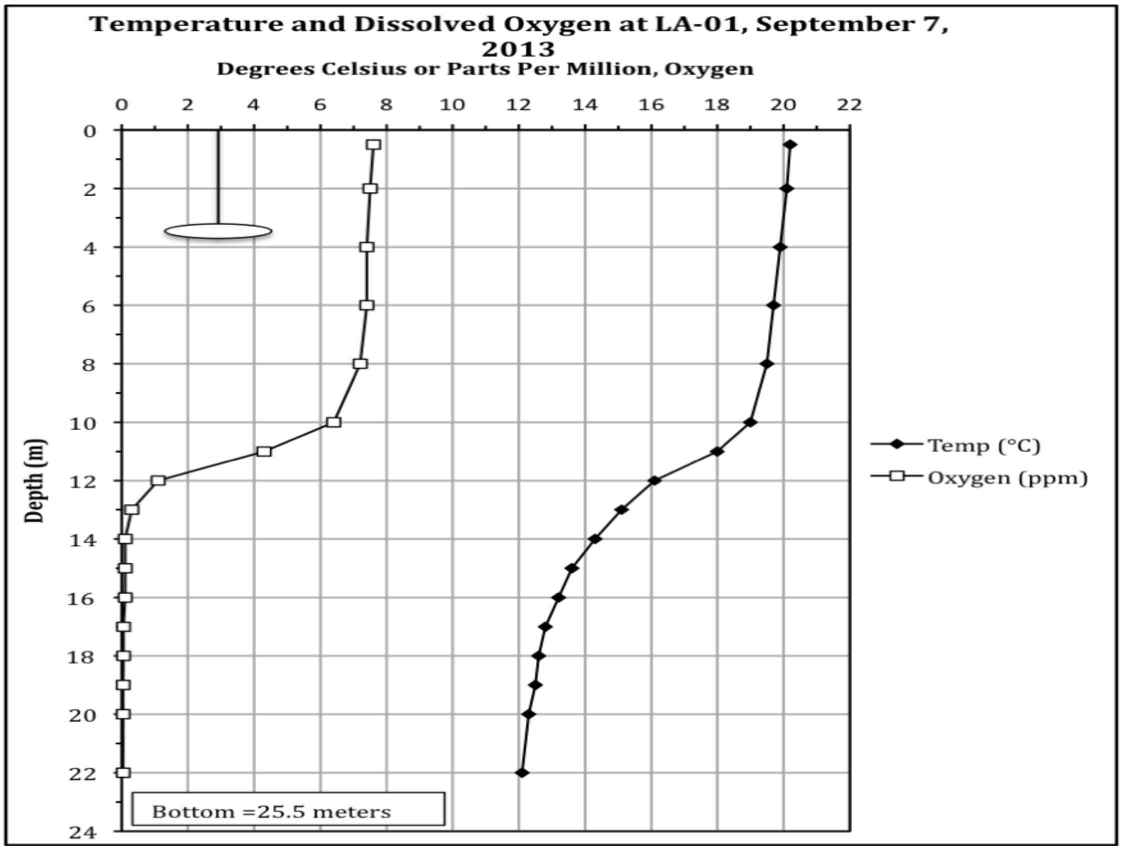


Figure 2 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-01, During 2013



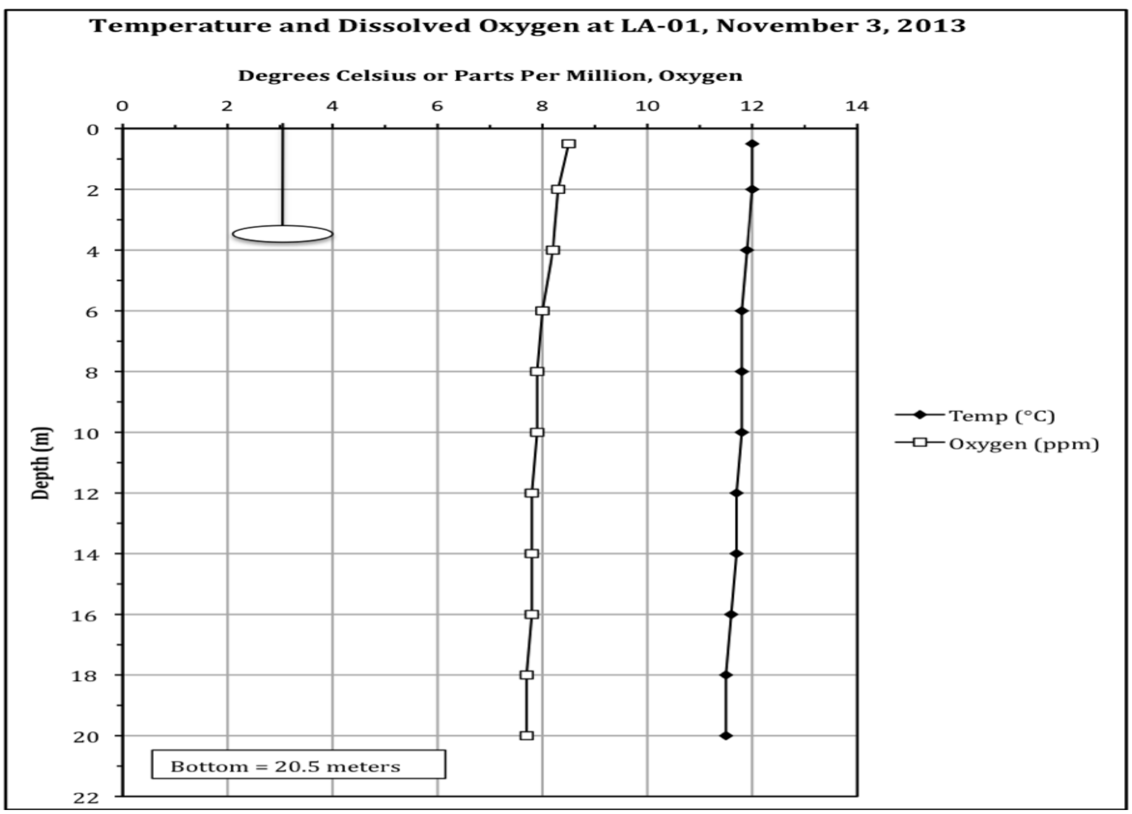
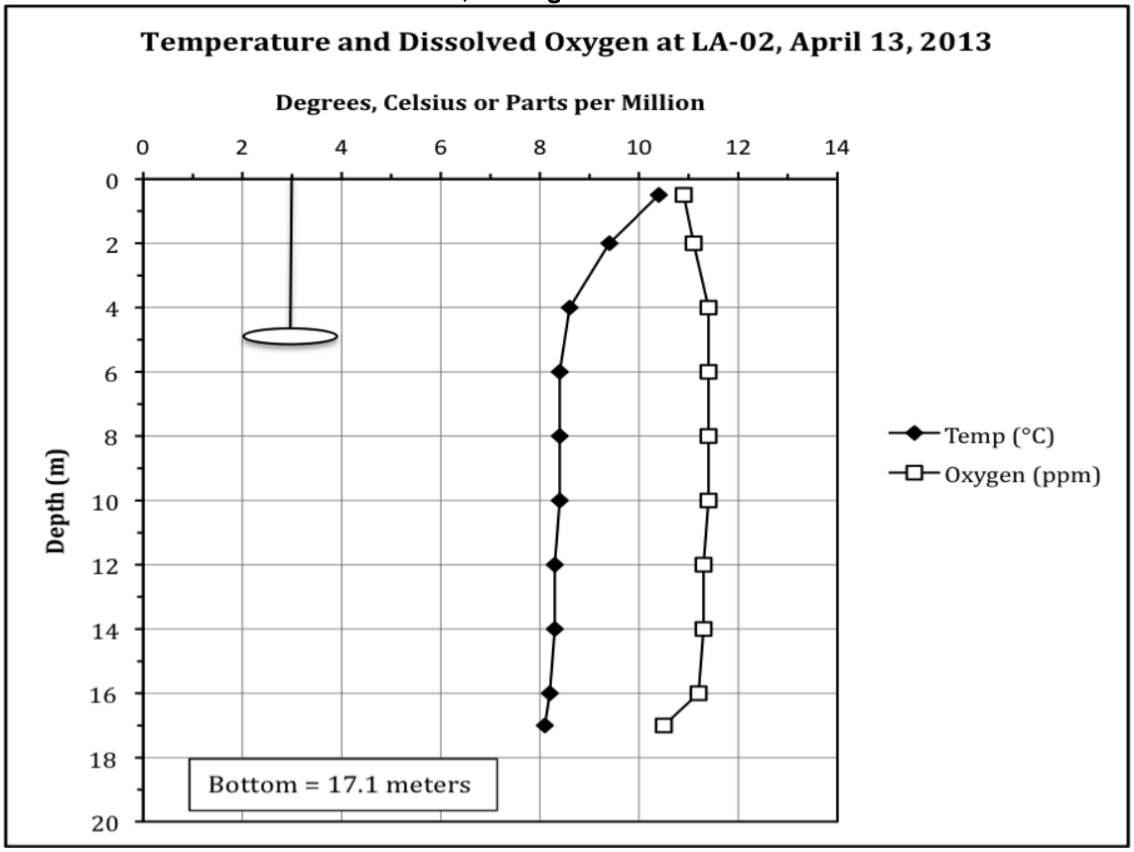


