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Santa Clara Valley Water District

December 9, 2013

Mr. Bruce H. Wolfe, Executive Officer
California Regional Water Quality Control Board
San Francisco Region
1515 Clay Street, Suite 1400
Oakland, CA 94612

Subject: Technical Report on Methyl Mercury Production and Control Studies

Dear Mr. Wolfe:

Attached is the 2013 technical report on Methyl Mercury Production and Control Studies (Report). The Report provides an update of activities conducted voluntarily by the Santa Clara Valley Water District (District), to address the Total Maximum Daily Load Implementation Plan for Mercury in the Guadalupe River Watershed. The Report also describes the District's ongoing projects to evaluate treatment methods for reducing methyl mercury production in three reservoirs and one lake impacted by past mining activities in the Guadalupe River Watershed. The District voluntarily initiated these studies in 2005 and is pleased to report that:

1. The first treatment device installed in 2006, followed by three others in 2007 and 2008, continue to suppress methyl mercury production in the water column of Lake Almaden.

2. Similar treatment devices installed in 2007 have proven ineffective at improving water quality at Almaden and Guadalupe Reservoirs.

3. In November 2011, the District installed an oxygenation system at Calero Reservoir, to address hypolimnetic methyl mercury production. Operation of the system was delayed until April 2013, and was limited during 2013 due to the installation of power. The system is planned to be operated on a full time basis in 2014.

4. In May 2013, the District installed an oxygenation system at Guadalupe Reservoir, to address hypolimnetic methyl mercury production. The system was operated on a limited basis (50 hours per week) from July to October using temporary power. The system is planned to be operated on a full time basis in 2014.

5. The District is planning to install a hypolimnetic oxygenation system at Almaden Reservoir in 2014.

The purpose of this report is to address Special Studies 1 and 2 as described in the Basin Plan Amendment (BPA) of 2008. The data in this technical report are preliminary and subject to change as the study progresses.

Special Study 1 addresses the question "*How do the reservoirs and lakes in the Guadalupe River watershed differ from one another*?" The key findings so far that respond to this question are:

- Lake Almaden has much higher seasonal concentrations of nutrients and methyl mercury than the reservoirs;

- Reservoir outlet works do not affect methyl mercury concentrations, simplifying the method for calculating dry season loads;

- The data indicate that circulation has significant effects on water column methyl mercury concentrations in Lake Almaden; and
- The limited operation of the oxygenation systems demonstrated that dissolved oxygen concentrations and Oxidation Reduction Potential values are improved without disruption of the thermocline.

With respect to Special Study 2 where the District is required to assess the possibility of increasing the assimilative capacity for methyl mercury in reservoirs and lakes, our approach is to assess the effects of hypolimnetic circulation and hypolimnetic oxygenation. This will be done by measuring changes in seasonal methyl mercury maximum concentrations, correlating them with fish tissue mercury concentrations. The District is also conducting fish sampling to augment the Coordinated Monitoring Program data, to provide a qualitative and semi-quantitative evaluation of oxygenation system operation on fish assemblages. In this context, assimilative capacity may be increased by reducing the amount of methyl mercury available for bioaccumulation and/or by improving the fish assemblages.

Please note that this Report is a proactive effort by the District to comply with the 2008 BPA provisions. The District remains committed to environmental stewardship including addressing legacy issues such as mercury in the Guadalupe Watershed, and we are voluntarily transmitting this report as a proactive step in that direction.

If you have any questions, please contact Mr. Dave Drury or myself at (408) 265-2600.

Sincerely,

Liang Lee
Deputy Operating Officer
Watersheds Stewardship and Planning Division

Attachment: Progress Report Methyl Mercury Production and Control in Lakes and Reservoirs Contaminated by Historic Mining Activities in the Guadalupe River Watershed, Dated December 31, 2013
By Electronic Mail: bwolfe@waterboards.ca.gov, caustin@waterboards.ca.gov
cc/enc: Carrie Austin, California Regional Water Quality Control
cc: B. Goldie, L. Lee, S. Dharasker, B. Cabral, F. Brewster, D. Drury
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Santa Clara Valley Water District

PROGRESS REPORT

METHYL MERCURY PRODUCTION AND CONTROL IN LAKES AND RESERVOIRS CONTAMINATED BY HISTORIC MINING ACTIVITIES IN THE GUADALUPE RIVER WATERSHED

Prepared by

David D. Drury, P.E.
Senior Engineer

December 31, 2013

Watershed Stewardship Division
Santa Clara Valley Water District

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EXECUTIVE SUMMARY

This document presents a description and interim findings of applied studies to reduce methyl mercury concentrations in three reservoirs and one lake in the Guadalupe River Watershed. These studies were voluntarily initiated in 2005 by the Santa Clara Valley Water District (District) as part of early implementation of actions by the District to restore these water bodies that have been identified as impaired due to mercury concentrations in fish that exceed applicable criteria. In October 2008, the Regional Water Quality Control Board (Regional Board) adopted a Total Maximum Daily Load (TMDL) for Mercury in the Guadalupe River Watershed into its San Francisco Bay Basin Water Quality Control Plan. This TMDL recognizes the District's voluntary efforts and requires only that the District provide periodic progress reports regarding its studies of methyl mercury production and controls. The District voluntarily agreed to submit this progress report to the Regional Board by December 31, 2013.

The data interpretation, data analysis, and conclusions in this report are preliminary and subject to change as the study progresses.

In 2003, the District contracted with Tetra Tech, Inc. to collect data and prepare several technical reports regarding mercury contamination, fate and transport in the Guadalupe River Watershed. These reports, produced from 2003 through 2005, were voluntarily funded solely by the District to support the development of a science-based TMDL, to ensure that remedial actions would be cost-effective. A key finding of the effort relevant to this document was that methyl mercury concentrations in reservoirs and lakes achieved seasonal maxima during the summer months and these maxima appeared to coincide with anoxic conditions in the hypolimnia. In 2005, the District voluntarily initiated a monitoring program in the three reservoirs and one lake in the Guadalupe River Watershed that confirmed this finding.

After confirmation that methyl mercury concentrations varied with anoxia in the hypolimnia, the District reviewed various treatment alternatives available to reduce the extent and duration of anoxic conditions. In 2006, the District conducted a pilot test of a treatment device in one lake to demonstrate whether or not methyl mercury concentrations could be affected by mechanical means. A solar-powered circulator was operated for approximately nine months to treat a portion of the lake, achieving reductions of methyl mercury concentrations as high as 90% in the water column as compared to the previous year. Additional deployments of these circulators in the lake and in Almaden and Guadalupe reservoirs occurred in 2007 and 2008 to evaluate this method on a larger scale. As reported in the District's December 31, 2011 Progress Report, this method is ineffective at controlling methyl mercury production in the reservoirs.

During the reporting period (January 1, 2012–December 31, 2013), the District continued its monitoring and sampling program of its applied studies to test the hypotheses presented in the December 2011 Progress Report; completed installation of a full scale oxygenation system in Calero Reservoir and operated the system for portions of the stratification period; abandoned the plan to conduct pilot tests of hypolimnetic oxygenation in Almaden Reservoir and instead purchased full scale oxygenation equipment; and purchased and installed a full scale oxygenation system in Guadalupe Reservoir and operated the system for a portion of the stratification period.

The hypotheses being tested in these applied studies are:

- Hypolimnetic circulation will reduce methyl mercury concentrations in Lake Almaden to meet the seasonal maximum concentration specified in the TMDL, which is expected to result in fish tissue concentrations that meet the objectives specified in the TMDL.

- Oxygenation of the hypolimnion in the three reservoirs will result in seasonal maximum concentrations of methyl mercury that meet the criterion specified in the TMDL and fish tissue concentrations that meet the targets specified in the TMDL.

The applied studies are scheduled to continue until the best available technology is identified for each water body. Monitoring of water quality parameters was initiated in 2005 and continues at the targeted frequency of monthly sampling during the months of October through March, and twice-monthly sampling from April through September. Treatment systems installed in the water bodies occurred or is planned as follows:

- In 2006, one circulator was installed in Lake Almaden; in 2007, a second circulator was installed; in 2009, two circulators were installed. The four circulators are sufficient to provide treatment of the entire lake.

- In 2007, three circulators were installed in Almaden Reservoir; one circulator provides hypolimnetic circulation of the deepest portion of the reservoir, and the other two provide epilimnetic circulation of the entire reservoir.

- In 2007, three circulators were installed in Guadalupe Reservoir; all of these together provided epilimnetic circulation of the entire lake.

- In 2011, a pilot hypolimnetic oxygenation system was purchased for use in Almaden Reservoir; the pilot tests were scheduled to begin in July 2012. However, deployment of this system was found to be infeasible at this site.

- In 2011, a full scale hypolimnetic oxygenation system was purchased for installation in Calero Reservoir. Site preparation difficulties delayed operation until late May 2013, when the system was operated on temporary power (diesel generator) for two weeks at 52 hours per week. Conversion from temporary to permanent power interrupted operation of the system for most of the month of June. The system was operated 100 hours per week in July and August, then continuously in September 2013.

- In May 2013, a full scale hypolimnetic oxygenation system was installed in Guadalupe Reservoir, but due to vandalism operation was delayed until July 2013. The system was operated 52 hours per week on temporary power (diesel generator) for the months of July, August, and September 2013.

- In 2013, a full scale hypolimnetic oxygenation system was purchased for Almaden Reservoir with installation and operation planned for 2014.

Key findings presented in this progress report are as follows:

- Methyl mercury production in hypolimnetic sediments are the main source of methyl mercury in water (and, presumably, fish).
- Low levels of methyl mercury persist in the water column of all of the water bodies year round, although concentrations at Calero Reservoir are substantially lower than those observed at the other water bodies.
- Bottom releases at the reservoirs (Almaden, Calero) result in lower seasonal maximum concentrations of methyl mercury in the hypolimnion as compared to Lake Almaden and to one reservoir (Guadalupe) with an outlet located about three meters above the bottom.
- Hypolimnetic circulation significantly reduces seasonal maximum concentrations of methyl mercury in the metalimnion and hypolimnion at Lake Almaden.
- Outlet works do not alter methyl mercury concentrations in releases as compared to concentrations in the hypolimnion.
- Lake Almaden discharges less methyl mercury than it receives from Alamitos Creek.
- Hypolimnetic oxygenation produces interesting profile patterns revealing zones of oxygen demand in the water column.
- Hypolimnetic oxygenation should begin prior to the establishment of anoxic conditions in the hypolimnion.

1.0 INTRODUCTION

Santa Clara County is located at the southern end of San Francisco Bay, and includes the largest producing mercury mines in North America (New Almaden Mining District) which ceased operations circa 1970. The Santa Clara Valley Water District (District) provides wholesale water supply and flood protection services to the communities in the county. The District owns three reservoirs and one lake impacted by the mercury mines. These water bodies were listed as impaired in 1999, and a Total Maximum Daily Load (TMDL) was adopted by the San Francisco Bay Regional Water Quality Control Board (Regional Board) in 2008 for these water bodies as part of the Guadalupe River Watershed TMDL. In the TMDL, it is recognized that the District initiated voluntary applied studies in these water bodies prior to its adoption, and that continuation of these studies is one means of compliance with regulatory enforceable portions of the TMDL applicable to the District. As specified in the TMDL, this progress report from the District regarding these studies is due December 31, 2013. This report covers the reporting period of January 2012 through December 2013. This study is intended to respond to the Special Studies 1 and 2 described in the TMDL and articulated as the following questions: “How do the reservoirs and lakes in the Guadalupe River watershed differ from one another?” and, “Is it possible to increase the assimilative capacity for methyl mercury in reservoirs and lakes?” The data collected to date do not fully address these questions, and the conclusions presented in this report are preliminary and subject to change as the study progresses.

Almaden, Calero and Guadalupe Reservoirs were constructed in the 1930’s for the purpose of water conservation, with design capacities of 1,780, 10,050, and 3,723 acre-feet, respectively. All three reservoirs are located in the Guadalupe River Watershed that drains to San Francisco Bay and all are impacted by mercury mining operations that began in the 1840’s and ended in the 1970’s. Lake Almaden was created by in- and off-stream gravel quarry operations circa 1950-1960. The lake is fed by Los Alamitos Creek (drains Almaden and Calero Reservoirs) and its outlet is the confluence with Guadalupe Creek (drains Guadalupe Reservoir) that forms the main stem of Guadalupe River. The lake is approximately 40 acres in area, with a maximum depth of 13 meters (43 feet), and is used for recreation, including boating, swimming, and fishing. Only Almaden Reservoir exhibits extensive macroscopic vegetation. Fish in these water bodies are contaminated with mercury at concentrations that exceed applicable criteria.

Solar-powered circulators have been installed in Almaden and Guadalupe Reservoirs and in Lake Almaden to evaluate the effect of circulation on methyl mercury production and methyl mercury concentrations in fish tissue. Three circulators in Almaden Reservoir provide both hypolimnetic (one device) and epilimnetic (two devices) circulation. In 2013, the circulators in Guadalupe Reservoir were replaced with a full scale hypolimnetic oxygenation system. Four circulators in Lake Almaden provide hypolimnetic circulation.

This report examines the similarities and differences of methyl mercury production in these water bodies before, during, and after seasonal thermal stratification, and evaluates the effects of circulation and hypolimnetic oxygenation on methyl mercury production spatially and temporally. Correlations and comparisons of other water quality parameters to methyl mercury production are also evaluated. The effects of circulation and hypolimnetic oxygenation are expected to reduce seasonal methyl mercury maximum concentrations while improving the ecology of the water bodies, leading to a more robust fishery. In this context, assimilative capacity is to be increased by reducing the amount of methyl mercury available for bioaccumulation and increasing the biomass amongst which the methyl mercury is distributed.

2.0 BASELINE CONDITIONS

In 2003, the District contracted with Tetra Tech. Inc. to conduct a study of mercury fate and transport in the Guadalupe River Watershed. In the Tetra Tech, Inc. February 8, 2005 Data Collection Report, Volume I, page 4–31, a key finding was "[t]he most significant production of methylmercury occurred when the hypolimnion [of Almaden and Guadalupe Reservoirs] was largely anoxic (dissolved oxygen levels less than 1 mg/l), as expected for microbial transformations by sulfate reducers that require anoxia." Fish tissue concentrations in target species were also presented in this report.

In 2005, the District initiated a comprehensive monitoring program to develop a database of seasonal changes in concentrations of nutrients, physical parameters, and mercury species in three reservoirs (Almaden, Calero, Guadalupe) and Lake Almaden. These data (Figures 1 and 2, 4, 5 and 6) confirmed the seasonal production of methyl mercury associated with anoxia in the hypolimnion. These data are collected annually and serve as comparator data to similar data collected following the installation and operation of solar-powered circulators and/or hypolimnetic oxygenation systems in the reservoirs and in Lake Almaden.

In 2012 and 2013, the District and others conducted fish tissue sampling of the lake and reservoirs to establish baseline conditions for the Guadalupe River Watershed Mercury TMDL. The results are recorded elsewhere in Coordinated Monitoring Program reports submitted to the Regional Board. The District also independently conducted sampling of zooplankton in the reservoirs and measured mercury and methyl mercury concentrations to evaluate food web effects of hypolimnetic oxygenation, and conducted fish surveys to document fish assemblages present and fish populations (as a measurement of assimilative capacity), and to assess the body burden of mercury levels of a wider range of target fish species.

3.0 STUDY DESCRIPTIONS

3.1 THEORETICAL BASIS

The basic premise of these applied studies is to determine the following:

- Can anoxia in the hypolimnion be mechanically influenced in a manner that reduces methyl mercury production?
- Does reduction in methyl mercury production result in reduced concentrations of methyl mercury in fish?
- Does the method used to influence anoxia result in improved ecological conditions that supports a more robust fishery, thereby improving assimilative capacity of the water body?

The District has empirically shown the coincidence of methyl mercury production with seasonal anoxia in each of the water bodies. Numerous techniques are available for mechanically influencing anoxia in the hypolimnion, including aeration or oxygenation with bubblers, Speece cones, and circulation. Bubbler and Speece cone systems are energy intensive, requiring energy to produce and deliver oxygen or air to the delivery system and, in the case of the Speece cone, to operate the circulating pump. Circulation systems are less energy intensive, requiring energy only for pump circulation.

In (Stewart, et al. 2008) the authors state that the results of their study "suggest an important role for plankton dynamics in driving the MeHg content of zooplankton and ultimately MeHg bioaccumulation in top predators in pelagic-based food webs." In the Tetra Tech, Inc. June 7, 2004, Draft Final Conceptual Model Report, pages 4-5 and 4-6, it is stated that "the largest single jump in concentration [of methyl mercury in the food web] occurs from the water to algae." In the figure on page 4-6 of that report, it is shown that the biomagnification of methyl mercury is increased by 100,000 times from the water to algae, whereas the biomagnification factor is 2 to 5 times from algae to zooplankton, zooplankton to prey fish, and prey fish to predator fish. If these factors are correct, influencing methyl mercury concentrations in the water column is the most efficient method of reducing mercury in the food web.