Figure 3. Temperature and Dissolved Oxygen at Lake Almanor, Station LA-02, During 2013



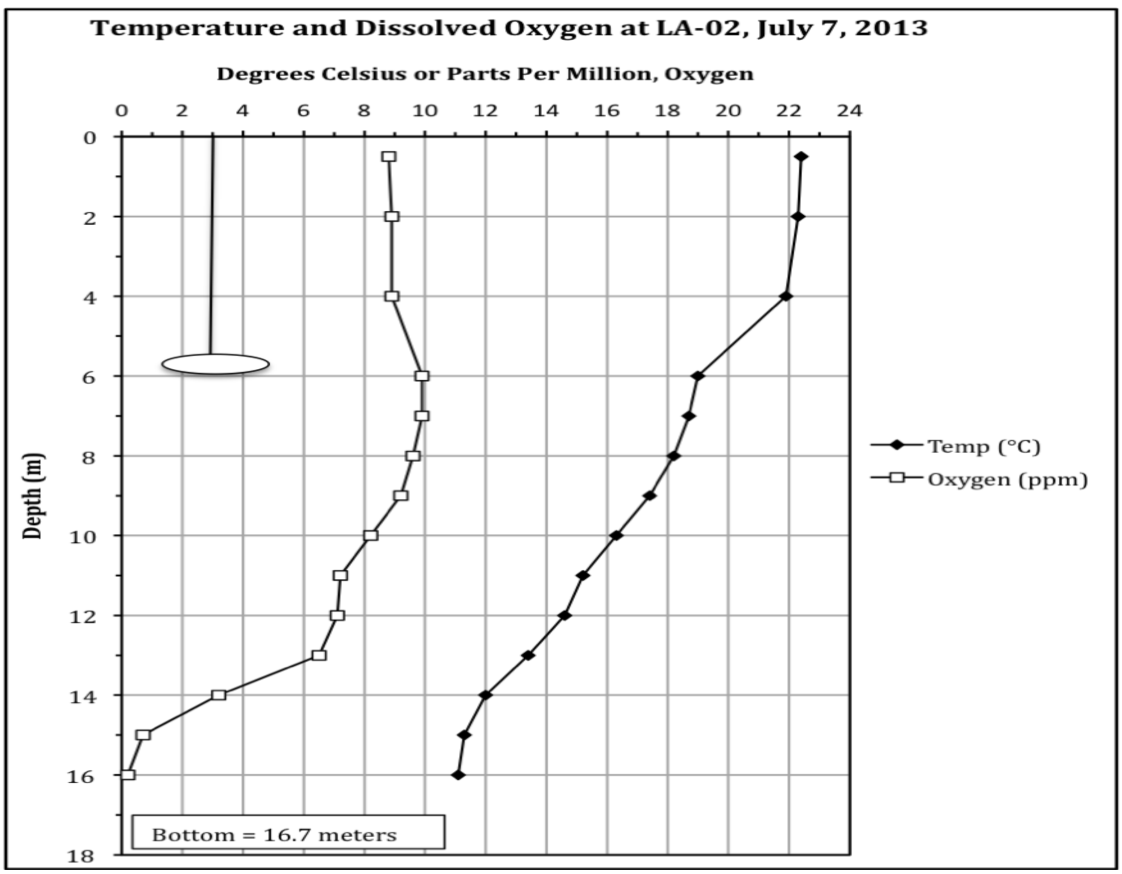
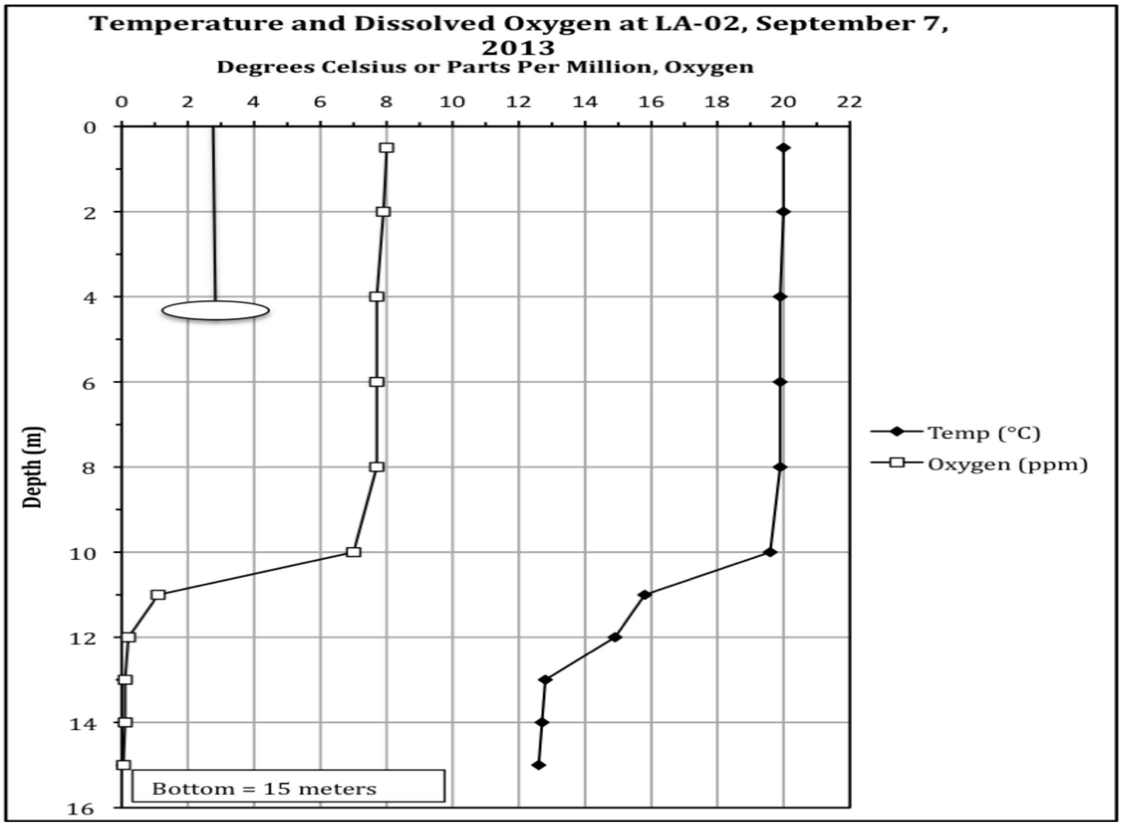


Figure 3 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-02, During 2013



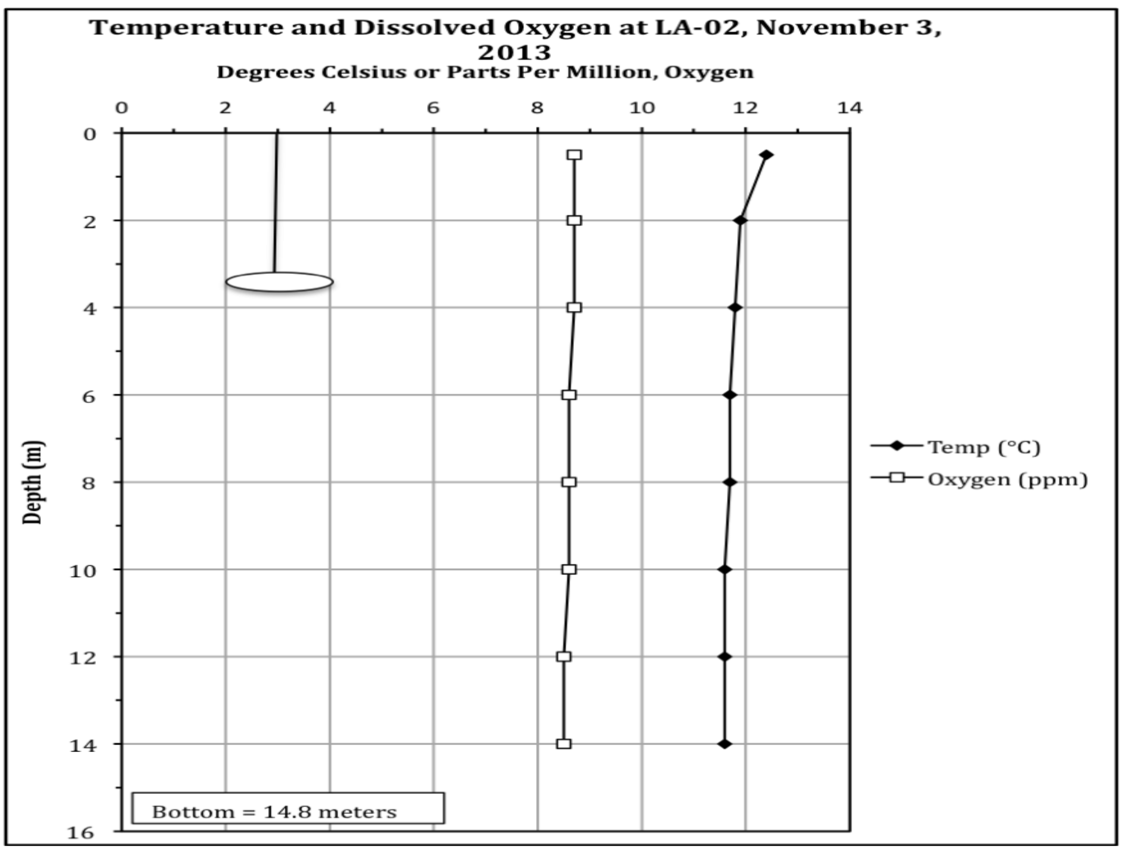
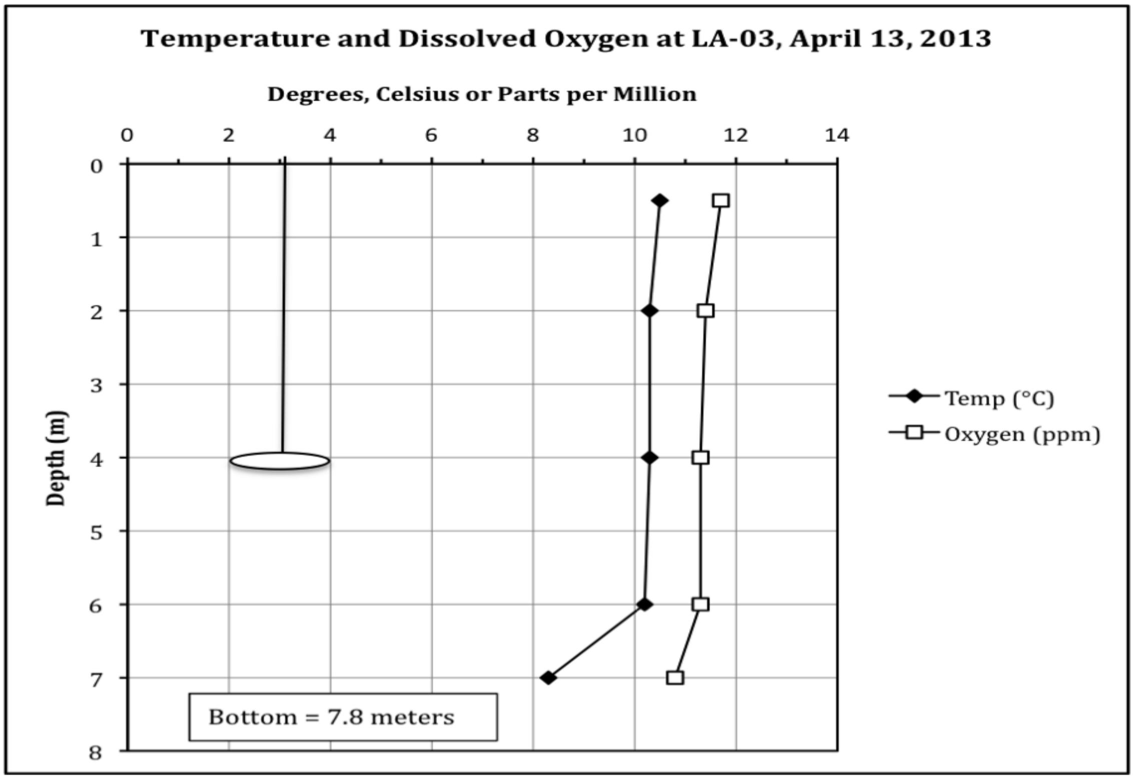


Figure 4. Temperature and Dissolved Oxygen at Lake Almanor, Station LA-03, During 2013



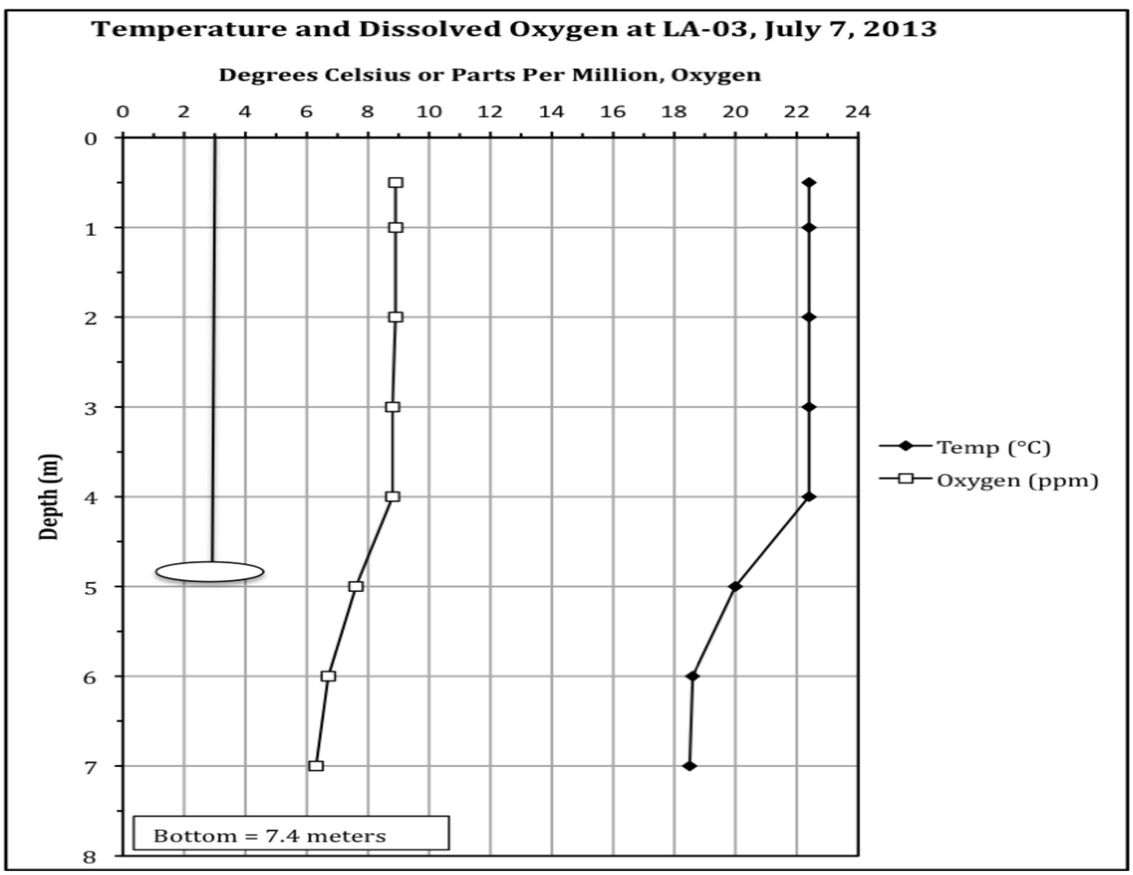
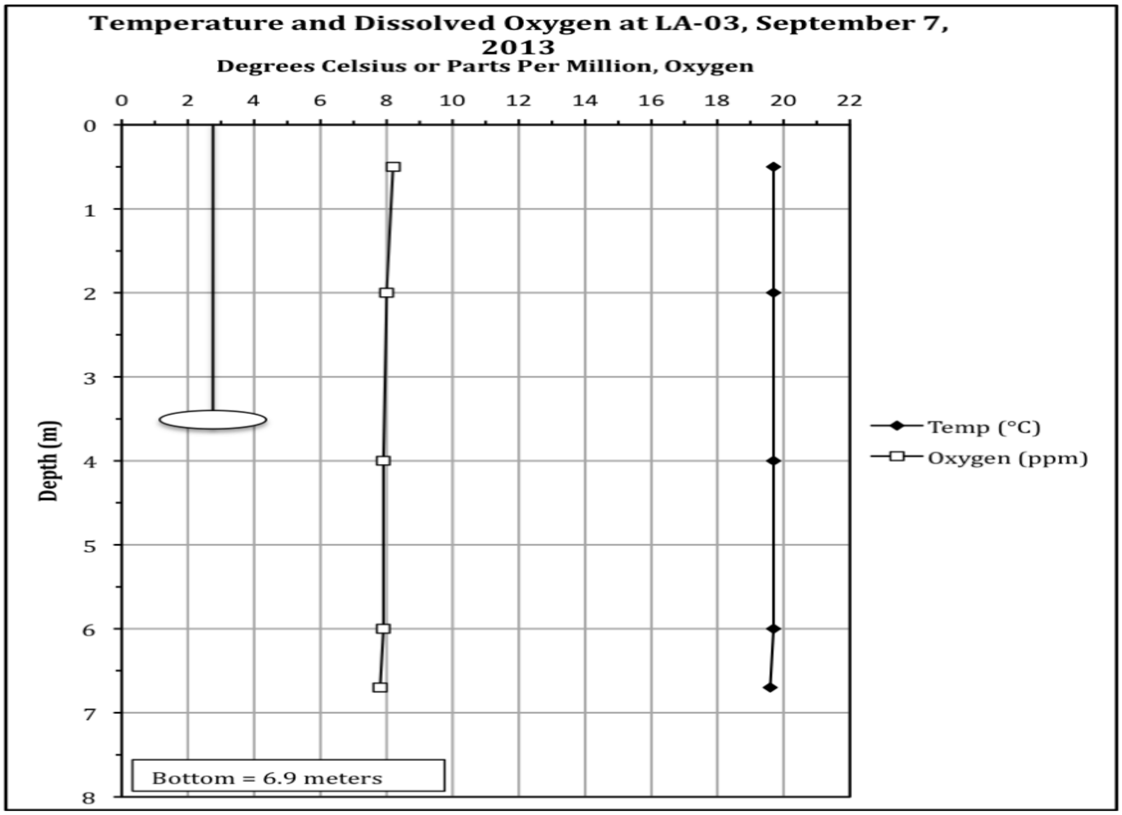