The question posed in the TMDL (*Is it possible to increase the assimilative capacity for methyl mercury in reservoirs and lakes?*) relevant to these studies is being approached from the perspective of improving the water body to support a more robust fishery. The intent of this approach is to couple improved fish populations with less methyl mercury, in effect comparatively spreading less mercury amongst more fish so that each fish has less mercury than current measured concentrations. Additional approaches may be considered (including fish management) that might shift the balance of and distribution of methyl mercury in the biomass of each water body.

In this study, the solar-powered circulators and hypolimnetic oxygenation were chosen to provide the dual benefits of delivering oxygen to the hypolimnion and improving the ecology of the water bodies in a way that would improve the fisheries. The manufacturer of the solar-powered devices suggests that circulation of the epilimnion eliminates the competitive advantage of Cyanobacteria (blue-green algae) over green algae and diatoms. Unfortunately, there has been no observable effect on Cyanobacteria blooms attributable to the operation of the circulators in any of the water bodies; in particular, the Lake Almaden blooms became worse over the time period and have prevented contact swimming for the past three years; the cause of the blooms was attributed to increased nutrient input from an infestation of gulls.

Anoxia in the hypolimnion is primarily caused by digestion of organic matter, or utilization of nutrients in the water column, during naturally-occurring periods of stratification. Typically after many years of operation of a reservoir, there is a build-up of organic matter at the bottom (sometimes termed sediment oxygen demand) that would continue to cause anoxia even if all inputs of new organic matter and nutrients were eliminated. After dissolved oxygen is utilized, anaerobic digestion of organic matter produces ammonia, which is an important nutrient for the production of algae. This is why late season blooms of Cyanobacteria are common. The ammonia is near the thermocline and the Cyanobacteria can take advantage of this nutrient source using buoyancy control. In some waterbodies, the seasonal production of Cyanobacteria becomes the dominant source of organic matter that settles to the bottom and is available for digestion. In this study, hypolimnetic oxygenation may prevent or reduce Cyanobacteria blooms by preventing or reducing the production of ammonia.

3.2 STUDY APPROACH

Circulation was chosen as the preferred method of improving water quality conditions in the two reservoirs and the lake because it is a method that somewhat mimics nature and can be implemented using solar power. The short term benefits of circulation include reduced nutrient cycling, improved planktonic assemblages, and reduced methyl mercury production. The long term benefits include improved fish assemblages and lower concentrations of mercury in fish. With respect to the TMDL, circulation is expected to achieve seasonal maximum concentrations of methyl mercury in the hypolimnion that approach target concentrations, and fish tissue concentrations that approach water quality objectives. The only benefit that has been realized is methyl mercury in the water column of Lake Almaden is reduced compared to the uncirculated condition.

Oxygenation of the hypolimnion was chosen to prevent the establishment of reducing conditions that result in the production of methyl mercury. The method chosen (bubble diffuser) is intended to maintain cold water temperatures in the hypolimnion (to comply with regulatory requirements to maintain cold water flows to support downstream fisheries) while achieving benefits of reduced nutrient cycling and reduced methyl mercury production. The goal is to achieve seasonal maximum concentrations of methyl mercury in the hypolimnion that approach target concentrations, and fish tissue concentrations that approach water quality objectives.

3.3 HYPOTHESES TESTED

The deployment of circulators was implemented in three ways: hypolimnetic-only circulation; epilimnetic-only circulation; and a combination of both. All three deployments were tested, along with additional supplemental activities to enhance the effects of circulation.

3.3.1 Almaden Reservoir—Hypolimnetic and Epilimnetic Circulation and Source Control

The hypothesis tested in this reservoir is multi-faceted:

- Epilimnetic circulation will improve planktonic assemblages and reduce organic load to the bottom of the reservoir.

- Hypolimnetic circulation will reduce methyl mercury production and accelerate digestion of historic organic matter.
- Source control will eliminate sediment-derived input of mercury to the reservoir, resulting in reduced methyl mercury production.
- As a result of these actions, fish tissue concentrations of methyl mercury will decrease as compared to present data.

In this reservoir, three circulators were deployed in April 2007. Two circulators provide epilimnetic circulation to improve the ecology (described above) while one provides hypolimnetic circulation to address anoxia and reduce methyl mercury production. In August-October 2009, the only source of mining waste mercury to the reservoir was removed by a creek restoration project conducted by the District and reported elsewhere (see Jacques Gulch Restoration at www.valleywater.org). The circulators and source control actions did not have any observable effect on any of these parameters.

3.3.2 Guadalupe Reservoir—Epilimnetic Circulation and Hypolimnetic Oxygenation

The hypothesis tested in this reservoir is as follows:

- Epilimnetic circulation will improve planktonic assemblages and reduce organic load to the bottom of the reservoir.
- Hypolimnetic oxygenation will reduce methyl mercury production and accelerate digestion of historic organic matter.
- As a result of these actions, fish tissue concentrations of methyl mercury will decrease as compared to present data.

In this reservoir, three epilimnetic circulators were deployed in July 2007. The circulators actions did not have any observable effect on any of these parameters and were removed in June 2013. An oxygenation system was installed in June 2013 and operated on a limited basis from July through September.

3.3.3 Lake Almaden—Hypolimnetic Circulation

The hypothesis tested in this reservoir is:

- Hypolimnetic circulation will reduce methyl mercury production and accelerate digestion of accumulated organic matter.
- As a result of this action, fish tissue concentrations of methyl mercury will decrease as compared to present data.

In this lake, four circulators have been deployed. The first was installed in 2006, and was later modified in October 2007 to improve performance. The second device was installed in March 2007; the other two devices were installed in January 2009. Although methyl mercury production has been reduced, reductions in fish tissue concentrations have not been observed.

3.3.4 Reservoirs—Hypolimnetic Oxygenation

The hypothesis tested in the reservoirs is:

- Hypolimnetic oxygenation will reduce methyl mercury production and seasonal maxima to meet the target concentration in the TMDL.
- As a result of this action, fish tissue concentrations of methyl mercury will decrease as compared to present data.

During this reporting period, oxygenation systems were installed in two reservoirs (Calero and Guadalupe) and operated on a limited basis during the summer anoxic period.

4.0 MATERIALS AND METHODS

4.1 RESERVOIR MONITORING SITES

One location in each reservoir was selected to obtain data profiles at depth intervals of ¼- to 1-meter. Sampling locations corresponded with the deepest portion of the reservoir generally near the outlet works (all reservoirs are bottom-release penstocks), and located using a handheld sounding device. Sampling was also conducted at the outlet works downstream of the reservoirs.

4.2 LAKE MONITORING SITES

The bathymetry of Lake Almaden has been developed using echo sounding equipment (Figure 3). The information indicates that there are four distinct areas of significant depth. The two deepest areas (maximum depths of 13 [Site 1] and 11 meters [Site 2], respectively) are separated from each other and from the portion of the lake through which Los Alamitos Creek enters and exits by remnant dike material that ranges 1 to 2 meters below the surface. Seven monitoring locations were established, five of which are in the deepest areas of the lake, and one at each of the inlet and the outlet of the lake.

4.3 DETAILS OF MONITORING

Field data collected at the reservoir outlets (beginning 2008) with a Horiba U-10 Water Quality Checker (replaced in September 2010 with Hanna Instruments HI 93414 Turbidity Meter and YSI Incorporated Professional *Plus* multi-parameter data collector) included pH, specific conductivity, turbidity, dissolved oxygen and temperature logged by hand. Field data collected with a Hydro-Lab DS5 Sonde included depth profiles of pH, temperature, ORP (beginning 2006), specific conductivity, dissolved oxygen, chlorophyll *a,* and phycocyanin (beginning 2006) logged into a portable computer. Profile data were logged at ¼-meter intervals to a depth of 1 meter, at 1-meter intervals through the epilimnion, at ¼-meter intervals through the thermocline, and at 1 meter intervals through the hypolimnion. Secchi Transparency Depth measurements were also recorded by hand at each sampling event.

Water samples were collected using a Wildco beta-type Van Dorn sampling device (2.2 liter) at discrete depths. In the epilimnion, water samples were collected at a depth of 2 meters. In the hypolimnion, water samples were collected at 1 meter or less above the bottom and at a mid-depth between the epilimnion and hypolimnion sample depths. During the methyl mercury production season, additional sample depths were utilized to collect samples for methyl mercury analyses to develop a more comprehensive profile of methyl mercury concentrations in the water column.

Samples were dispensed using “Clean Hands-Dirty Hands” procedures of EPA Method 1669 into:

- Unpreserved 1-liter volume amber glass containers for analyses for chlorophyll *a* (epilimnion only).

- Unpreserved 0.5-liter volume polypropylene containers for analyses for sulfate, nitrate, and nitrite (epilimnion and hypolimnion only).

- 0.5-liter and 0.25-liter volume polypropylene containers preserved with H_2SO_4 for analyses for ammonia and total phosphorus, respectively (epilimnion and hypolimnion only).

- 0.25-liter volume FPE containers (Brooks-Rand) preserved with HCl for analyses for methyl mercury (all depths).

- Unpreserved 0.25-liter polypropylene containers for low level total mercury analyses (epilimnion, hypolimnion and inlet/outlet all specified locations) and for low level dissolved mercury analyses (epilimnion, hypolimnion and outlet at Almaden Reservoir only).

- Unpreserved 0.5-liter volume polypropylene containers for Total Suspended Solids (TSS) analyses (hypolimnion and outlet only).

4.4 LABORATORY ANALYSIS METHODS

- Unfiltered (Total) Methyl Mercury was determined using EPA Method 1630, with a Practical Quantification Limit of 0.050 ng/l.

- Unfiltered (Total) and Filtered (Dissolved) Mercury was determined using EPA Method 1631E, with a Reporting Limit of 0.500 ng/l.

- Ammonia as Nitrogen was determined using EPA Method 350.1, with a Reporting Limit of 0.100 mg/l. Prior to April 2009, lower Reporting Limits were sometimes achieved, as reported in the December 31, 2009 Progress report.

- Total Phosphorus was determined using EPA Method 365.3, with a Reporting Limit of 0.050 mg/l.

- Nitrate as NO3, Nitrite as NO2, and Sulfate as SO4 were determined using EPA Method 300.0, with Reporting Limits of 1.0 mg/l. Prior to April 2009, lower Reporting Limits were sometimes achieved, as reported in the December 31, 2009 Progress report.

- Total Suspended Solids (TSS) was determined using EPA Method SM 2540D, with a Reporting Limit of 10 mg/l.

5.0 RESULTS AND DISCUSSION

5.1 DISSOLVED OXYGEN

Oxygen depletion in the hypolimnia of lakes and reservoirs following thermal stratification is a well-documented phenomenon. Subsequent microbial digestion of other available forms of oxygen (e.g. nitrate, sulfate, carbon dioxide) leads to the production of nuisance chemical species and methyl mercury, as discussed below. Data from several years of monitoring were used to estimate the volume of anoxic water in acre-feet and as a percentage of total volume that occurs each year in Almaden, Calero, and Guadalupe reservoirs. This analysis allows for a comparison of the extent of oxygen depletion amongst the reservoirs and its relation to methyl mercury production (Figures 4, 5, 6).

Almaden Reservoir (Figure 4) seasonal maximum hypolimnion methyl mercury concentrations coincide with annual anoxia in the hypolimnion, remaining below 10 ng/L each year. Methyl mercury seasonal maxima do not fluctuate with the total volume of storage attained each year, nor with the percentage of total volume that becomes anoxic. The portion of the total volume that becomes anoxic ranges from 20 to 45 percent. The duration of anoxia ranges from one to four months. Circulation has had no apparent effect on methyl mercury concentrations or on algae production.

Calero Reservoir (Figure 5) is similar to Almaden Reservoir with respect to seasonal maximum hypolimnion methyl mercury concentrations (<10 ng/L annually); however, it differs in other parameters: higher portions of the total volume that become anoxic (35-55 percent); the duration of anoxia, ranging from four to five months, is longer than Almaden Reservoir, and the pattern of methyl mercury production in Calero also appears to differ from that observed in Almaden Reservoir, with Calero exhibiting an attenuated rise to maximum. Note that in 2013 that the hypolimnion exhibited anoxia in April, recovered (possibly due to operation of the oxygenation system), then went anoxic again a few weeks later, producing the lengthiest anoxic period observed to date in the hypolimnion.

Guadalupe Reservoir (Figure 6) differs from both Almaden and Calero reservoirs in most respects: seasonal maximum hypolimnion methyl mercury concentrations exceed 10 ng/L annually, ranging as high as 40 ng/L; the portion of total volume that becomes anoxic consistently ranges from 30 to 50 percent (which is similar to the other reservoirs); the duration of anoxia ranges from six to seven months; and, the pattern of methyl mercury production is more variable during each season as compared to the other two reservoirs. This is likely due to the outlet works being located approximately 3 meters above the bottom of the reservoir, resulting in a stagnant hypolimnetic pool that persists for several months (see Mercury/Methyl Mercury Cycling, *Guadalupe Reservoir*). The inflection in the 2013 DO<1 curve is likely due to the limited operation of the oxygenation system in summer 2013.

5.2 NUTRIENT CYCLING

5.2.1 Nitrogen

Nutrients required for living cells, in order of abundance, include carbon, hydrogen, oxygen, nitrogen and phosphorous (Horne, A.J., Course Materials: Ecology and Management of Lakes and Reservoirs, Continuing Education in Business and Technology, University Extension, University of California, Berkeley 2004). Nitrate

(NO_3) is the most common form of this nutrient in lakes and streams, and its concentration and rate of supply is directly related to land use practices in the watershed. Nitrate ions are easily soluble and move easily through soils. Ammonia (NH_4) is the preferred form of nitrogen for phytoplankton and plant growth, and is produced by decay of organic material under anoxic conditions. Generally in the reservoirs and lake of this study, Nitrate is the predominant form of nitrogen during the fall and winter and Ammonia is the predominant form of nitrogen during the summer (Figures 7 through 11).

In Almaden Reservoir (Figure 7), excursions of Nitrate concentrations above the laboratory analysis reporting limit did not occur in the epilimnion nor in the hypolimnion during the reporting period (2012-2013). Ammonia concentrations in both the epilimnion and hypolimnion exhibit seasonal cycling at relatively low concentrations (particularly as compared to Lake Almaden, see below), similar to Calero Reservoir. These results are generally similar to previous years.

In Guadalupe Reservoir (Figure 8), Nitrate concentrations above the laboratory reporting limit occurred only twice in the hypolimnion and not at all in the epilimnion during the reporting period (2012-2013); this was similar to 2009, 2010 and 2011, but quite different from previous years' results when prolonged (up to several months) excursions above the reporting limit appeared in the hypolimnion in late spring and summer of 2006 and 2008. Ammonia concentrations in the hypolimnion exhibit a seasonal pattern, with higher concentrations in the summer months, as observed in previous years, and the concentrations are significantly higher than those observed in Almaden and Calero. Ammonia concentrations in the epilimnion remained near the reportable limit throughout the year, also similar to previous years.

In Calero Reservoir (Figure 9), Nitrate concentrations above the laboratory analysis reporting limit occurred only once in the epilimnion and once in the hypolimnion during the reporting period; this was similar to 2009 and 2010, but quite different from previous years' results when prolonged excursions were observed in both the epilimnion and hypolimnion over the winter of 2006 and in the hypolimnion in the spring of 2008. Ammonia concentrations in the epilimnion and hypolimnion exhibited seasonal cycling, with concentrations in the epilimnion being somewhat more pronounced as compared to previous years.

Concentrations of Ammonia and Nitrate in Lake Almaden (Figures 10 and 11) remain significantly higher than those measured in the three reservoirs, which may reflect the urban surroundings of this lake location. Nitrate concentrations exhibited strong seasonal patterns in the epilimnion and hypolimnion at both sampling sites, similar to previous years, and appear to be unaffected by circulation. Ammonia concentrations exhibited strong seasonal patterns in the hypolimnion at both sampling sites prior to installation and operation of the circulators (2005 at Site 1 and 2005-2006 at Site 2), before modification of the device near Site 1 (2006-2007), and during the malfunction of the device near Site 2 (2009), and were suppressed during the reporting period (2012-2013) due to effects of the circulators. Ammonia concentrations in the epilimnion remained near the laboratory analysis reporting limit year-round at both sites.

5.2.2 Summary-Nitrogen

Solar-powered circulators were installed in Almaden Reservoir (April 2007), Guadalupe Reservoir (July 2007), and Lake Almaden (2006 near Site 1, 2007 near Site 2), as described above. The circulators in Lake Almaden appear to have affected the seasonal cycling of Ammonia, particularly when the intake is set at the bottom. The intake of the circulator near Site 1 was originally set at one meter above the bottom for operation in 2006 and 2007; it was reset at the bottom in early 2008. The intake of the circulator near Site 2 is set at the bottom; in 2009 the circulator at Site 2 malfunctioned and did not provide sufficient circulation to affect Ammonia concentrations, which reverted to the pre-circulator seasonal pattern. The circulators functioned regularly during the reporting period and suppressed ammonia cycling in the hypolimnia as compared to uncirculated conditions in previous years. The circulators do not appear to have had any effect on nitrogen concentrations in the reservoirs (Almaden and Guadalupe) nor has the limited operation of the oxygenation systems (Calero and Guadalupe).