Figure 4 (continued). Temperature and Dissolved Oxygen at Lake Almanor, Station LA-03, During 2013



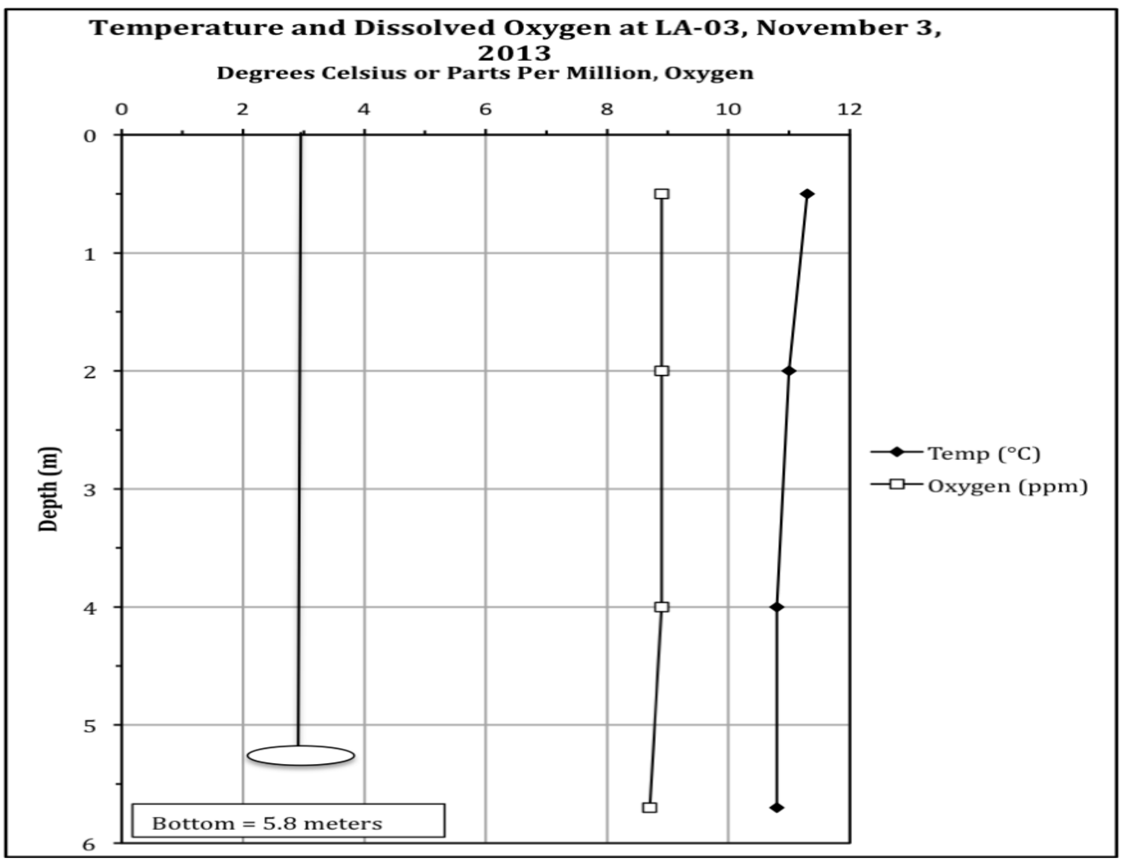
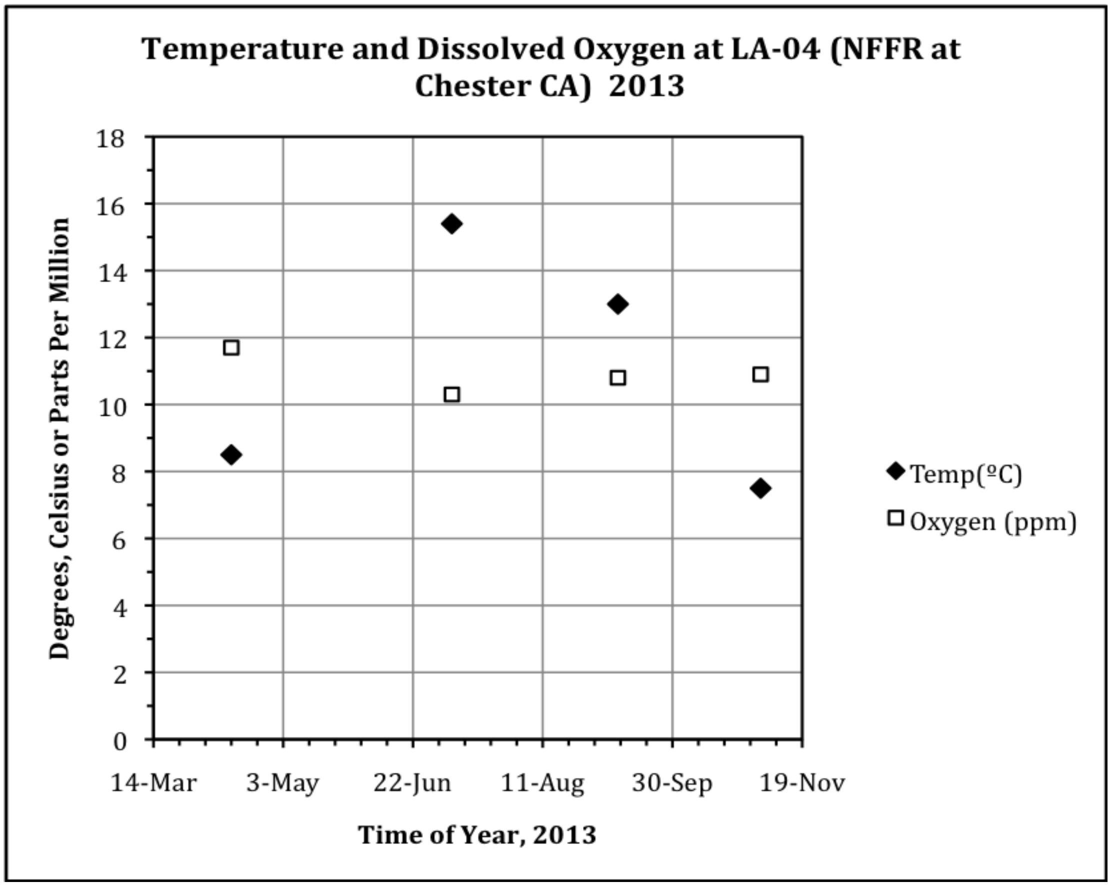


Figure 5. Temperature and Dissolved Oxygen at Chester, Station LA-04, During 2013



In the hypolimnion decomposition consumed oxygen at a faster rate than photosynthesis could produce it, so oxygen levels dropped. In the deepest part of the hypolimnion at LA-01 and LA-02, oxygen was near zero, lower than in 2012. Oxygen at LA-03 was between 6-8 ppm.

By September 2013, oxygen was still near 8 ppm in the epilimnion of LA-01 and LA-02, and throughout the water column at LA-03. In the region of the thermocline at LA-01 and LA-02, oxygen levels dropped off very abruptly to less than 5 ppm. Below 12 meters, the hypolimnion at both stations was essentially devoid of oxygen. These conditions were more severe than in 2012 where the anoxic region was below 14 meters.

As the lake cooled in the autumn, the thermal stratification broke up. By November, all stations were again well-mixed and oxygen levels were between 8 and 9 ppm throughout.

An examination of the DWR data base (1989-2004) for Lake Almanor showed that the annual pattern for temperature and oxygen has been about the same since their records began. Low levels of oxygen in the hypolimnion are the “norm” for most of summer. Data for the lake prior to 1989 is patchy, so it is difficult to determine when oxygen depletion in the hypolimnion began.

As discussed in earlier reports, the low levels of oxygen stress the cold-water fish species in the lake, since the regions where both temperature and oxygen preferences are met become scarce. In dry years such as 2013, it appears that the region of suitable temperature and oxygen is even smaller.