5.2.3 Phosphorus and Sulfate

Phosphorus is an essential nutrient for living systems, as a structural link in genetic material, as a component of cell walls, and as a component in the energy system of cells (Horne, A.J., Course Materials: Ecology and Management of Lakes and Reservoirs, Continuing Education in Business and Technology, University Extension, University of California, Berkeley, 2004). It is naturally occurring in sediment and most of this form is inorganic and inert. The usable phosphorus is the organic form of phosphorus (PO4). Measurement of unfiltered samples for Total Phosphorus (TP) includes both inorganic and organic forms. Generally, in lake and river systems Total Phosphorus concentrations are high during winter when sediment is mobilized by runoff; organic phosphorus may also be important in urban or rural areas where excessive or improper use of fertilizers occurs. During the summer, phosphorus is bound in the sediment and becomes a limiting nutrient for phytoplankton; however, under anoxic conditions the organic form of phosphorus is released from the sediment into the hypolimnion.

Sulfate (SO4) is the oxygen source for sulfate-reducing bacteria, which are generally known to be associated with the production of methyl mercury in the hypolimnia of lakes. These bacteria convert sulfate into the acid hydrogen sulfide (HS^-) and the gas hydrogen sulfide (H_2S). The latter is associated with taste and odor problems for treated water, and as a potential factor in fish kills. Measurements of sulfate throughout the year provide a means of tracking the activity of these bacteria to supplement physical measurements of oxygen and oxidation reduction potential, and to observe the effects of circulation.

In Almaden Reservoir (Figure 12), Sulfate concentrations vary in a narrow range (+/- 6 mg/l) throughout the year in both the hypolimnion and epilimnion. Total Phosphorus concentrations rarely exceed the laboratory analysis reporting limit (0.050 mg/l) in the epilimnion, with some notable occurrences. In the hypolimnion, Total Phosphorus concentrations vary within a narrow range near the reporting limit (+/- 0.1 mg/l). These data indicate that phosphorus in the water column is more a function of internal cycling of phosphorus than of sediment input.

In Guadalupe Reservoir (Figure 13), Sulfate concentrations vary over a range of +/- 20 mg/l throughout the year in the epilimnion and hypolimnion. The seasonal effect is exhibited strongly in the hypolimnion, with seasonal minima corresponding with seasonal maximum Total Phosphorus concentrations. This effect was profound in 2011, where sulfate concentrations in the hypolimnion approached the laboratory reporting limit of 1 mg/l. The seasonal effect in the epilimnion is present, but is not as pronounced as observed in the hypolimnion. Total Phosphorus concentrations rarely exceed the laboratory analysis reporting limit in the epilimnion. In the hypolimnion, Total Phosphorus concentrations vary within a narrow range near the reporting limit (+/- 0.1 mg/l), exhibiting a summer seasonal effect. These data indicate that phosphorus in the water column is more a function of internal cycling of phosphorus than of sediment input.

In Calero Reservoir (Figure 14), Sulfate concentrations vary over a range of +/- 20 mg/l throughout the year in the epilimnion and hypolimnion. The seasonal effect is exhibited in both the epilimnion and the hypolimnion, with seasonal minima corresponding with seasonal maximum Total Phosphorus concentrations in the hypolimnion. Total Phosphorus concentrations rarely exceed the laboratory reporting limit in the epilimnion. In the hypolimnion, Total Phosphorus concentrations vary within a narrow range near the reporting limit (+/- 0.2 mg/l), exhibiting a summer seasonal effect. These data indicate that phosphorus in the water column is more a function of internal cycling of phosphorus than of sediment input.

Concentrations of Sulfate and Total Phosphorus in Lake Almaden (Figures 15 and 16) were significantly higher than those measured in Almaden and Guadalupe. Sulfate concentrations were somewhat higher than those observed in Calero. Concentrations of both species exhibited strong seasonal patterns in the hypolimnion at both sampling sites, varying widely (+/- 45 mg/l for Sulfate, and +/- 1.5 mg/l for Total Phosphorus) at both sampling sites prior to installation and operation of the circulators (2005 at Site 1 and 2005-2006 at Site 2), before modification of the device near Site 1 (2006-2007), and during the malfunction of the device near Site 2 (2009). Concentrations of both species in the epilimnion at both sites varied over a narrower range (+/- 20 mg/l for Sulfate, and +/- 0.15 mg/l for Total Phosphorus) and the seasonal effect was comparatively muted by the effects of circulation during the reporting period (2012-2013).

5.2.4 Summary–Phosphorus and Sulfate

Solar-powered circulators were installed in Almaden Reservoir (April 2007), Guadalupe Reservoir (July 2007), and Lake Almaden (2006 near Site 1, 2007 near Site 2), as described above. The circulators in Lake Almaden appear to have affected the seasonal cycling of both Sulfate and Total Phosphorus, but only when the intake is set at the bottom. The intake of the circulator near Site 1 was originally set at one meter above the bottom for operation in 2006 and 2007; it was reset at the bottom in early 2008. The intake of the circulator near Site 2 is set at the bottom; in 2009 the circulator at Site 2 malfunctioned and did not provide sufficient circulation to affect Sulfate and Total Phosphorus concentrations, which reverted to the pre-circulator seasonal pattern. Suppression of the cycling of these species resumed during the reporting period, during which the circulators functioned normally. The circulators do not appear to have had any effect on Sulfate or Total Phosphorus concentrations in the reservoirs (Almaden and Guadalupe) nor has the limited operation of the oxygenation systems (Calero and Guadalupe).

5.3 MERCURY/METHYL MERCURY CYCLING

Methyl mercury concentrations vary seasonally in the reservoirs and the lake of this study, corresponding with anoxia in the hypolimnia (Figures 1 and 2). The intent of this study is to evaluate the effects of circulation on the methyl mercury concentrations in the water column, as deployed and as supplemented by additional actions as described above.

5.3.1 Almaden Reservoir

Methyl mercury concentrations measured in Almaden Reservoir (Figures 17 and 18) show a production season that lasts approximately three months from July through October annually. Methyl mercury increases in the water column are generally associated with areas of anoxia; however, Oxidation Reduction Potential (ORP) may be a more specific indicator of optimum conditions for methylation, as methyl mercury concentrations tend to increase as ORP values decrease below 100 millivolts (mV). During the reporting period, maximum concentrations in the hypolimnion, mid-depth and epilimnion were consistent with previous years. The TMDL target concentration (1.5 ng/l) for hypolimnetic seasonal maximum concentration is typically exceeded for 1-2 months between July and September annually (Figure 19). The only exception was in 2009 when the target concentration was exceeded for about 4 months between July and October. The circulators installed in this reservoir in 2007 do not appear to have had any effect on methyl mercury concentrations in the water column.

Mercury concentrations in the epilimnion and hypolimnion exhibit seasonal effects for both unfiltered (total) and filtered (dissolved) species (Figure 20). Generally, seasonal maximum concentrations of total mercury are observed during the wet season and seasonal maximum concentrations of dissolved mercury are observed during the dry season in both the epilimnion and hypolimnion. During the summer and fall of 2009, the Jacques Gulch Restoration Project was constructed above Almaden Reservoir, which resulted in significant removal of source mercury to the reservoir. The data indicate that seasonal maximum concentrations of total mercury in the epilimnion are lower in 2009-2013 than in previous years, and that seasonal maximum concentrations in the hypolimnion appear to be slightly lower since 2010. Dissolved mercury seasonal maxima do not appear to have been affected by the restoration project, which is not unusual since dissolved mercury is largely a product of internal processes rather than loading. Note that seasonal maxima for the epilimnion since 2009 were below 30 ng/l, and below 40 ng/l in the hypolimnion.

5.3.2 Guadalupe Reservoir

Methyl mercury concentrations measured in Guadalupe Reservoir (Figures 21 and 22) show a production season that lasts from seven to nine months from April through November annually. Methyl mercury increases in the water column are generally associated with areas of anoxia; however, Oxidation Reduction Potential (ORP) may be a more specific indicator of optimum conditions for methylation, as methyl mercury concentrations tend to increase as ORP values decrease below 100 millivolts (mV). During the reporting period, maximum concentrations in the hypolimnion, mid-depth and epilimnion were consistent with previous years. In Figure 22, the effects of oxygenation operation are evident as inflections in the Dissolved Oxygen and ORP curves for the months of July and August. The TMDL target concentration (1.5 ng/l) for hypolimnetic seasonal maximum concentration is typically exceeded for 5-8 months between April and November annually (Figure 23). During the reporting period, maximum concentrations in the hypolimnion, and epilimnion were consistent with previous years. The mid-depth maximum for 2013 was higher than the previous three years. The circulators installed in this reservoir in 2007 do not appear to have had any effect on methyl mercury concentrations in the water column, and were removed in June 2013.

Mercury concentrations in the epilimnion and hypolimnion exhibit seasonal effects for unfiltered (total) mercury (Figure 24). Generally, seasonal maximum concentrations of total mercury are observed during the wet season in both the epilimnion and hypolimnion. Note that seasonal maxima for the epilimnion since 2009 were below 30 ng/l, but were nearly 100 ng/l in the hypolimnion.

5.3.3 Calero Reservoir

Methyl mercury concentrations measured in Calero Reservoir (Figures 25 and 26) show a production season that lasts approximately four months from June through October annually. Methyl mercury increases in the water column are generally associated with areas of anoxia; however, Oxidation Reduction Potential (ORP) may be a more specific indicator of optimum conditions for methylation, as methyl mercury concentrations tend to increase as ORP values decrease below 100 millivolts (mV). However, even though the ORP profiles in Figure 26 indicate that oxygenation was successful in improving ORP values in the water column in 2013, methyl mercury production does not appear to have been reduced compared to 2012 (Figure 25). During the reporting period, maximum concentrations in the hypolimnion, mid-depth and epilimnion were consistent with previous years. The TMDL target concentration (1.5 ng/l) for hypolimnetic seasonal maximum concentration is typically exceeded for 5-8 months between April and November annually (Figure 27).

Mercury concentrations in the epilimnion and hypolimnion exhibit seasonal effects for unfiltered (total) mercury (Figure 28). Generally, seasonal maximum concentrations of total mercury are observed during the wet season in both the epilimnion and hypolimnion. These concentrations are significantly lower than the other two reservoirs and Lake Almaden, with seasonal maxima in the epilimnion below 10 ng/l since 2008, and below 20 ng/l in the hypolimnion.

5.3.4 Lake Almaden

Methyl mercury concentrations measured in Lake Almaden at Site 1 (Figures 29 and 30) show a production season that lasts approximately seven months from April through November annually. Methyl mercury increases in the water column are generally associated with areas of anoxia; however, Oxidation Reduction Potential (ORP) may be a more specific indicator of optimum conditions for methylation, as methyl mercury concentrations tend to increase as ORP values decrease below 100 millivolts (mV). Annual maximum concentrations in the hypolimnion varied over the study period, and were obviously affected by the circulator after it was set at the bottom in 2008 (Figure 31). In 2005-2007 the maximum concentration in the hypolimnion was about 70 ng/l; in 2008 through 2011, the maximum concentration ranged from 15 to 30 ng/l, and in 2012-2013 the maximum concentration averaged 14 ng/l. Mid-depth seasonal maximum concentrations were immediately affected by the circulator following installation in 2006, and have ranged from 1 to 5 ng/l from 2010-2013. Hypolimnetic seasonal maxima concentrations above the target concentration (1.5 ng/l) are generally exceeded for 5-6 months in May-November annually.

Mercury concentrations in the epilimnion and hypolimnion exhibit seasonal effects for unfiltered (total) mercury (Figure 32). Generally, seasonal maximum concentrations of total mercury are observed during the wet season in both the epilimnion and hypolimnion, and are significantly higher than the three reservoirs, with seasonal maxima in the epilimnion above 50 ng/l since 2009, and ranging above 150 ng/l in the hypolimnion.

Methyl mercury concentrations measured in Lake Almaden at Site 2 (Figures 33 and 34) show a production season that lasts approximately seven months from April through November annually, similar to Site 1. Annual maximum concentrations in the hypolimnion varied over the study period, and were obviously affected by the circulator after it was installed in 2007 (Figure 35) and malfunctioned in 2009. In 2005 and 2006 the maximum concentration in the hypolimnion was about 60 and 70 ng/l, respectively; in 2007 and 2008, the maximum concentration was about 17 ng/l; in 2009, the maximum concentration was 48 ng/l; from 2012-2013 the maximum concentration ranged from 10 to 17 ng/l. Mid-depth seasonal maximum concentration was immediately affected by the circulator following installation in 2007, but was unaffected by the malfunction in 2009. The maximum concentration at mid-depth in 2005 and 2006 was 78 and 112 ng/l, respectively; in 2010-2013 the maximum concentration ranged from 2 to 8 ng/l, respectively. Hypolimnetic seasonal maxima concentrations above the target concentration (1.5 ng/l) are generally exceeded for 5-6 months in May-November annually.

Mercury concentrations in the epilimnion and hypolimnion exhibit seasonal effects for unfiltered (total) mercury (Figure 36). Generally, seasonal maximum concentrations of total mercury are observed during the wet season in both the epilimnion and hypolimnion, and are significantly higher than the three reservoirs, with seasonal maxima in the epilimnion above 50 ng/l since 2009, and ranging above 150 ng/l in the hypolimnion.

Methyl mercury concentrations measured in the hypolimnion of Lake Almaden at Sites 3, 4 and 5 (Figure 37) show a production season that lasts six months from May to November. Only a partial background season of data were obtained at Site 3 in 2010-2011 and Site 5 in 2008. In 2008, prior to the installation of the circulator in this area, the maximum concentration measured in the hypolimnion at Site 5 was 38 ng/l. Since then, the maximum concentration measured in the hypolimnion has ranged from 4 to 8 ng/l. The circulator installed at Site 3 in 2010 was used to circulate the epilimnion only, and methyl mercury concentrations in the hypolimnion were around 50 ng/l. Since then, the maximum concentration measured in the hypolimnion has ranged from 5 to 8 ng/l. Hypolimnetic seasonal maxima concentrations above the target concentration (1.5 ng/l) are generally exceeded for 5-6 months in May-November annually.

5.4 SUMMARY—MERCURY/METHYL MERCURY CYCLING

Solar-powered circulators were installed in Almaden Reservoir (April 2007), Guadalupe Reservoir (July 2007), and Lake Almaden (2006 near Site 1, 2007 near Site 2, and 2009 near Site 3 and Site 5), as described above. The circulators in the two reservoirs do not appear to have had any effect on methyl mercury production or algal blooms. The circulators in Lake Almaden appear to have affected the seasonal cycling of methyl mercury most effectively when the intake is set at the bottom. The intake of the circulator near Site 1 was originally set at one meter above the bottom for operation in 2006 and 2007; it was reset at the bottom in early 2008. The intake of the circulator near Site 3 and Site 4 was originally set to circulate the epilimnion but was changed after to years and now circulators near Site 2, Site 3 and Site 5 are set at the bottom; in 2009 the circulator at Site 2 malfunctioned and did not provide sufficient circulation to affect methyl mercury concentrations in the hypolimnion, which reverted to the pre-circulator seasonal maxima, but did maintain mid-depth concentrations at low levels compared to pre-circulation data. Mercury concentrations in the water column are significantly lower in Calero than in the other two reservoirs and Lake Almaden, and significantly higher in Lake Almaden than the three reservoirs.

5.5 MERCURY/METHYL MERCURY LOADING

In the September 2008 Guadalupe River Watershed Mercury TMDL Staff Report (Staff Report, page 9-31), the Regional Board stated that the District would be “required to quantify dry season loads of methylmercury… discharged from reservoirs and lakes” using a method proposed in Section 4.4 of the Staff Report. The method proposed in Section 4.4 made a variety of assumptions, each of which would add and compound to error in estimating the load of methyl mercury. The District proposes the more direct and conventional method of sampling outlet flows and using concentration and gauged flow data to estimate loads.

In 2007 through 2011, the District collected samples from the outlet of the three reservoirs, and from the inlet and outlet of Lake Almaden, at the sampling frequency described above. As shown in Figure 38, the hypolimnion and outlet concentrations of methyl mercury for Almaden Reservoir are about the same; there is no loss of methyl mercury in the outlet works as postulated in the Staff Report (page 9-26).

In Figure 39, the hypolimnion and outlet concentrations of methyl mercury for Guadalupe Reservoir differ widely during the methyl mercury production season. This is not due to any losses in the outlet works; rather, it is due to the difference between the elevation of the outlet works sill (approximately three meters above the bottom of the reservoir) and the sample collection depth (within one meter above the bottom). Comparison of the concentrations of methyl mercury in samples collected at the sill elevation and the outlet (also shown in Figure 39) are essentially the same.

As shown in Figure 40, the hypolimnion and outlet concentrations of methyl mercury for Calero Reservoir are about the same; there is no loss of methyl mercury in the outlet works as postulated in the Staff Report (page 9-26). As shown in Figure 41, the inlet and outlet concentrations of methyl mercury for Lake Almaden indicate that the lake were previously a sink for methyl mercury (discharges less methyl mercury than it receives). However, inlet methyl mercury concentrations during the reporting period were lower than previous years, and there was no significant difference in inlet and outlet concentrations in 2012-2013.

5.5.1 Outlet Load Calculations

Using Santa Clara Valley Water District gauge data, and mercury (Hg) and methyl mercury (MeHg) concentrations in the outlet discharge, wet season and annual loads were calculated for the Almaden, Calero, and Guadalupe reservoirs for the period October 1 through April 30 (wet season) and October 1 through September 30 (annual) in each of water years 2011 and 2012. Daily flow rates were multiplied by the measured concentrations in order to determine the amounts of Hg and MeHg discharged per year and per wet season, as shown in the table below:

Reservoir	Hg Discharged				MeHg Discharged			
	g/wet season		g/year		g/wet season		g/year	
	2011	2012	2011	2012	2011	2012	2011	2012
Almaden	2	2	56	63	0.3	0.9	2.7	3.6
Guadalupe	48	48	72	76	1.3	0.6	3.5	5.0
Calero	18	34	50	58	1.4	1.2	9.9	8.0

These results are similar to those reported by Tetra Tech, Inc. in their *Final Conceptual Model Report*, May 20, 2005. These reservoirs do not appear to be significant sources of Hg to the Guadalupe River or San Francisco Bay as compared to other local sources. The Guadalupe River annual discharge as stated in the San Francisco Bay TMDL is 92 kg Hg per year, whereas these three reservoirs in total discharged just 0.2 kg Hg in each of the past two years.

6.0 CONCLUSIONS

The data interpretation, data analysis, and conclusions in this report are preliminary and subject to change as the study progresses.

The Hypothesis being tested for Lake Almaden is:

> *Hypolimnetic circulation will reduce methyl mercury concentrations in Lake Almaden to meet the seasonal maximum concentration specified in the TMDL, which is expected to result in fish tissue concentrations that meet the objectives specified in the TMDL.*

To date, it has been demonstrated that the solar-powered circulators have significantly reduced methyl mercury concentrations in the water column as compared to pre-circulated conditions. With proper deployment and operation, near-bottom concentrations of methyl mercury in the water column are significantly reduced as well; however, the target concentrations in the TMDL have not yet been achieved.

The first Hypothesis being tested for Guadalupe Reservoir is:

> *Epilimnetic circulation will reduce blue green algae production in Guadalupe Reservoir in favor of green algae production, eventually reducing the extent and duration of anoxia in the hypolimnion while improving the fishery, resulting in lower seasonal maximum methyl mercury concentrations (due to less anoxia) and lower methyl mercury concentrations in fish (due to biodilution).*

To date, the data indicate that current blooms of blue green algae are low to modest in this reservoir. There is no background data for comparison, and collection and quantification of algae production is problematic, so it is not possible to quantifiably demonstrate if the circulators have had any effect on the blue green algae blooms; however, there has been no visual change observed. The data indicate that there has been no effect of circulation on hypolimnetic anoxia or water column concentrations of methyl mercury. This method has failed to achieve any observable or measurable improvement and was abandoned in June 2013.

The new Hypothesis being tested for Guadalupe Reservoir is:

> *Oxygenation of the hypolimnion will result in seasonal maximum concentrations of methyl mercury that meet the criterion specified in the TMDL and fish tissue concentrations that meet the targets specified in the TMDL.*

An oxygenation system was installed in May 2013 and was operated on a limited basis from June through October.

The Hypothesis being tested for Almaden Reservoir is:

> *Epilimnetic and hypolimnetic circulation in Almaden Reservoir combined with source reduction will reduce mercury available for methylation, reduce blue green algae production in favor of green algae production, eventually reduce the extent and duration of anoxia in the hypolimnion while improving the fishery, resulting in lower seasonal maximum methyl mercury concentrations (due to less anoxia and*

less mercury available for methylation) and lower methyl mercury concentrations in fish (due to biodilution).

The data indicate that there has been no effect of circulation on hypolimnetic anoxia or water column concentrations of methyl mercury. The restoration of Jacques Gulch in the summer and fall of 2009 has removed the only source of mining waste to this reservoir. While annual maximum total mercury concentrations in the water column appear to be lower than those measured prior to 2009, the annual maximum methyl mercury concentrations measured in the water column have not been reduced. Seasonal blooms of Cyanobacteria were visually observed annually each November, indicating that the epilimnetic circulation has not substantially affected the composition of phytoplankton in the reservoir.

An hypolimnetic oxygenation system is planned for installation and operation in this reservoir in calendar year 2014. This will revise the Hypothesis to: *Oxygenation of the hypolimnion in Almaden Reservoir combined with source reduction will result in seasonal maximum concentrations of methyl mercury that meet the criterion specified in the TMDL and fish tissue concentrations that meet the targets specified in the TMDL*.

The Hypothesis being tested for Calero Reservoir is:

> *Oxygenation of the hypolimnion in Calero Reservoir will result in seasonal maximum concentrations of methyl mercury that meet the criterion specified in the TMDL and fish tissue concentrations that meet the targets specified in the TMDL.*

A full scale oxygenation system was installed in Calero Reservoir in November 2011. The system was operated on a limited basis during Summer 2013, and is planned to be fully operated during calendar year 2014.

7.0 IMPLEMENTATION TIMELINE

To date, the District has conducted the following activities:

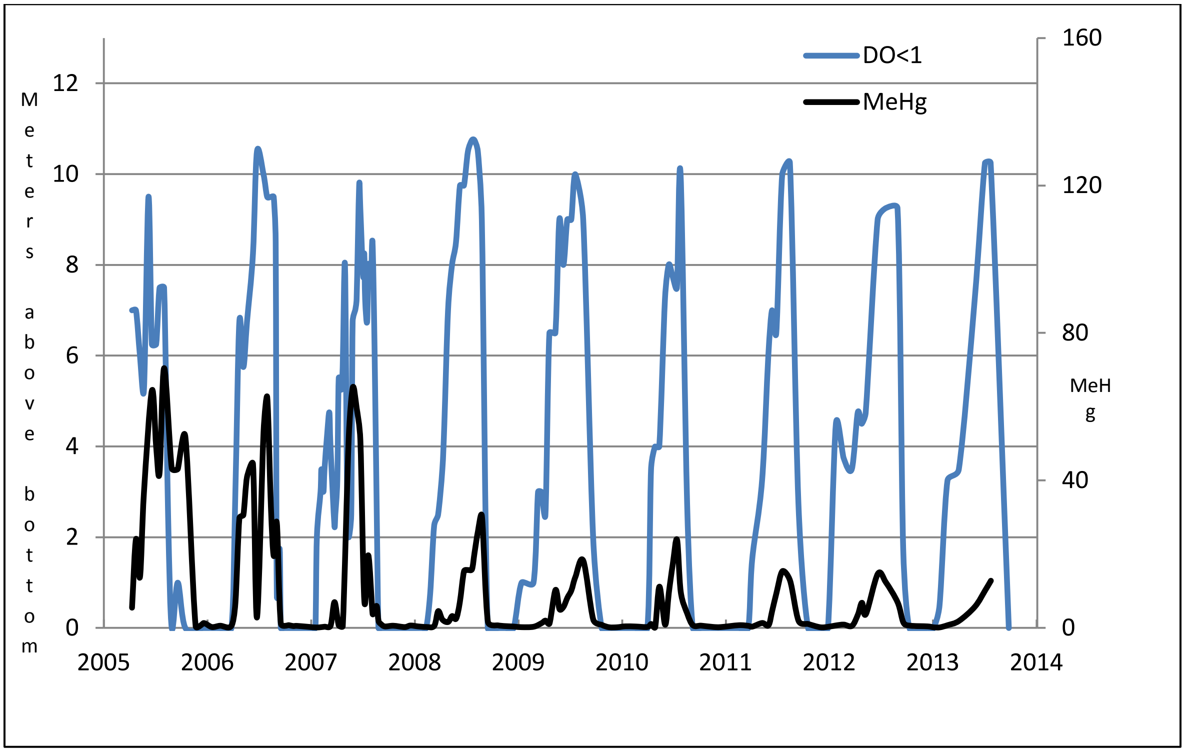
2003–2009	Source removal on all known source areas on District-owned property on Alamitos Creek.
2005–present	Monitoring and Sampling Program for three reservoirs and one lake.
2006–present	Installation and operation of a circulator at Site 1 in Lake Almaden, with modifications to deployment in 2008.
2007–present	Installation and operation of a circulator at Site 2 in Lake Almaden; Installation and operation of three circulators in Almaden Reservoir and three circulators in Guadalupe Reservoir; source removal of mining waste to Almaden Reservoir (Jacques Gulch Restoration).
2009–present	Installation and operation of two additional circulators in Lake Almaden; application for grant funding for oxygenation system for Calero Reservoir; application for grant funding for feasibility study for Alamitos Creek Restoration/Lake Almaden Bypass; application for grant funding for source reduction on private property on Alamitos Creek. All grant applications were unsuccessful.
2011	Installation of oxygenation system in Calero Reservoir; equipment procurement for oxygenation of Almaden Reservoir; completion of internal opportunities and constraints document for remediation of Lake Almaden.
2013	Installation and limited operation of oxygenation system in Guadalupe Reservoir. Limited operation of oxygenation system in Calero Reservoir.

Planned activities for the next reporting period:

2012–2013	Monitoring and Sampling Program for three reservoirs and one lake, continued operation of existing circulators in the lake.
2014-2015	Installation and operation of oxygenation system in Almaden Reservoir. Operation of oxygenation systems in Calero reservoir and Guadalupe Reservoir.
2014–2015	Further evaluation of alternatives for remediation of Lake Almaden.

APPENDIX A

Figures



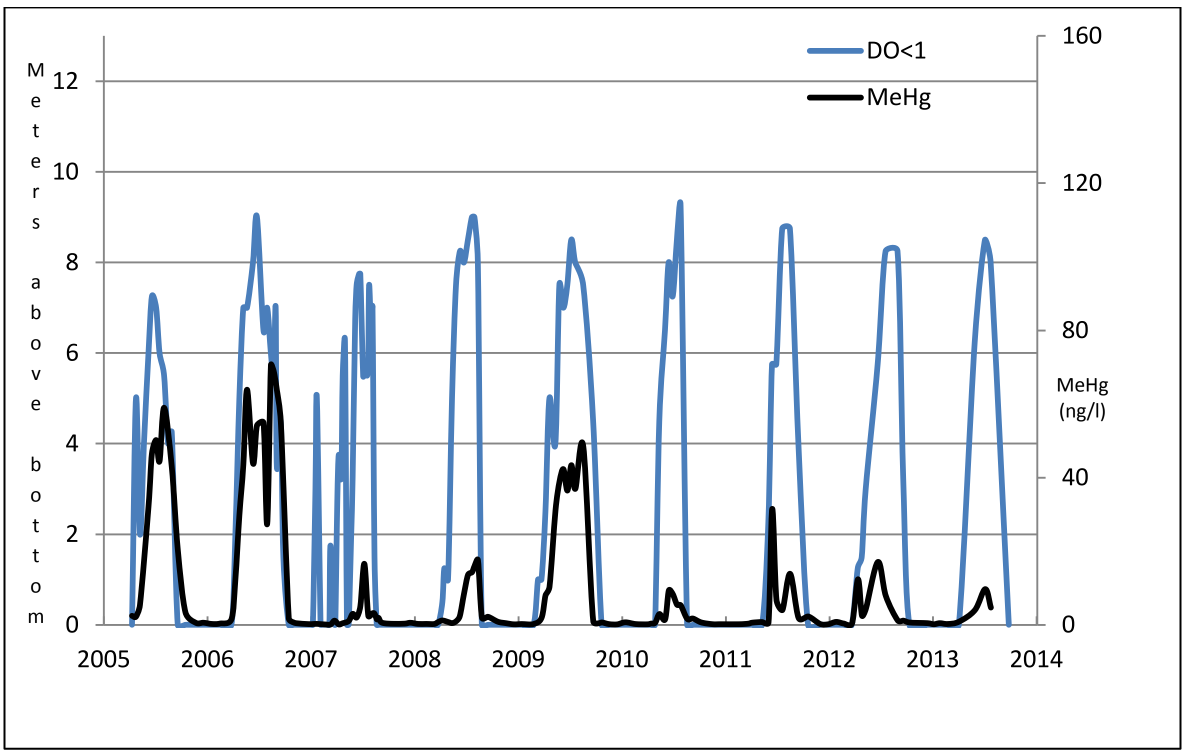
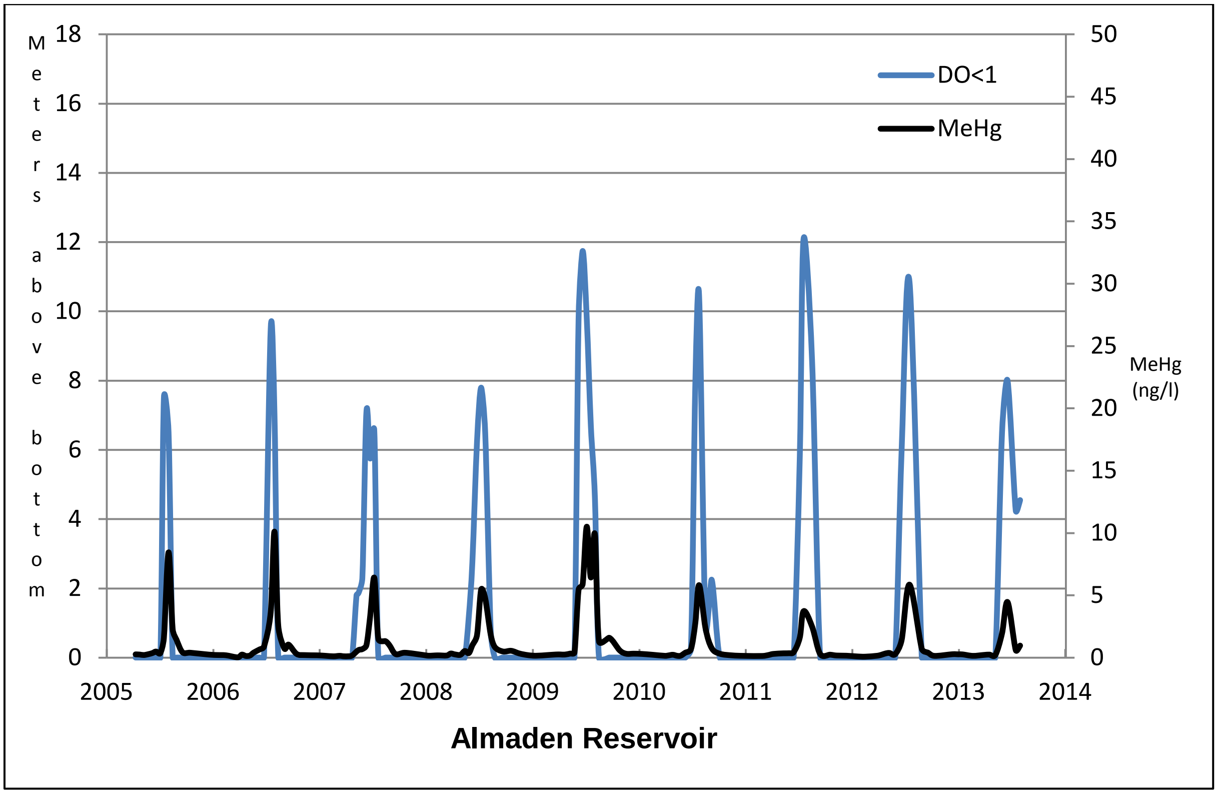


Figure 1: Annual Coincidence of Methyl Mercury Production With Seasonal Anoxia in Lake Almaden Site 1 (Top) and Site 2 (Bottom)