Oxygen levels in the Feather River are always higher than in the lake, primarily because of the colder water temperature and the turbulence of the water (See Figure 5).

c. Electrical Conductivity

Electrical conductivity is a measure of the dissolved salts in water. The data for this report is presented in Table 1 in the Appendix. Values ranged from 55-70 micro-Siemens/cm at the lake stations and from 31-52 micro-Siemens/cm in the Feather River. There was little difference between lake stations, although LA-03 tended to be lower, due to the influence of the river. The range of data is similar to that in the DWR data base for 1989-2004. The values are slightly higher than in 2012 due to the lack of precipitation throughout the spring of 2013.

d. Secchi Depth

Secchi depth is an indication of suspended particles in the water column. Data for Secchi depth is presented by a line and disk on the left-hand side of each graph, as well as in Table 1 in the Appendix. For LA-01 and LA-02 Secchi depth was about 4.5 meters and at LA-03 it was 4.1 meters in April. It increased to 5 meters or greater at all stations in July. In September it was 3.5 meters at all three stations. It was 3.5 at LA-01 and LA-02, but 5.8 at LA-03 in November. Variation is probably related to sediment carried by inflowing streams (lower values in April), as well as phytoplankton (lower values in November). Values were in agreement with those in the DWR data base and with the 2009 - 2012 studies.

2. Chemical Parameters: Nutrients

These tests were performed to get an estimate of the amount of nitrogen and phosphorus available to phytoplankton at the time of lake turnover in the spring and at the end of thermal stratification in September when nutrients in the hypolimnion would be at their highest concentration. Total nitrogen, nitrite plus nitrate, ortho-phosphate and total phosphorus were analyzed in April and September 2013 at LA-02 and LA-03. They were also analyzed at several inflows to the reservoir in April. Data are presented in Table 2 below.

Table 2. Nutrient Concentrations at LA-02 and LA-03 in 2013

Date	Station	Nitrite plus Nitrate (mg/L)	Total Nitrogen (mg/L)	Ortho-phosphate (mg/L)	Total Phosphorus (mg/L)
13 April	LA-02 surface	ND	0.46	ND	ND
13 April	LA-02 bottom	ND	0.22	ND	ND
13 April	LA-03 surface	ND	0.27	ND	0.02
13 April	LA-03 bottom	ND	0.14	ND	ND
13 April	Ham Branch above fish cages	0.05	ND	0.01	0.02
13 April	Ham Branch below fish cages	ND	0.2	ND	ND
13 April	Bailey Creek	ND	0.14	ND	ND
13 April	North Shore	ND	0.2	ND	ND
13 April	NFFR at Chester	ND	0.13	0.01	0.02
7 September	LA-02 surface	ND	0.19	0.01	ND
7 September	LA-02 bottom	ND	0.34	0.03	0.06
7 September	LA-03 surface	ND	0.2	ND	ND
7 September	LA-03 bottom	ND	0.3	0.02	ND

(Note: ND= Not Detected at the detection limit for the test)

Total nitrogen was detected in most samples in April, but values were low, close to the minimum detection limit. Total Phosphorus was detected in a few samples. The concentrations may have been low because there were already large populations of phytoplankton present in the lake in April and runoff was already low due to the lack of spring precipitation. The September data do show higher amounts, especially for ortho- phosphorus near the bottom of LA-02 and LA-03.

This is the result of release from the sediments due to anoxic conditions that develop over the summer.

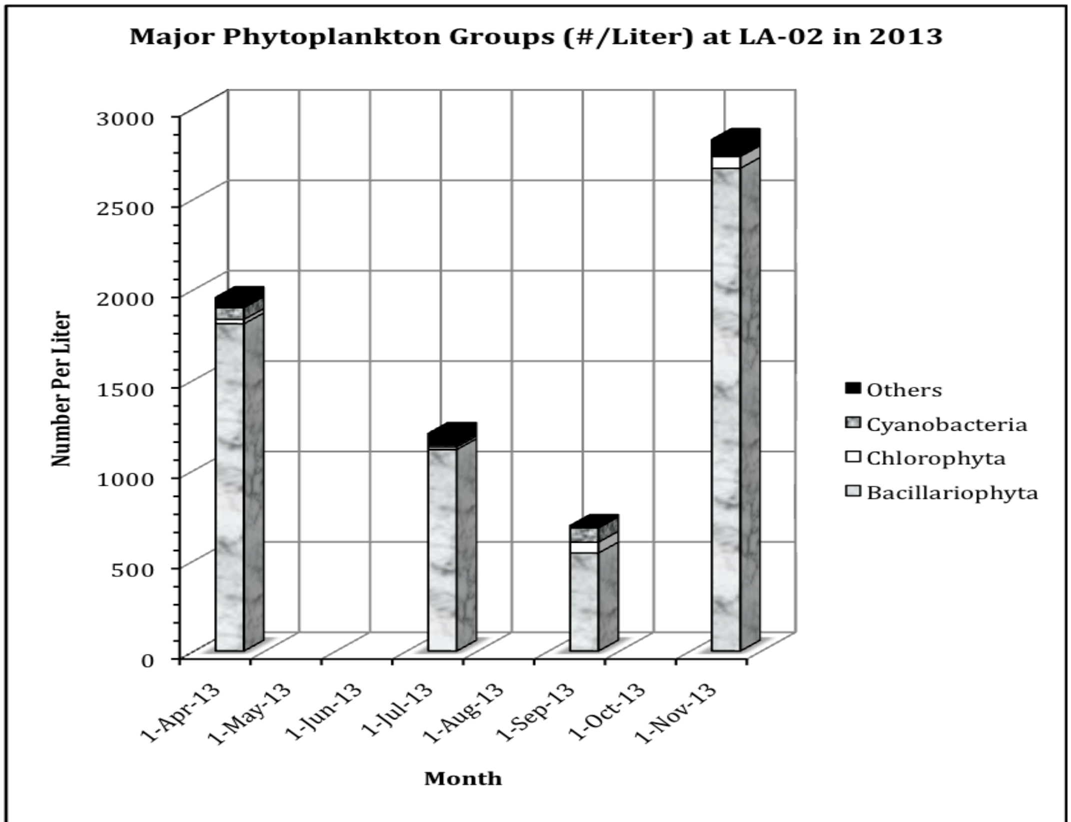
3. Phytoplankton and Zooplankton

Phytoplankton samples were collected at LA-02 and LA-03 on all four sampling dates. Data for the major groups of phytoplankton are presented in graphic form in Figures 6 and 7. More detailed data are in the Appendix. The data are presented in two different graphs for each station. The first graph shows the number of algal cells or colonies per liter of lake water. The second graph shows the volume of algal cells per milliliter of lake water (cubic microns per milliliter). This way of showing the data is more representative of the amount of algae present, since the size of individuals varies greatly.

In April diatoms (Bacillariophyta) were the dominant form at both LA-02 and LA-03, particularly *Fragilaria, Asterionella* and *Stephanodiscus.* By July some bluegreen algae appeared, primarily *Aphanizomenon*. This was the dominant alga at LA-03. Colonial green algae (Chlorophyta) were also abundant, primarily *Pleodorina and Volvox*. In September and November these genera were joined by more bluegreens, *Lyngbya* and *Microcystis*. Diatoms were still very abundant in November at both stations.

Although the species present were similar to those in previous years, the total amount of phytoplankton was considerably less than in 2012. Figure 8 shows the maximum amount of phytoplankton by volume at LA-02 and LA-03 from 2009 to 2013.

Figure 6. Major Phytoplankton Groups at Lake Almanor, By Number/Liter and By Volume (cubic microns/milliliter), Station LA-02 in 2013



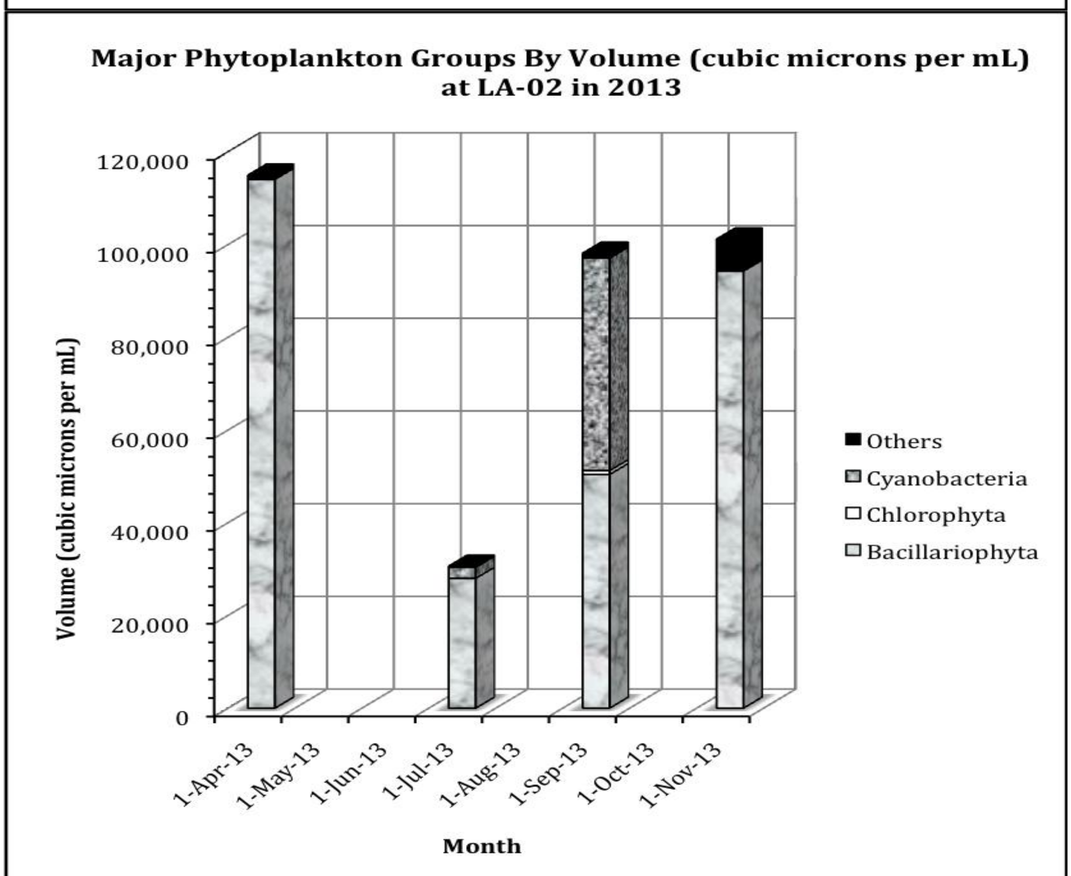
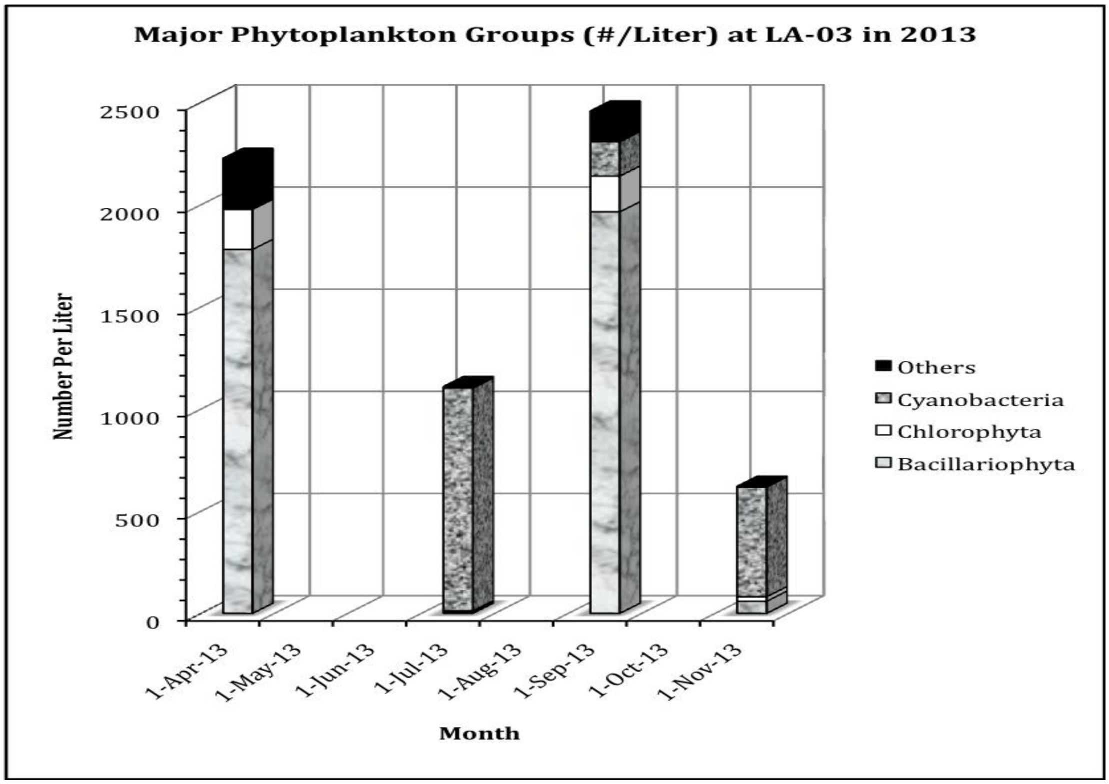


Figure 7. Major Phytoplankton Groups at Lake Almanor, By Number/Liter and By Volume (cubic microns/milliliter), Station LA-03 in 2013



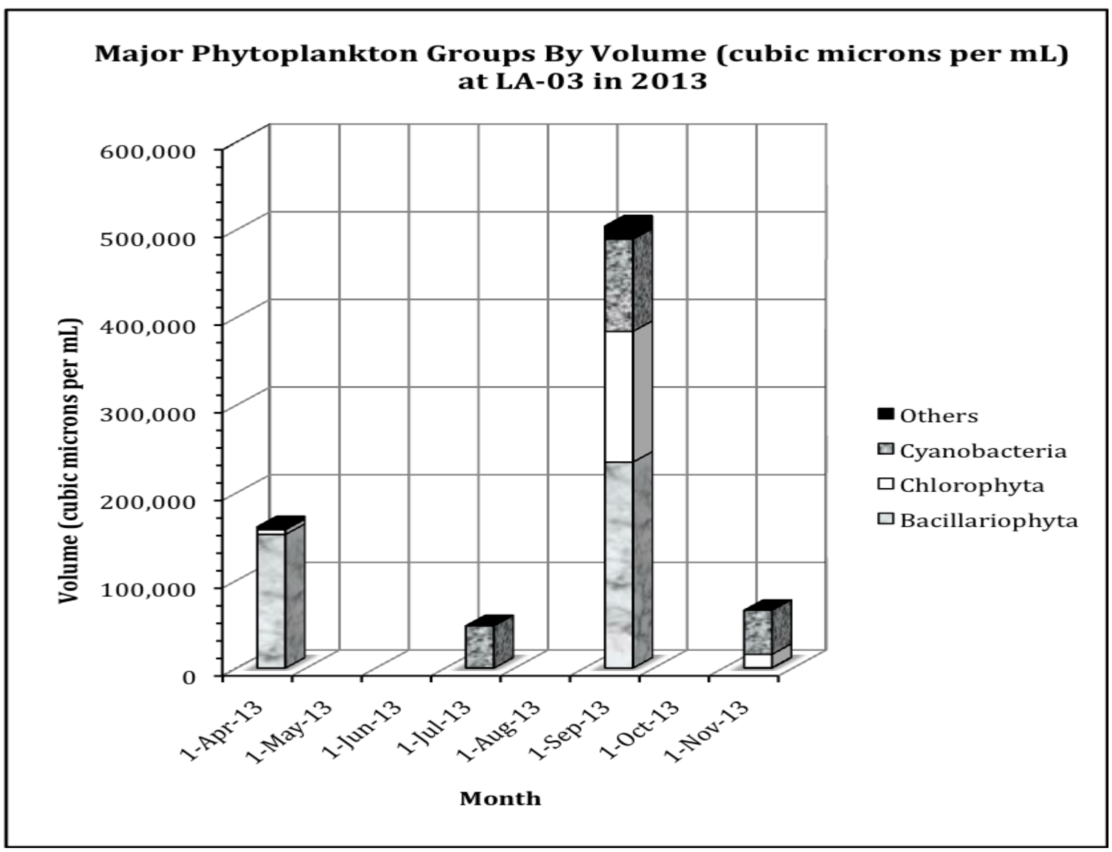
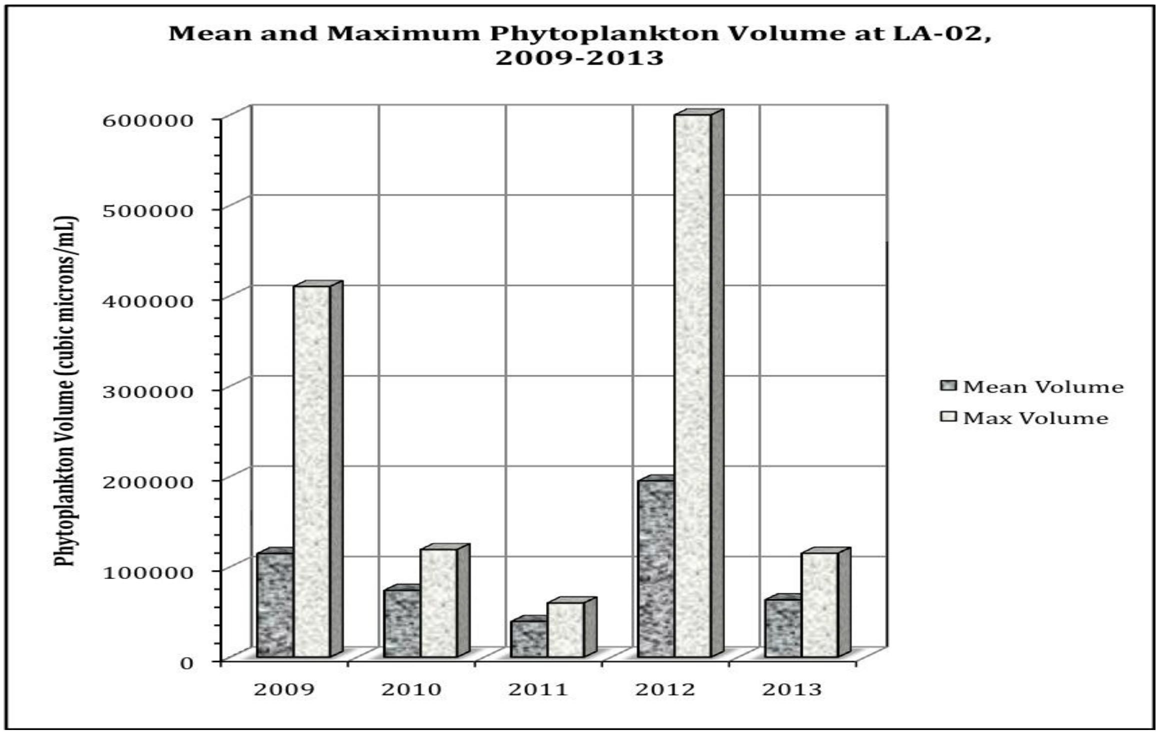
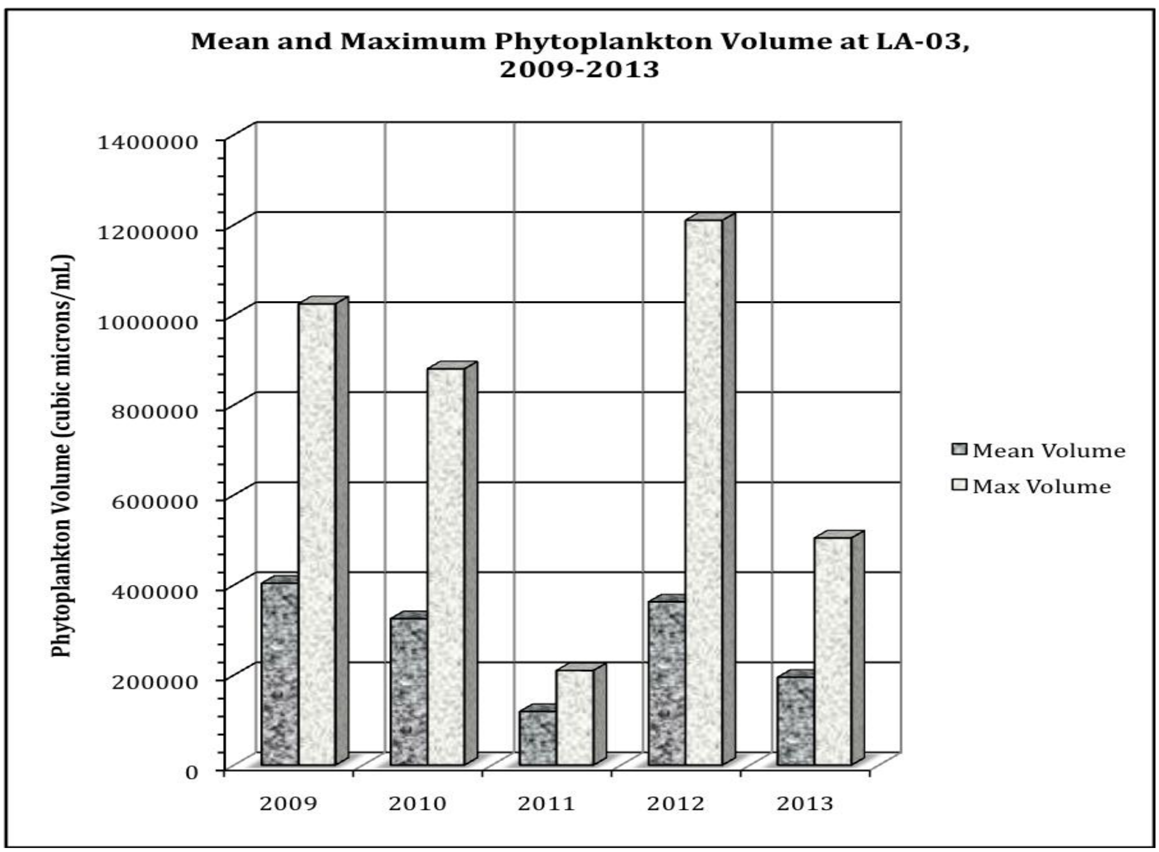