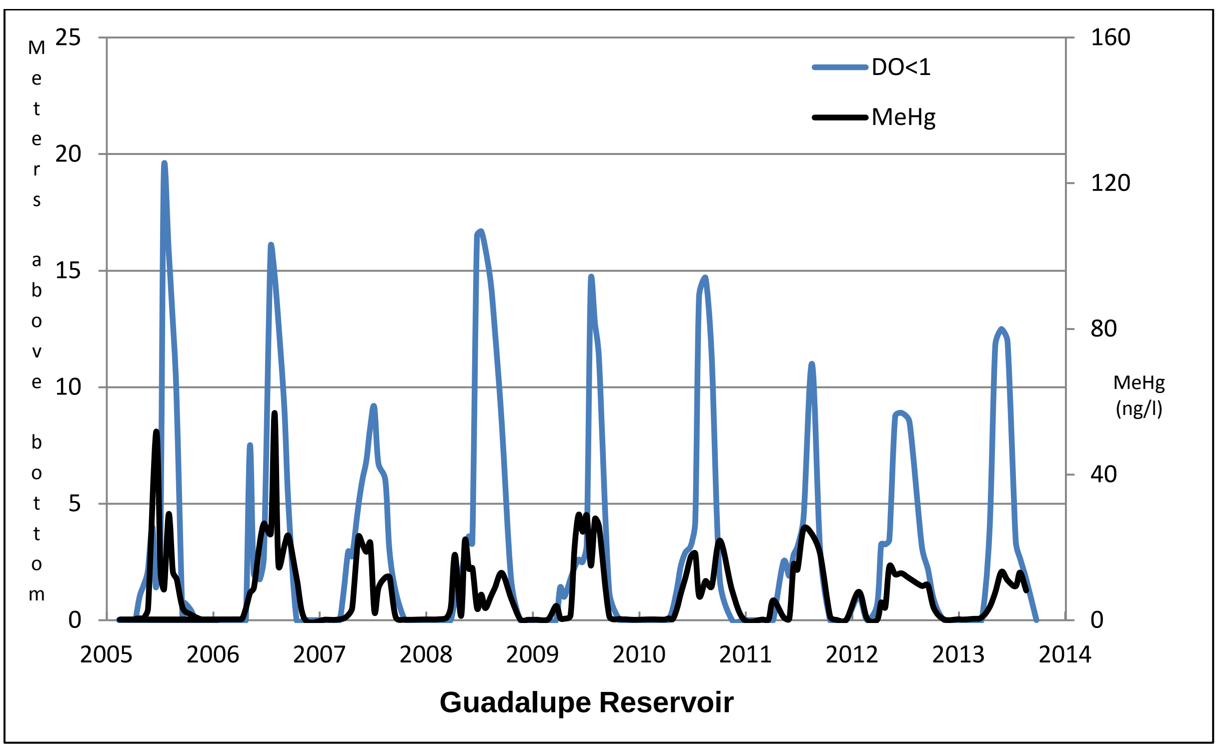


Figure 2: Annual Coincidence of Methyl Mercury Production With Seasonal Anoxia in Two Reservoirs

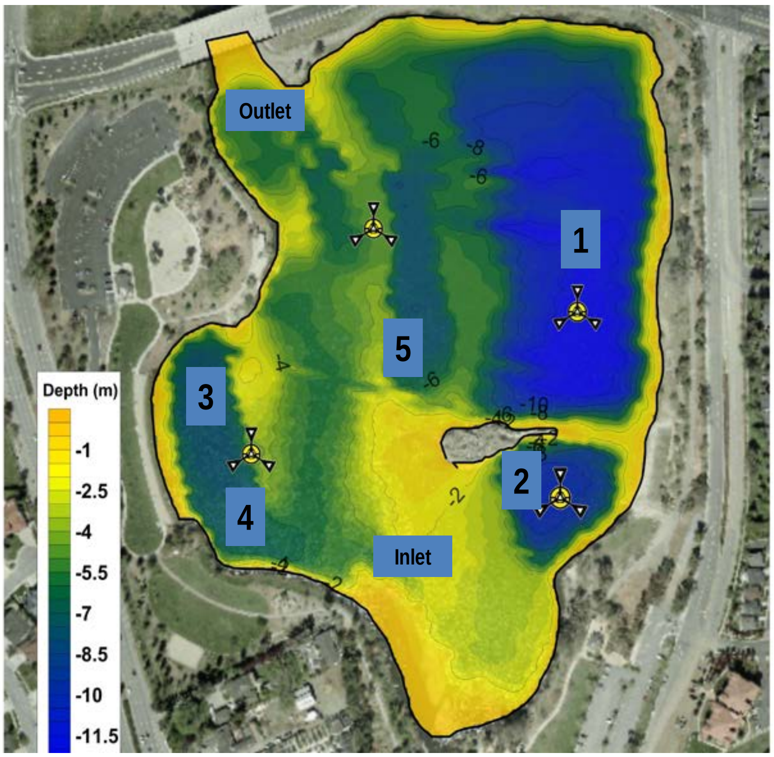


Figure 3: Lake Almaden Bathymetry and Site Map

Inlet = Sampling/Monitoring Location

 = Solar-powered Circulator Location

Figure 3: Lake Almaden Bathymetry and Site Map

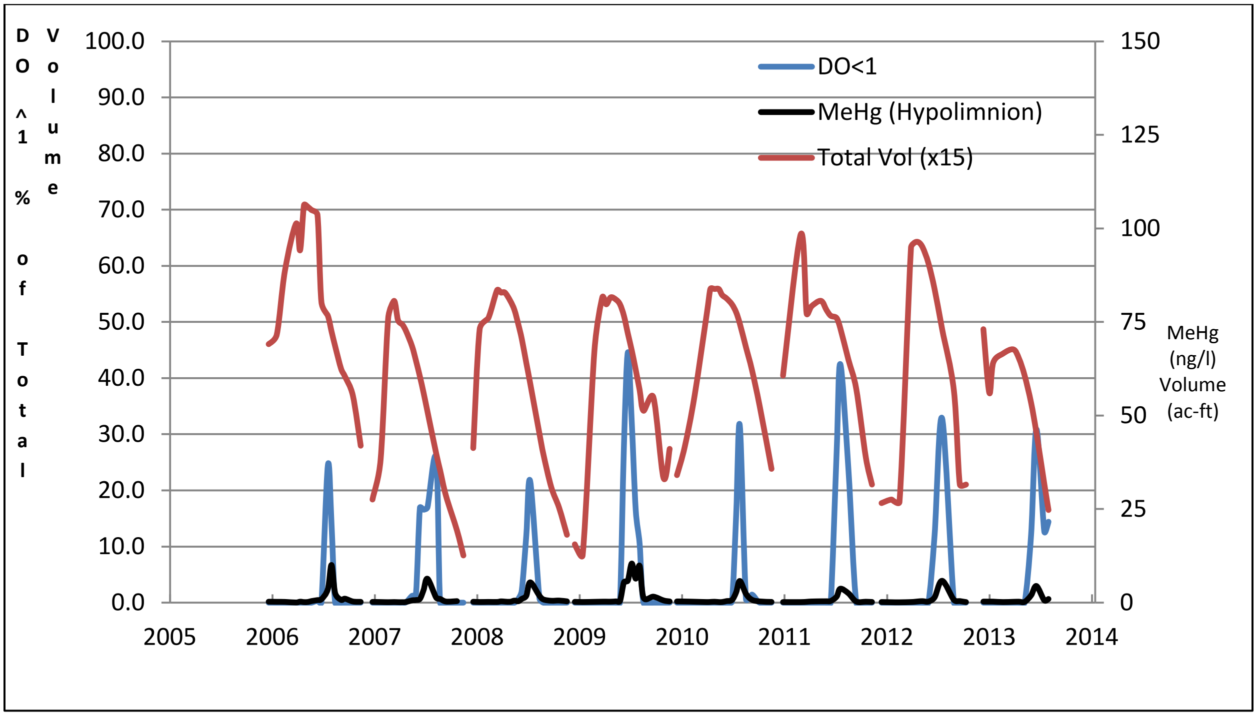


Figure 4: Seasonal Anoxic Volume (DO<1 mg/l) as a Percentage of Total Volume; Hypolimnion Methyl Mercury Concentrations (MeHg) in Almaden Reservoir

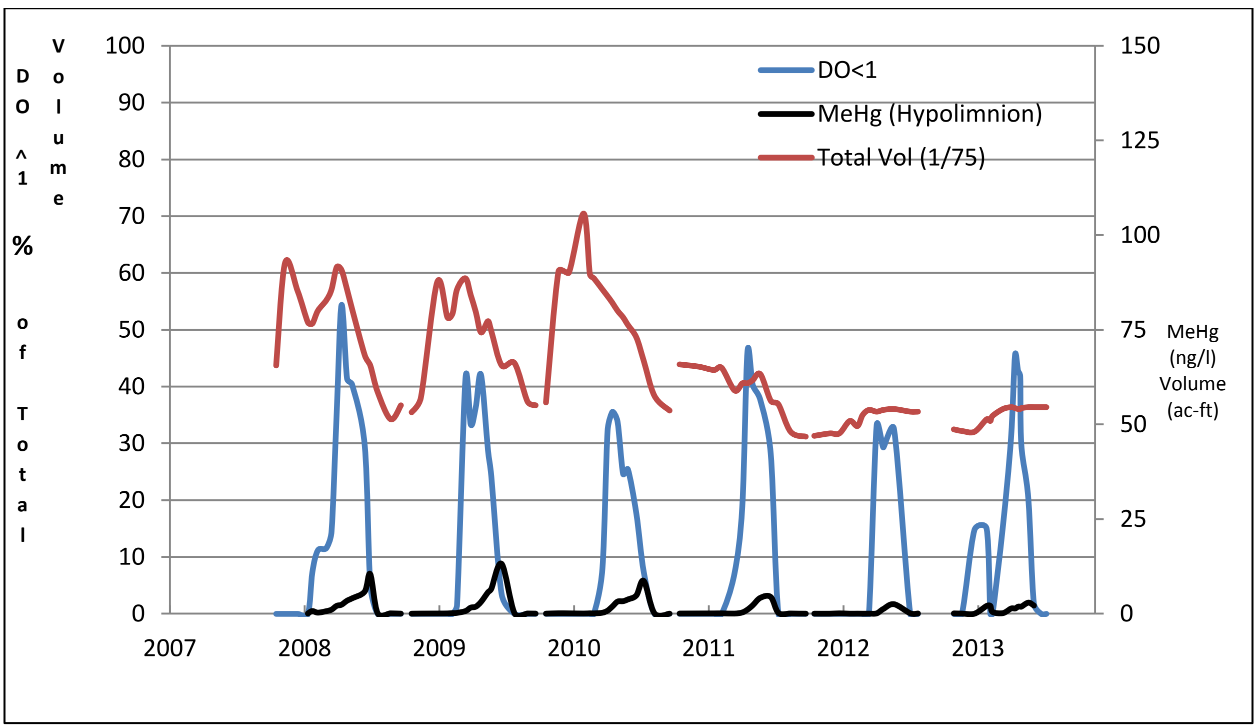


Figure 5: Seasonal Anoxic Volume (DO<1 mg/l) as a Percentage of Total Volume; Hypolimnion Methyl Mercury Concentrations (MeHg) in Calero Reservoir

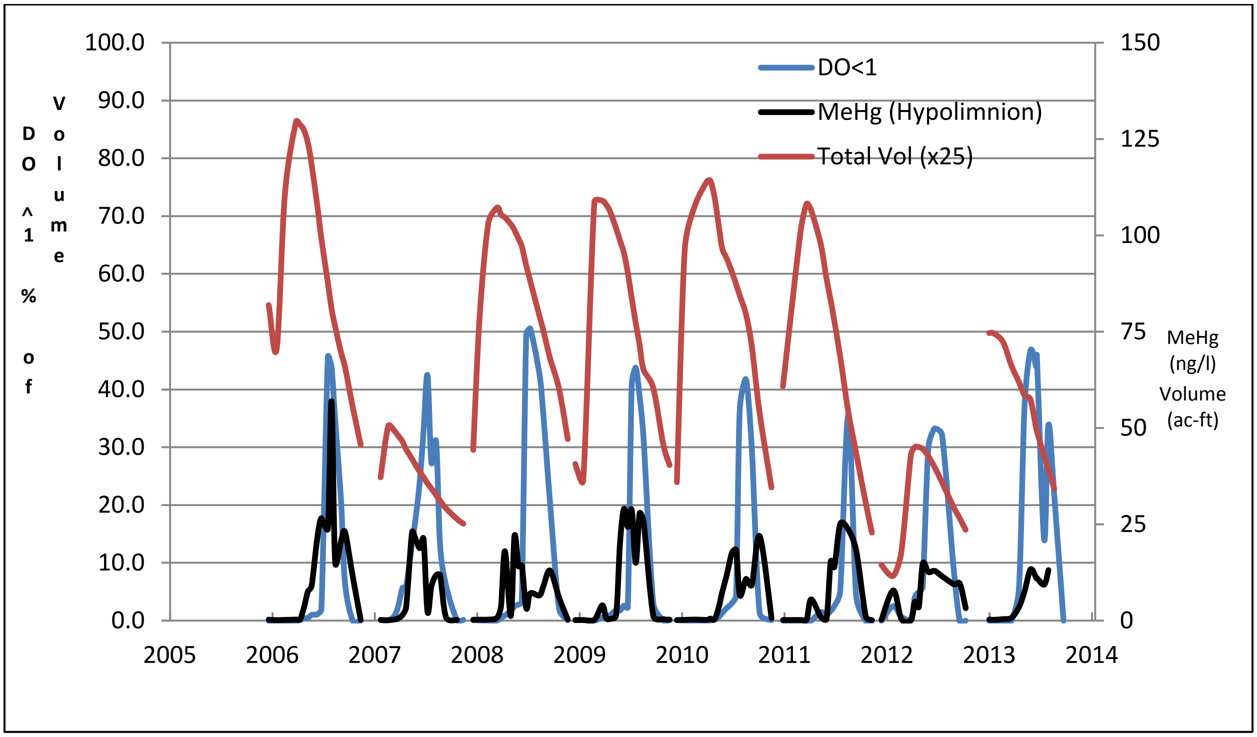
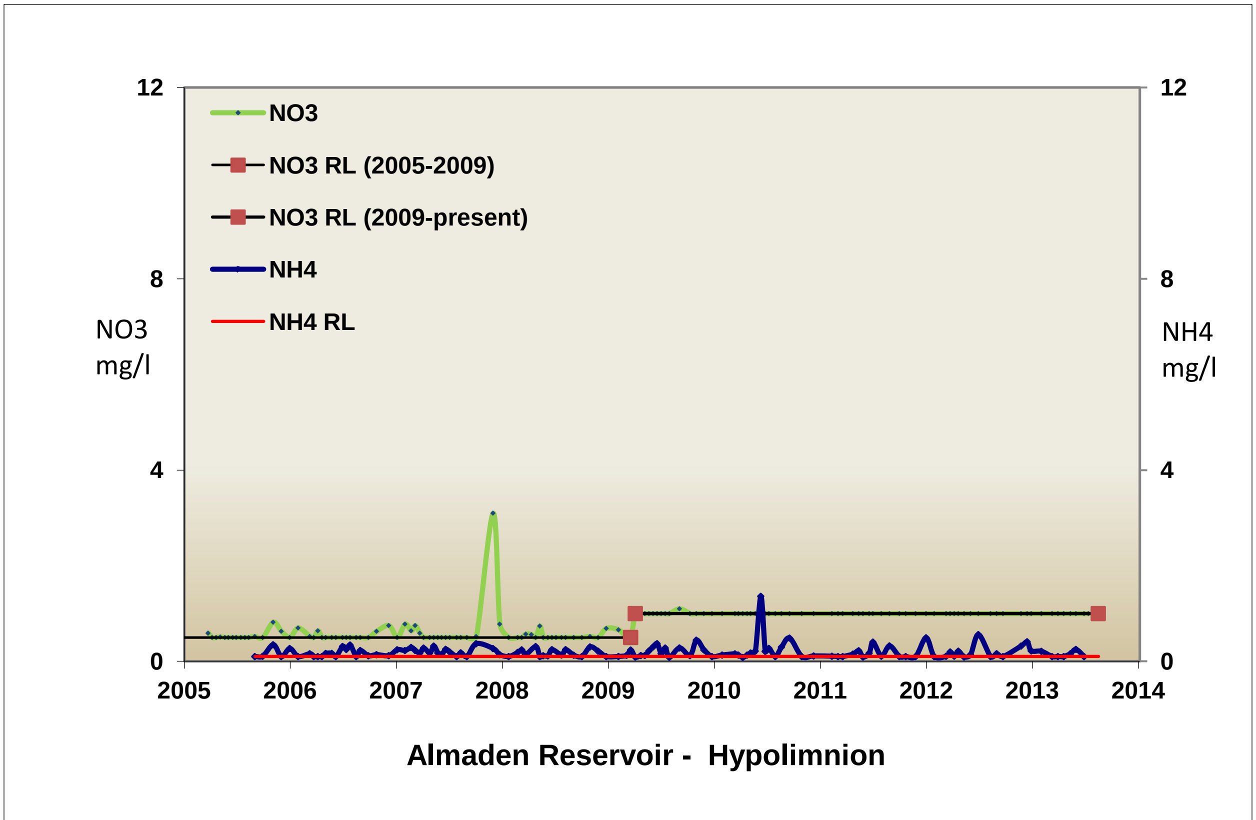