Figure 8. Mean and Maximum Phytoplankton Volume at LA-02 and LA-03, 2009 -2013





The maximum was generally in November. At LA-02 the amount in 2012 was 10 times more than in 2011. In 2013 it was very similar to 2010. At LA -03 the greatest volume in 2012 was five times the highest level in 2011. The highest level in 2013 was less than in 2009 and 2010. Bluegreen algae continued to be numerous in the late summer and fall. The lower amounts of algae overall in 2013 was probably due to the lack of runoff and lower precipitation than in 2012. These values are more like 2010 and 2011, especially at LA-02.

There are no recent data from DWR concerning the phytoplankton, but some tables from the 1970's show that many of the same species were present then. The assemblage of genera is characteristic of meso-trophic lakes.

Zooplankton were collected along with the phytoplankton and results are presented in Figures 9 and 10. More detailed data are in the Appendix.
The most abundant group at both stations was the Rotifera, with few Copepoda and Cladocera present. Most likely, their small size limits predation by small fish, whereas Copepoda and Cladocera are readily eaten. The most common genera were *Keratella* and *Polyarthra* at both stations. Their April abundance was generally similar to 2012, but populations were low in September. Perhaps this was because the phytoplankton was dominated by *Aphanizomenon*, which is not a food source for zooplankton. By November populations were higher. Cladocera were abundant at LA-03 and were possibly responsible for the low algal populations. Typically, LA-03 has a large population of algae in November.

Figure 9. Major Zooplankton Groups (#/Liter) at Lake Almanor, Station LA- 02, 2013

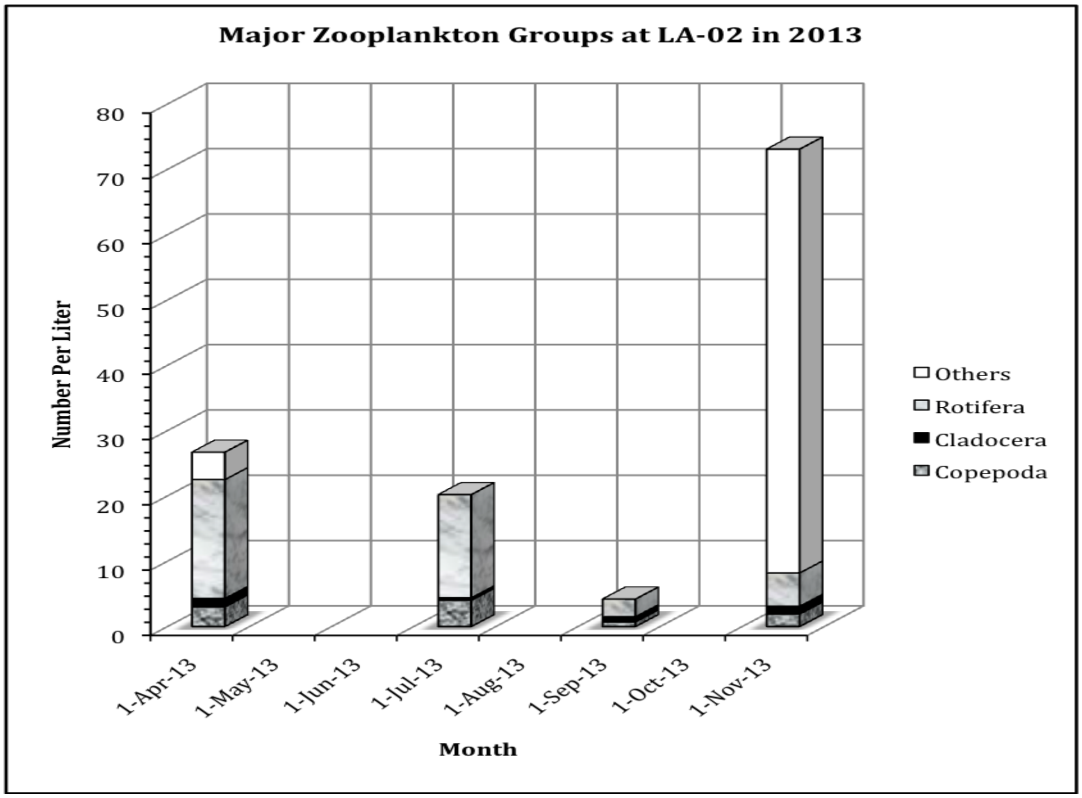
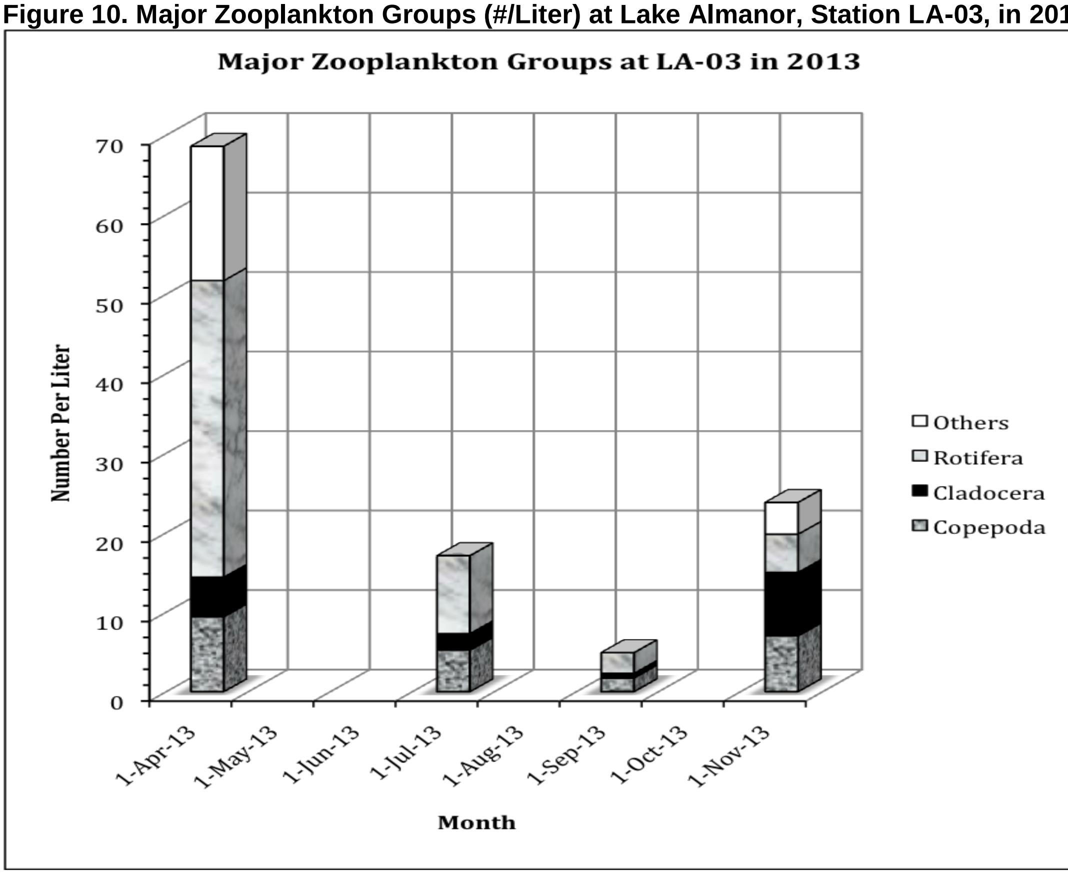