Figure 6: Seasonal Anoxic Volume (DO<1 mg/l) as a Percentage of Total Volume; Hypolimnion Methyl Mercury Concentrations (MeHg) in Guadalupe Reservoir



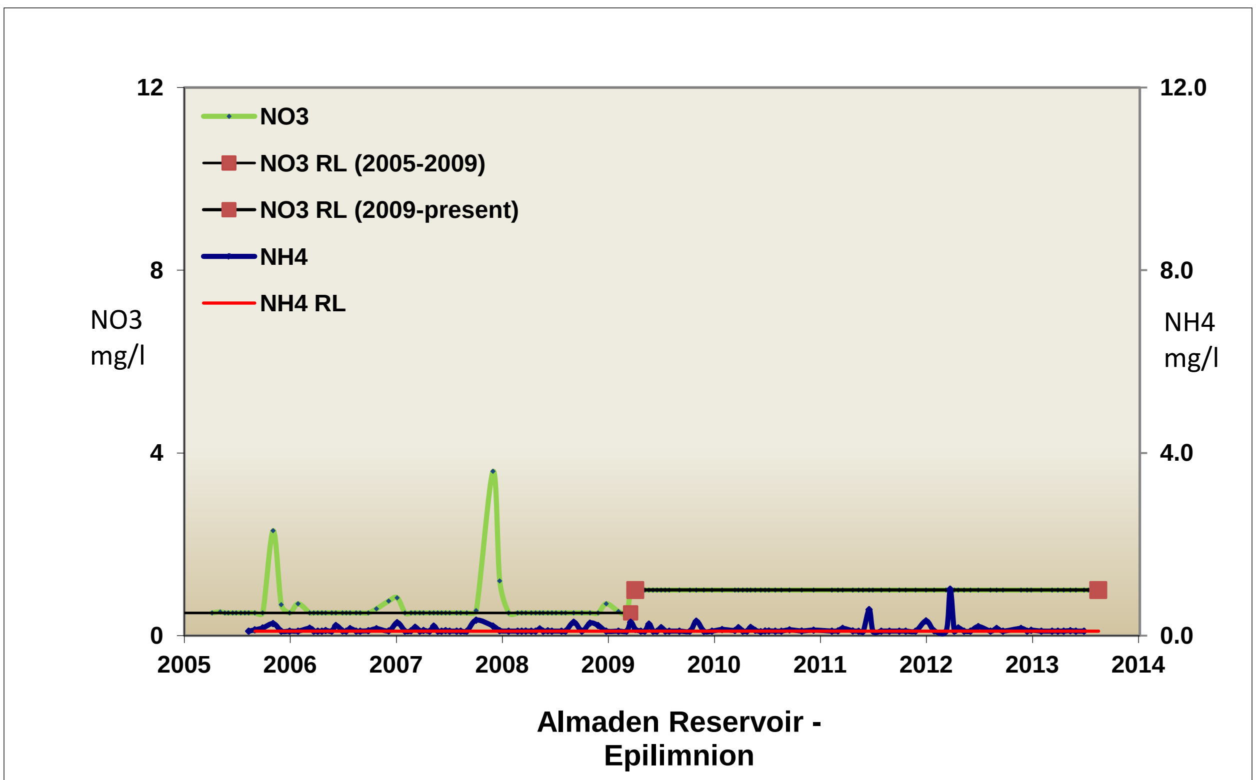
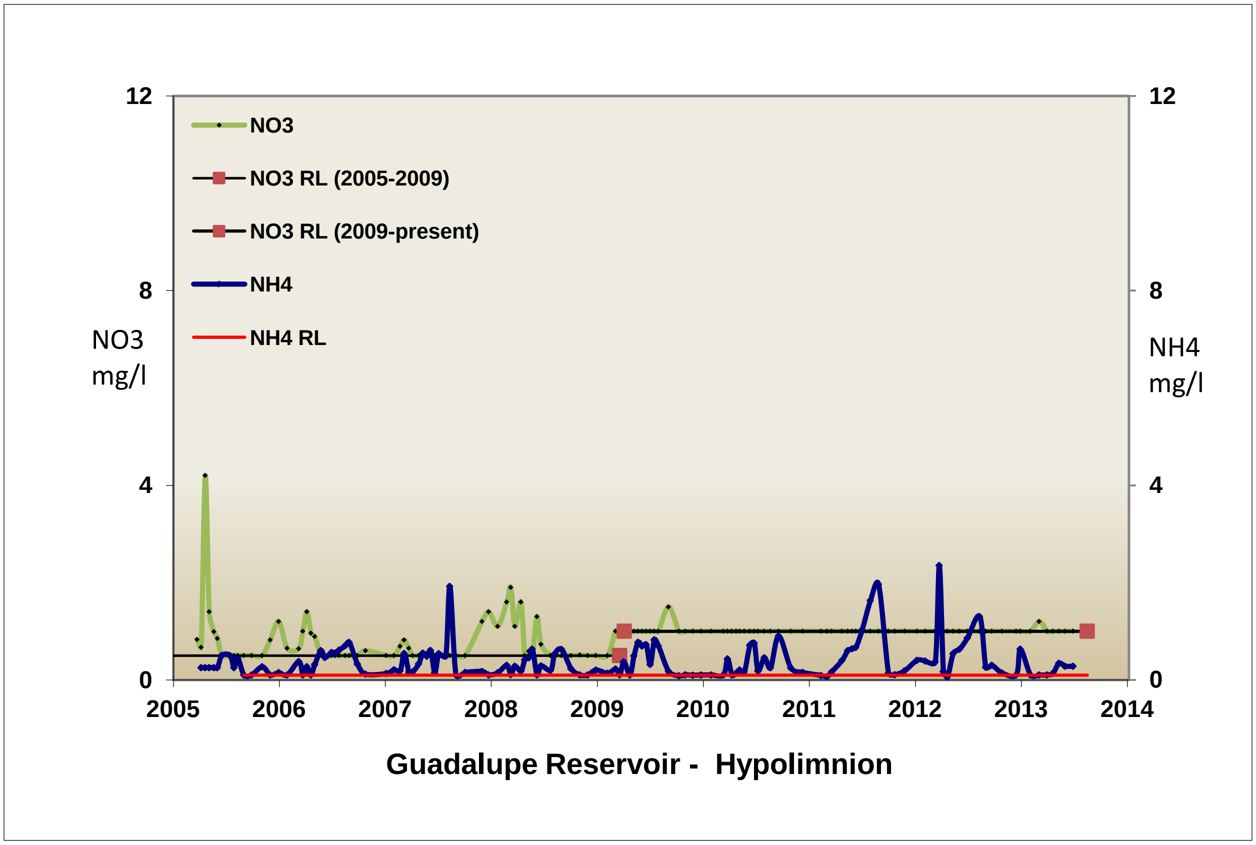


Figure 7: Nitrate (NO_3) and Ammonia (NH_4) Concentrations in Almaden Reservoir



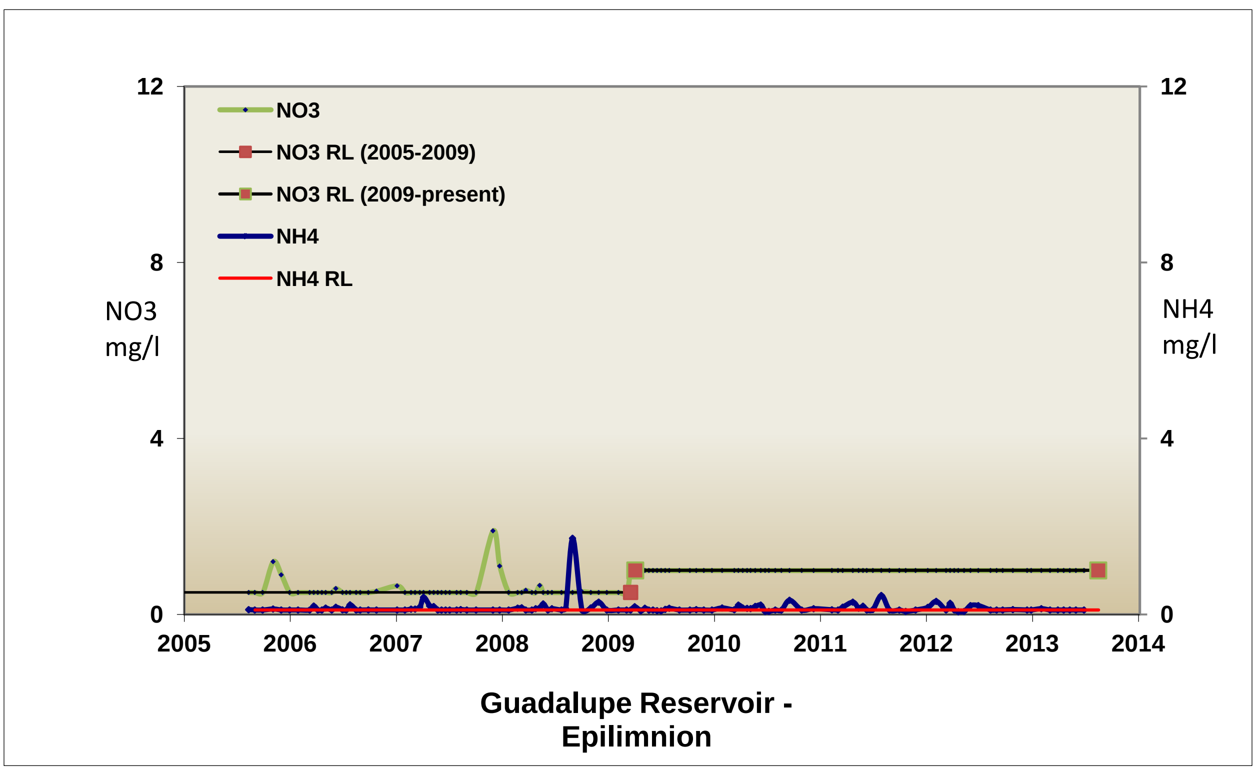
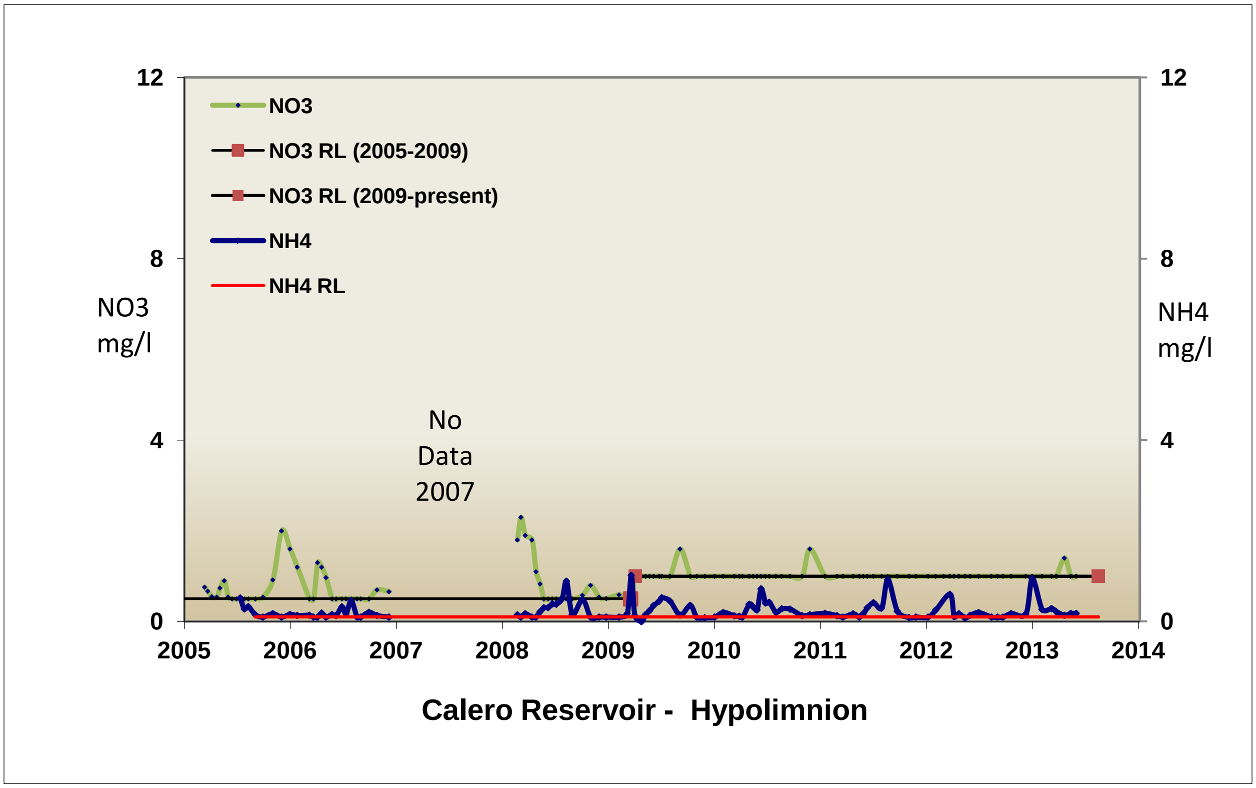


Figure 8: Nitrate (NO_3) and Ammonia (NH_4) Concentrations in Guadalupe Reservoir



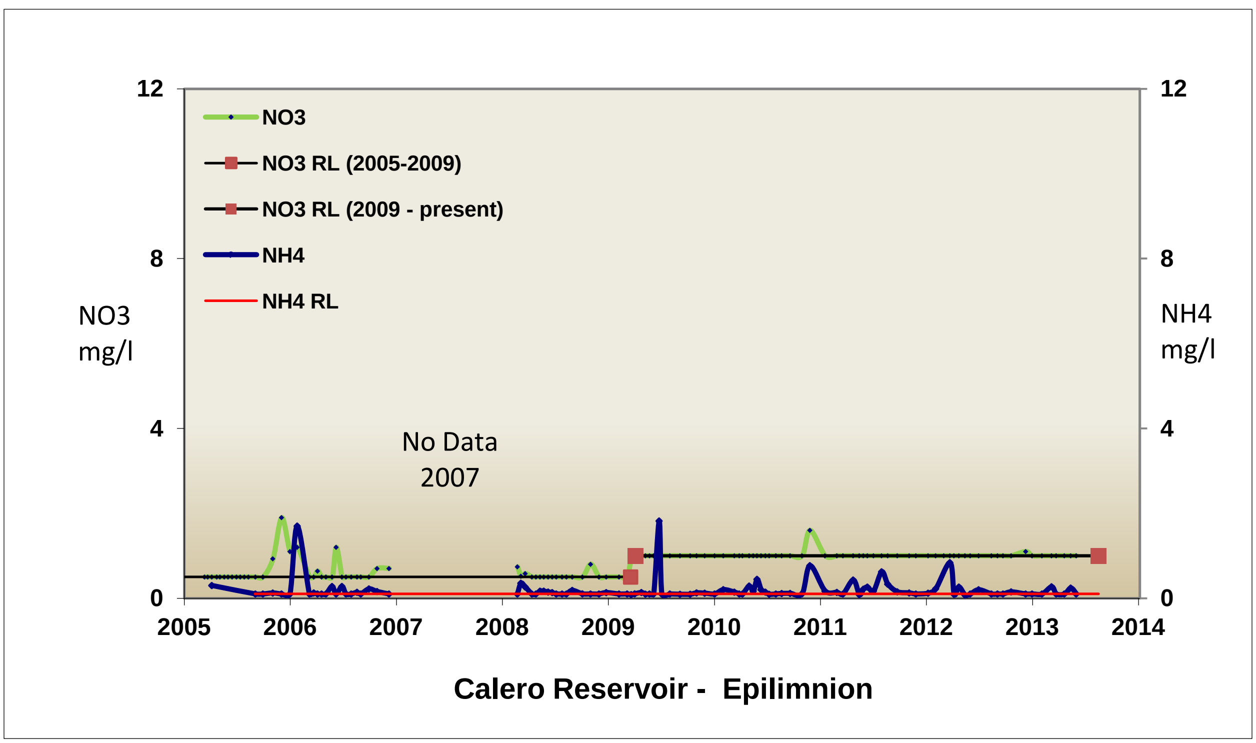
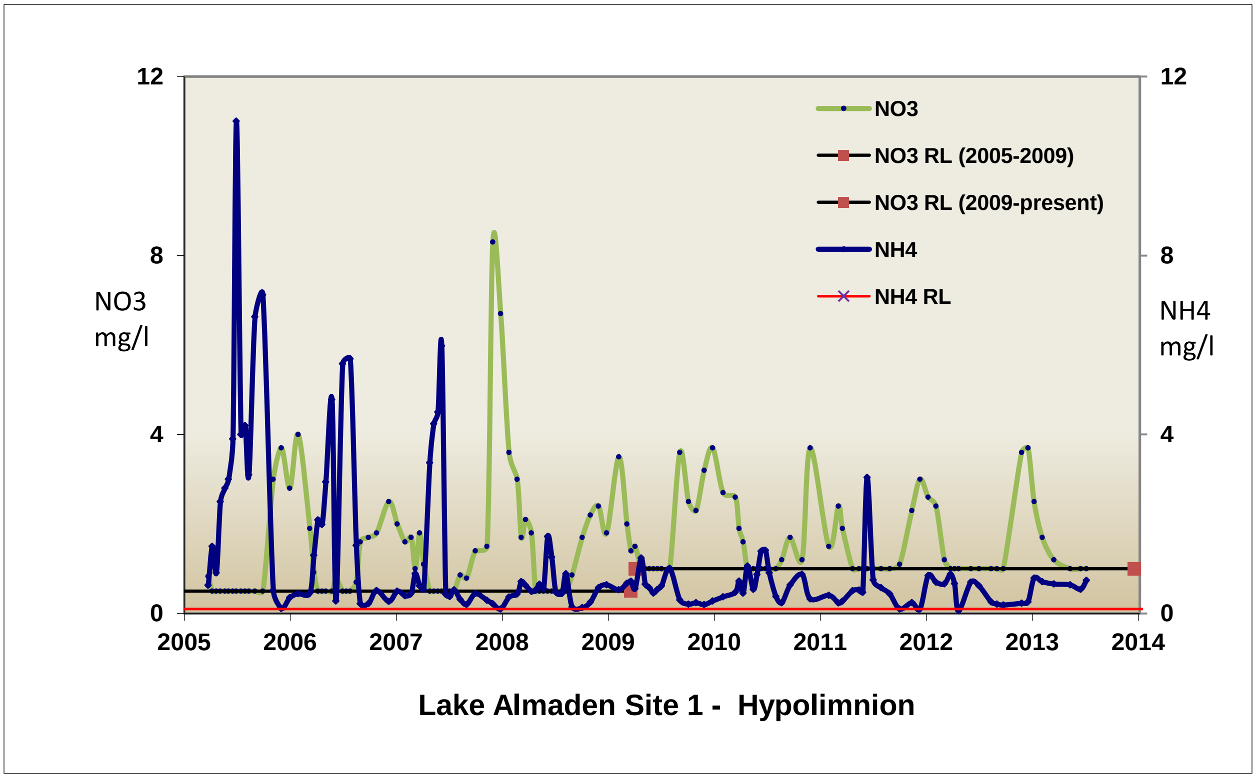


Figure 9: Nitrate (NO_3) and Ammonia (NH_4) Concentrations in Calero Reservoir



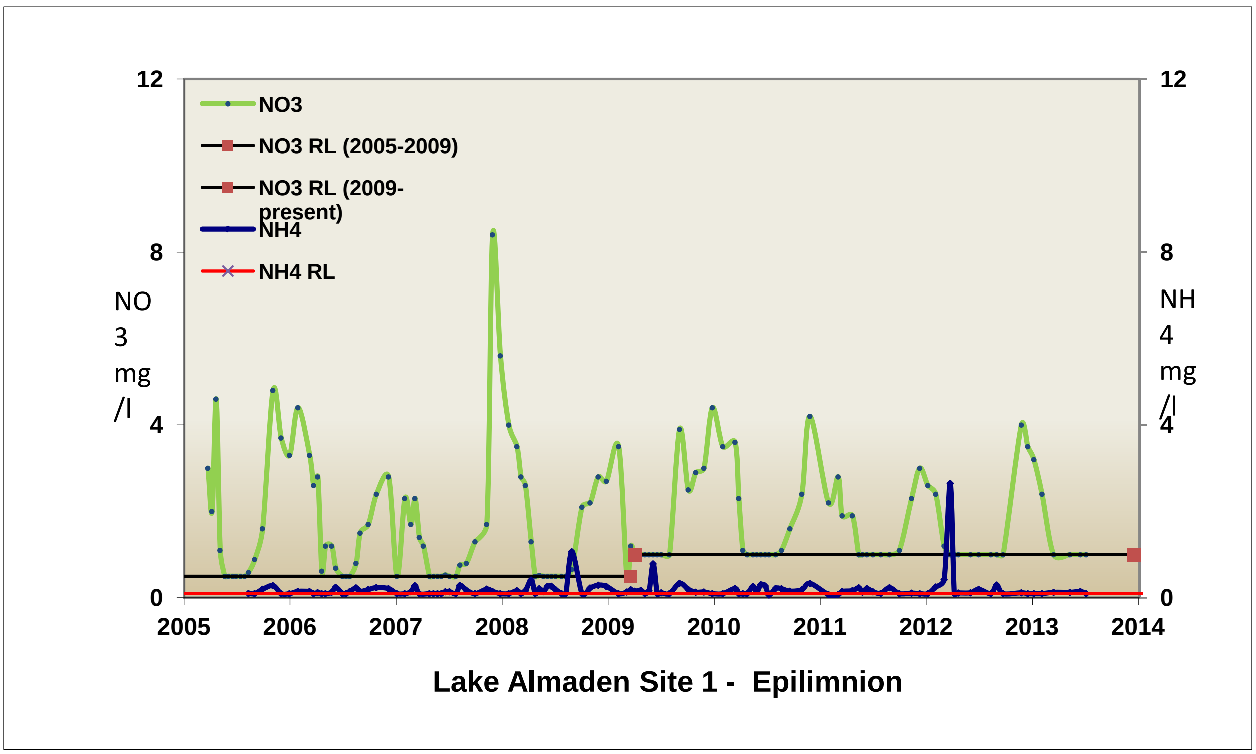
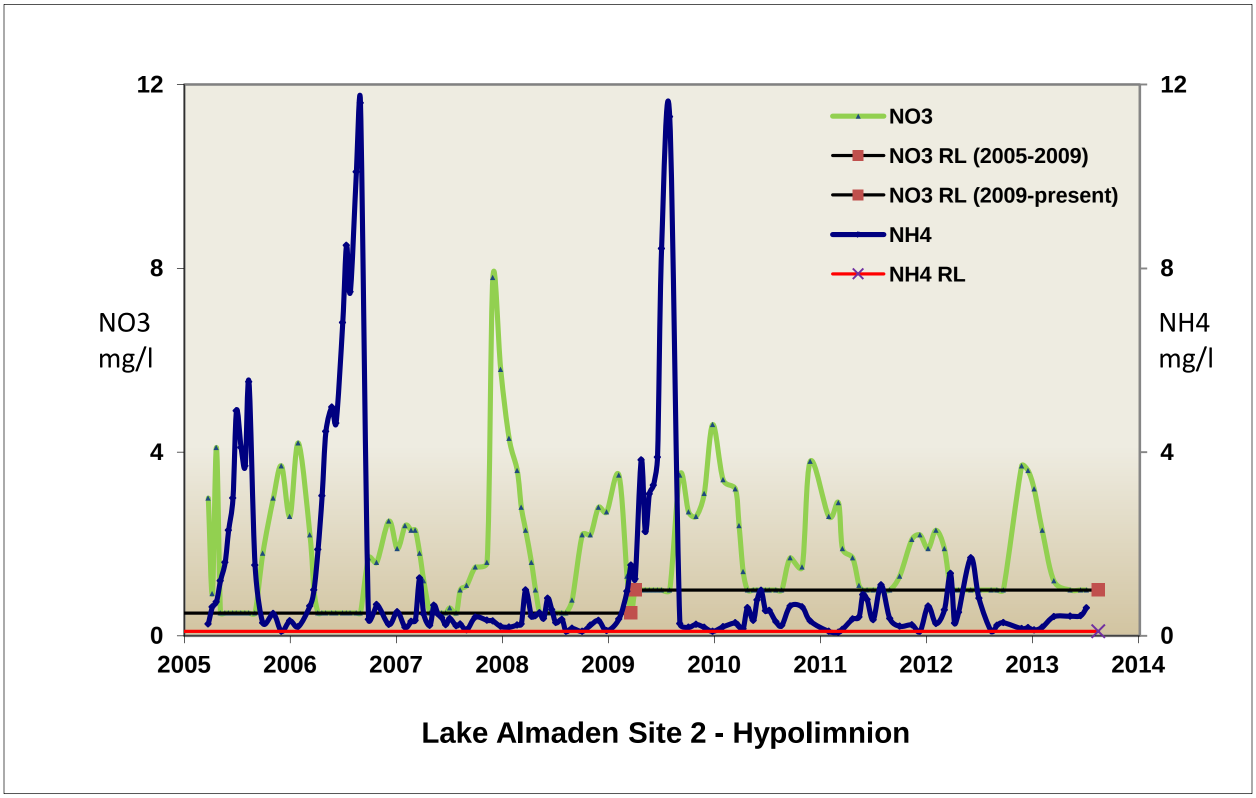


Figure 10: Nitrate (NO_3) and Ammonia (NH_4) Concentrations in Lake Almaden (Site 1)



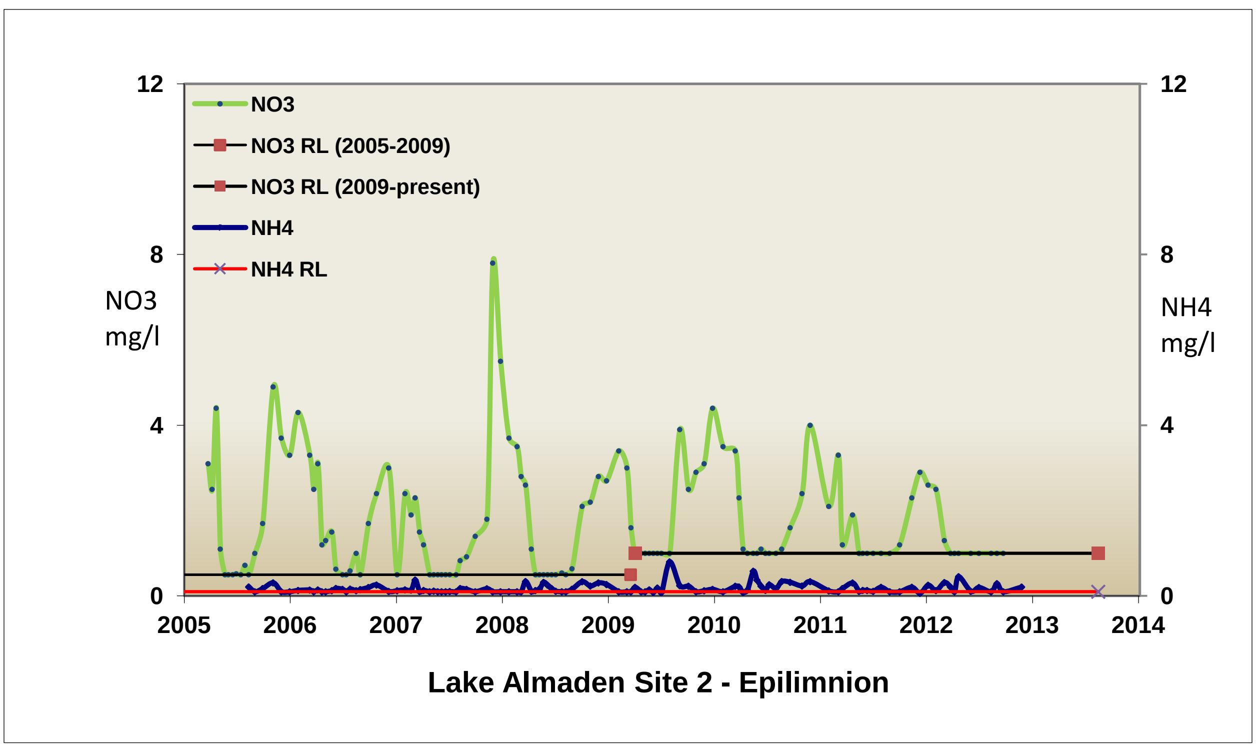
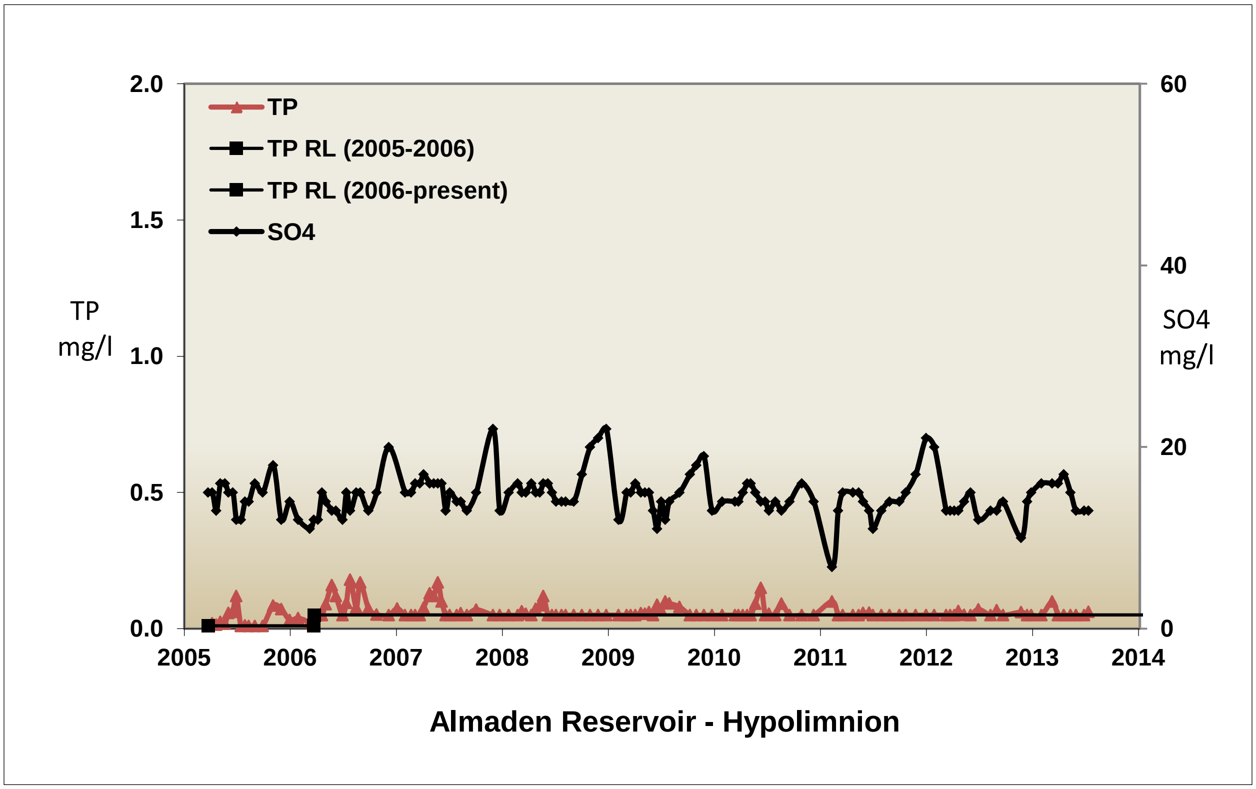


Figure 11: Nitrate (NO_3) and Ammonia (NH_4) Concentrations in Lake Almaden (Site 2)