Figure 10. Major Zooplankton Groups (#/Liter) at Lake Almanor, Station LA-03, in 2013



Conclusion

Lake Almanor is a fairly rich reservoir capable of supporting a diverse assemblage of plants and animals. Large populations of phytoplankton can develop during lake overturn in the spring and fall. Nutrients that collect in the hypolimnion during the period of thermal stratification in the summer are distributed throughout the water column during periods of overturn or mixing. When there is an abundance of precipitation and cool weather in the spring, this can slow population growth and favor green algae or diatoms over bluegreen algae. If summer and fall are warm, this favors blue-green algae. In 2012 the nuisance species of algae were much higher than in 2011 due to the warm, dry weather. However, if runoff in spring is reduced due to lack of precipitation, there may be less nutrient input and less algae growth. This seems to be the case in 2013.

A more extensive study of the nutrient budget of the lake might reveal major sources of nutrients. Loss of oxygen in the hypolimnion does result in release of nutrients from lake sediments, but other sources could be septic tanks, golf courses or lawn fertilizer.

General Discussion of Lake Conditions and the Importance of Monitoring

Lakes and reservoirs are often pristine right after they are created. However, when rivers, groundwater and human activities bring nutrients (phosphorus, nitrogen and other chemicals needed for plant and animal growth), sediment and other substances into them, they begin to change. The rate at which these substances enter can affect how quickly the system changes. Over time the lake or reservoir begins to accumulate sediment and nutrient concentration increases. Eventually, the nutrients are sufficient to support a large population of phytoplankton or other plants. If the growing conditions are suitable, certain nuisance species of phytoplankton (blue-greens) or rooted aquatic plants may become numerous to the point that they interfere with the use of the water for recreation or drinking. As more plant material is produced, only a portion of it is consumed by fish and other animals. This “extra” organic material settles out of the water and accumulates near the bottom. Bacteria will decompose the material and use up the dissolved oxygen in the deeper portion of the lake or reservoir. The loss of dissolved oxygen can become so severe that some fish species, such as trout, can’t survive. Tolerant species, such as catfish or carp, may become more abundant. The system continues to change physically and biologically until it becomes dominated by algae and aquatic plants, with a limited number of fish species that can tolerate these conditions.

Lake Almanor is a reservoir that is already undergoing many changes. Because of the lake’s high elevation, the cooler water temperature and the short growing season limit some plant growth. However, the western basin is shallow and the water is warm in the summer. Phytoplankton and larger aquatic plants can become very numerous at this time of year. There are enough nutrients coming in from the river, streams or from human activities (septic tanks, golf courses, lawns) to support abundant plant growth. As more homes are built in the watershed, the nutrient input will increase.

In the eastern basin, the water is deep enough to become thermally stratified in the summer. The warm, well-oxygenated water at the surface does not mix with the colder water deep in the lake. Over the summer, the deep water's oxygen supply gets depleted by bacterial decomposition and oxygen levels drop to zero. This is a stressful time for those fish species that need both cold water and sufficient oxygen, such as trout (Raleigh *et al*, 1984). The warm, nutrient-rich water near the surface may support large populations of phytoplankton, especially blue-green species. As these algae become more numerous, they will detract from the lake's appearance and may limit recreational use. Even though climatic variations from year to year may temporarily affect population size, nuisance species of algae will most likely increase in abundance as more development occurs in the watershed.

Data collected by California DWR and others show that oxygen depletion in some parts of the lake has been occurring at least since the 1970's. Since only a few locations have long-term data, we don't know if a change in the percentage of affected lake area has occurred. The data on algal composition and abundance has been more sporadic. There have been some bluegreen algae at least since the 1970's, but we don't know if the number of species and total amount of algae have increased. A long-term data base of reservoir conditions is vital to any land or water use management decisions. Historical data and the current monitoring program data suggest that the water quality is deteriorating, since the oxygen depletion in the summer seems to be widespread and the amount of bluegreen algae may be increasing. The lake is undergoing changes that will affect its esthetic appearance and our ability to use it for recreation. We need to continue a monitoring program that will provide the data to inform our land and water use decisions.

Suggestions for Future Monitoring

For the last five years we have collected physical and biological data and some nutrient data. While there have been variations due to weather, especially precipitation, the pattern of the physical data has been similar from year to year: mixing from fall to spring and thermal stratification at the deep stations (LA-01, LA-02 and LA-07) during the summer. The biological data have been less predictable. In November 2009, algal populations were over one million cubic microns/milliliter of lake water at LA-03 (mostly diatoms). In November 2010, the population was nearly 900,000 (mostly bluegreen algae). In November 2011, the population was about 240,000 (mostly diatoms). In November 2012, it was over one million again, but mostly bluegreen algae. In 2013 the highest population was in September at LA-03, about 500,000 cubic microns/milliliter, and it was a mix of algae. The biological component seems to respond very quickly to seasonal differences in temperature, precipitation and runoff.

Future monitoring of Lake Almanor must continue to include the collection of physical data as long as the construction of a thermal curtain remains a possible lake modification. It is important to document how limited the pool of cool water is in the lake during the summer months and to show that oxygen levels are low during this time. The inclusion of LA-07 last year allowed us to see that there is a limited pool of deep cool water in the western lobe that also becomes depleted of oxygen in the late summer. This year the water was generally warmer due to lack of snowmelt runoff and the anoxic conditions included more of the water column. This put fish at even greater stress in the summer months.

It is also important to monitor the phytoplankton and zooplankton so that we know the degree to which bluegreen algae are increasing and whether there are permanent changes to the foodchain base in the lake. The diversity of the phytoplankton and zooplankton indicate the biological health of the lake and its ability to support other life forms. At least two stations (LA-02 and LA-03) should be included because conditions in the two lake lobes are so different.

If more funds become available, nutrients should be monitored at inflowing streams and springs. This would allow us to determine if there are identifiable point sources of nutrients. Additional sampling along the reservoir perimeter would be needed to determine if there are nonpoint sources. Possibly, chloride monitoring should be included as an indicator of septic tank inputs. The timing of such monitoring would be dependent on the annual precipitation pattern. Because of the expense involved for sample collection and analysis, this may have to be postponed until the monitoring budget is larger.

The monitoring program of the last five years should be viewed as the minimum for understanding lake conditions. It should be continued as long as funds are available.

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