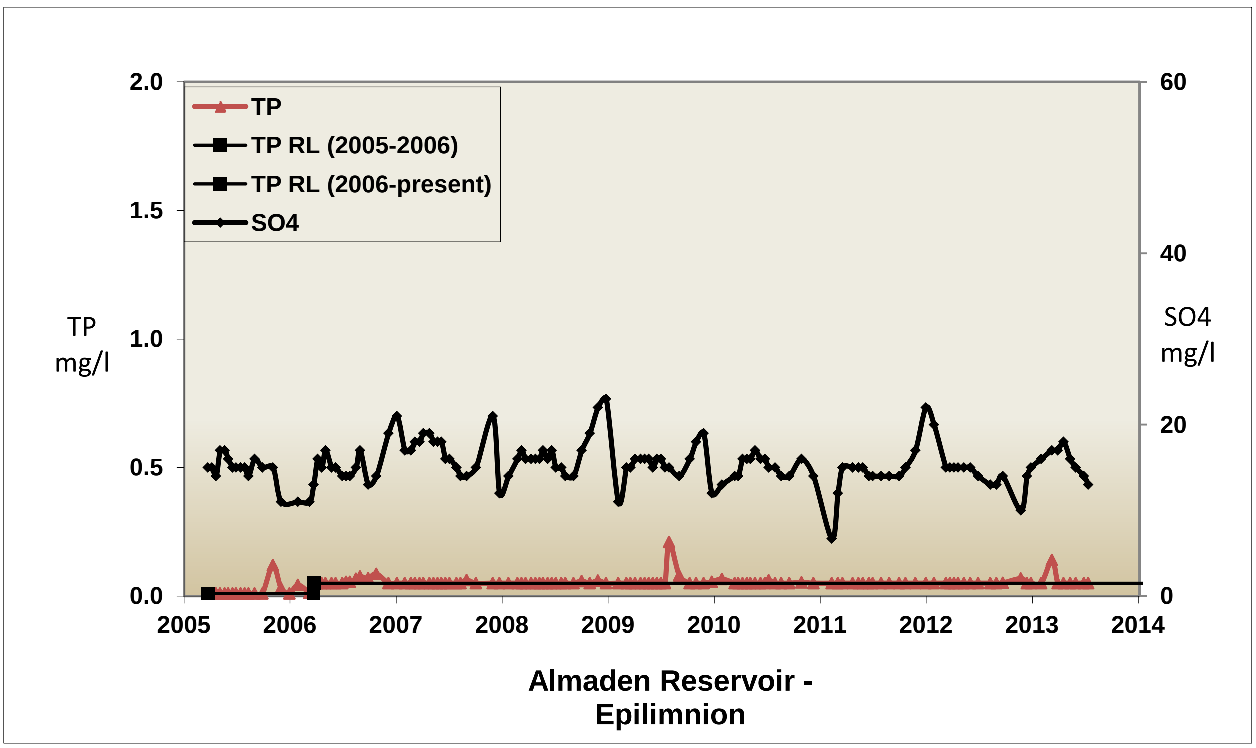
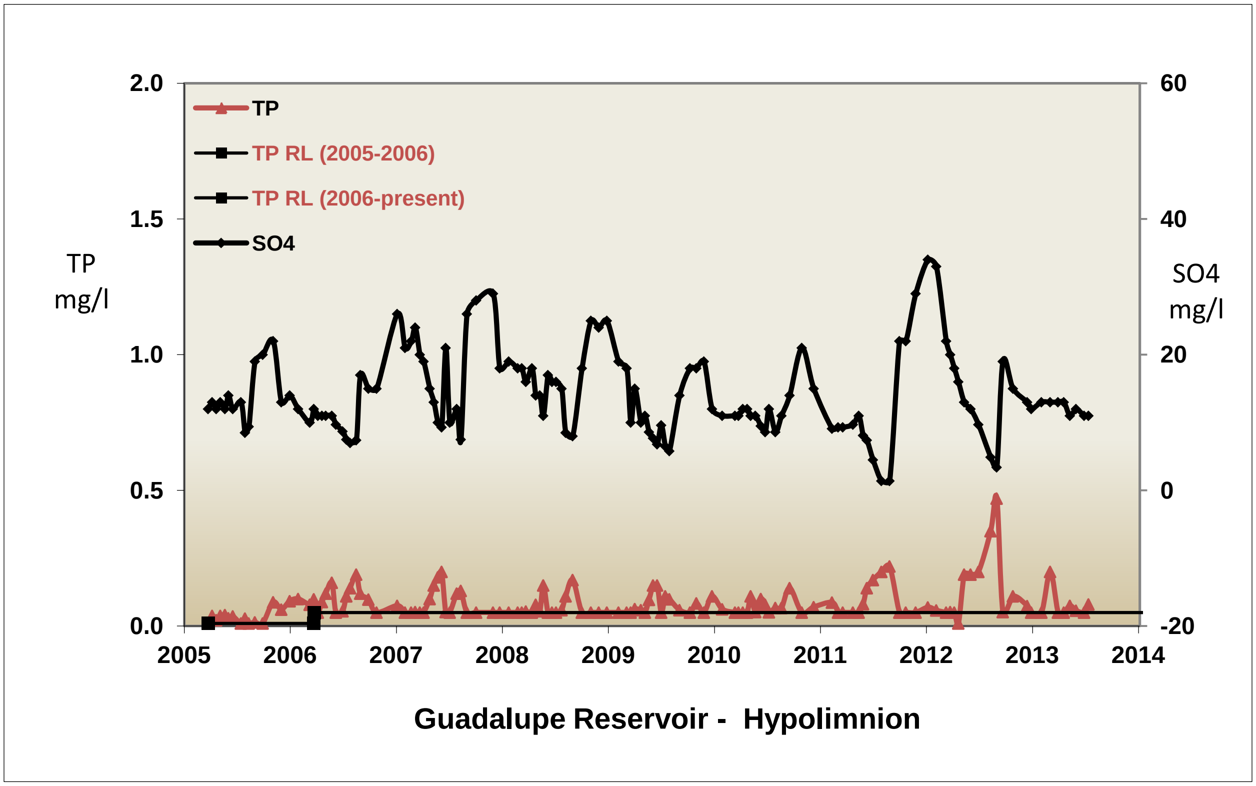


Figure 12: Total Phosphorus (TP) and Sulfate (SO_4) Concentrations in Almaden Reservoir



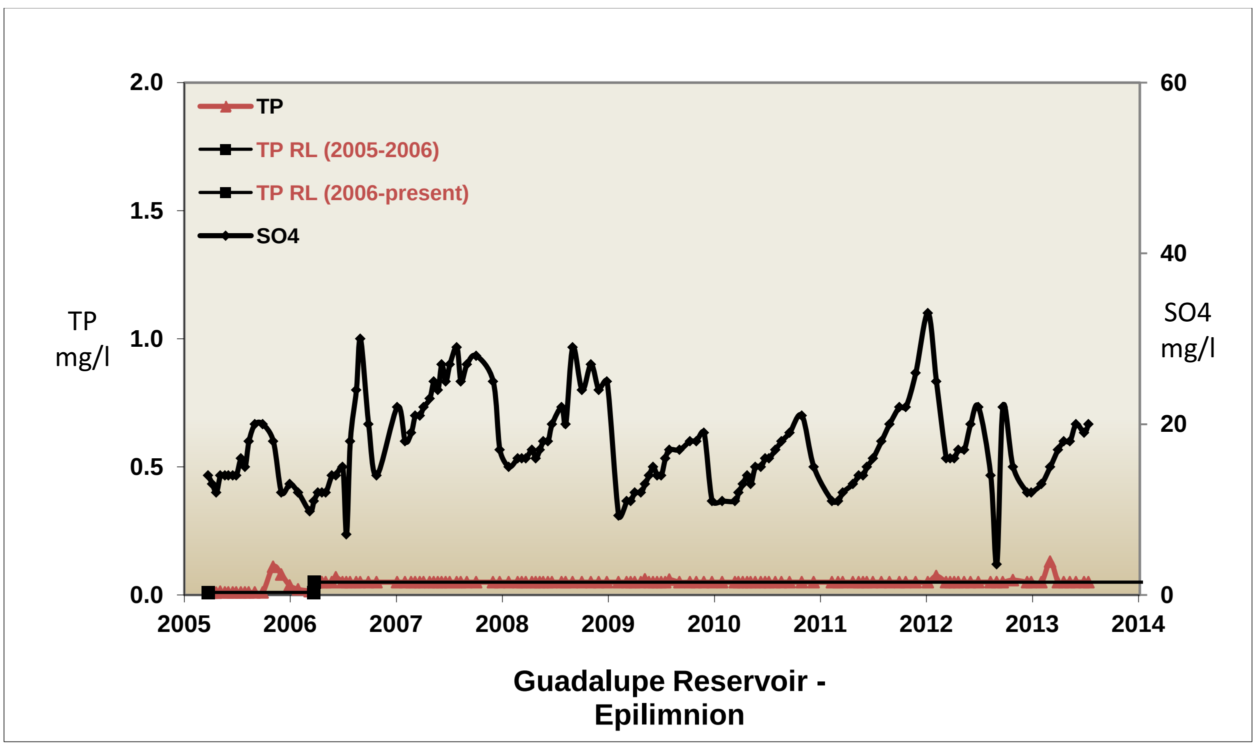
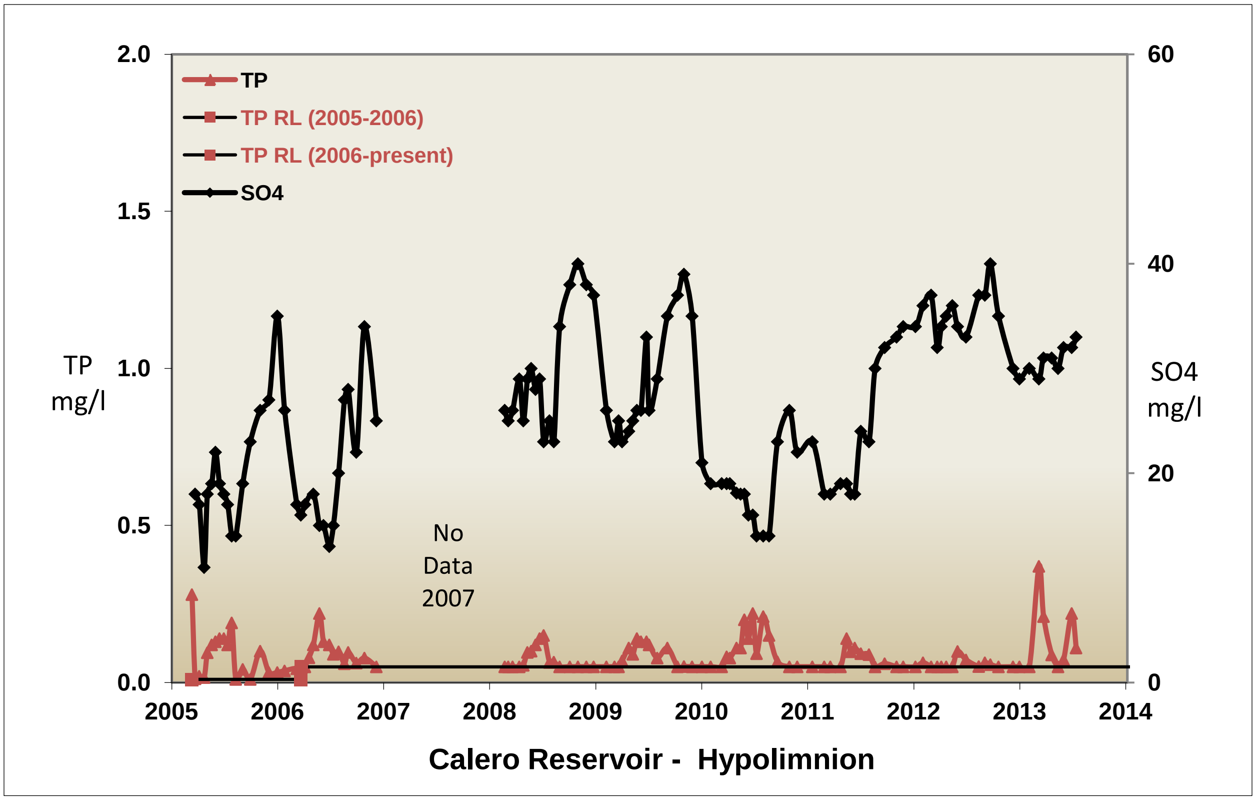


Figure 13: Total Phosphorus (TP) and Sulfate (SO_4) Concentrations in Guadalupe Reservoir



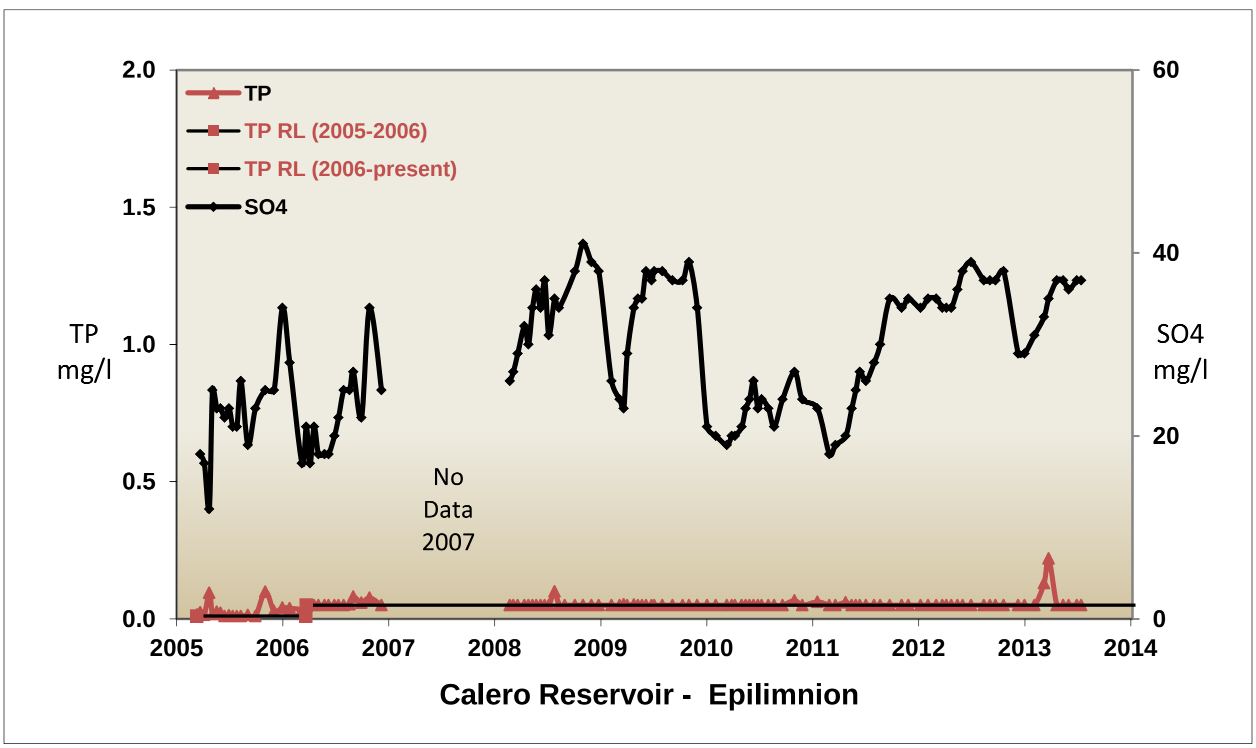
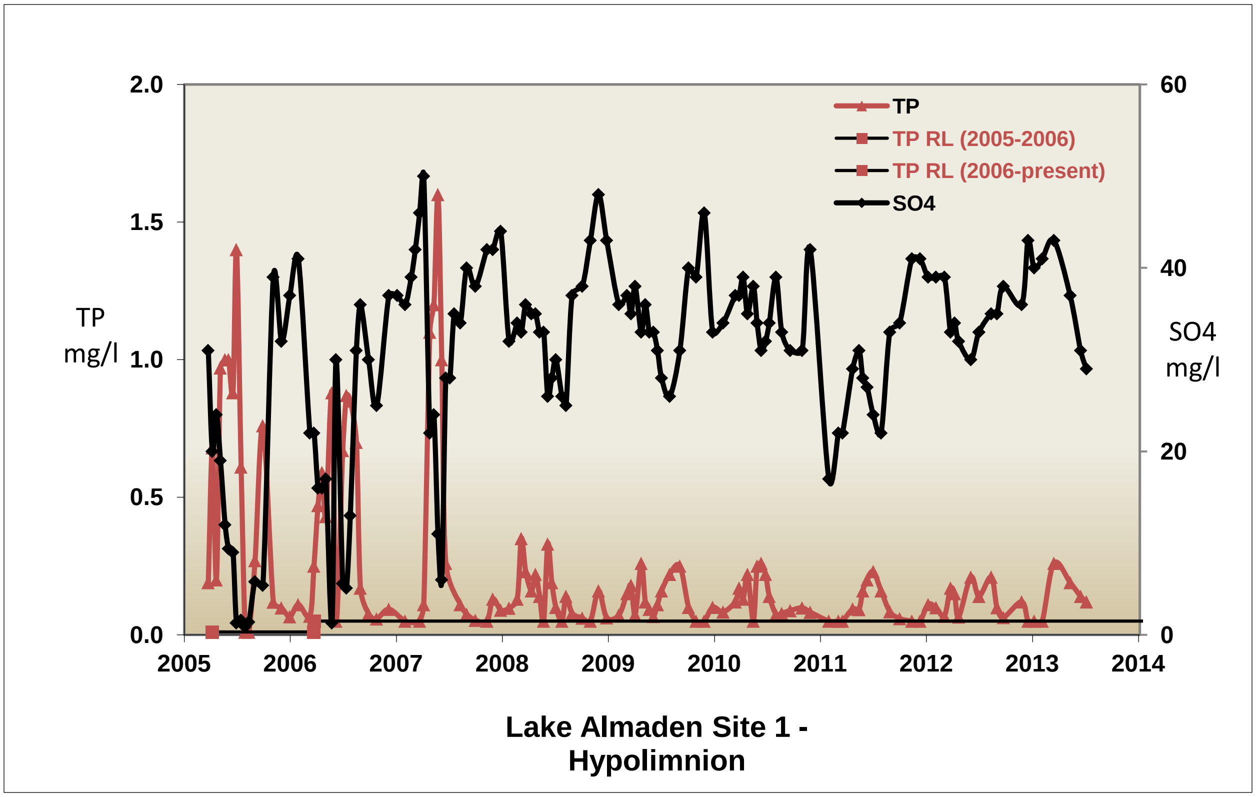


Figure 14: Total Phosphorus (TP) and Sulfate (SO_4) Concentrations in Calero Reservoir



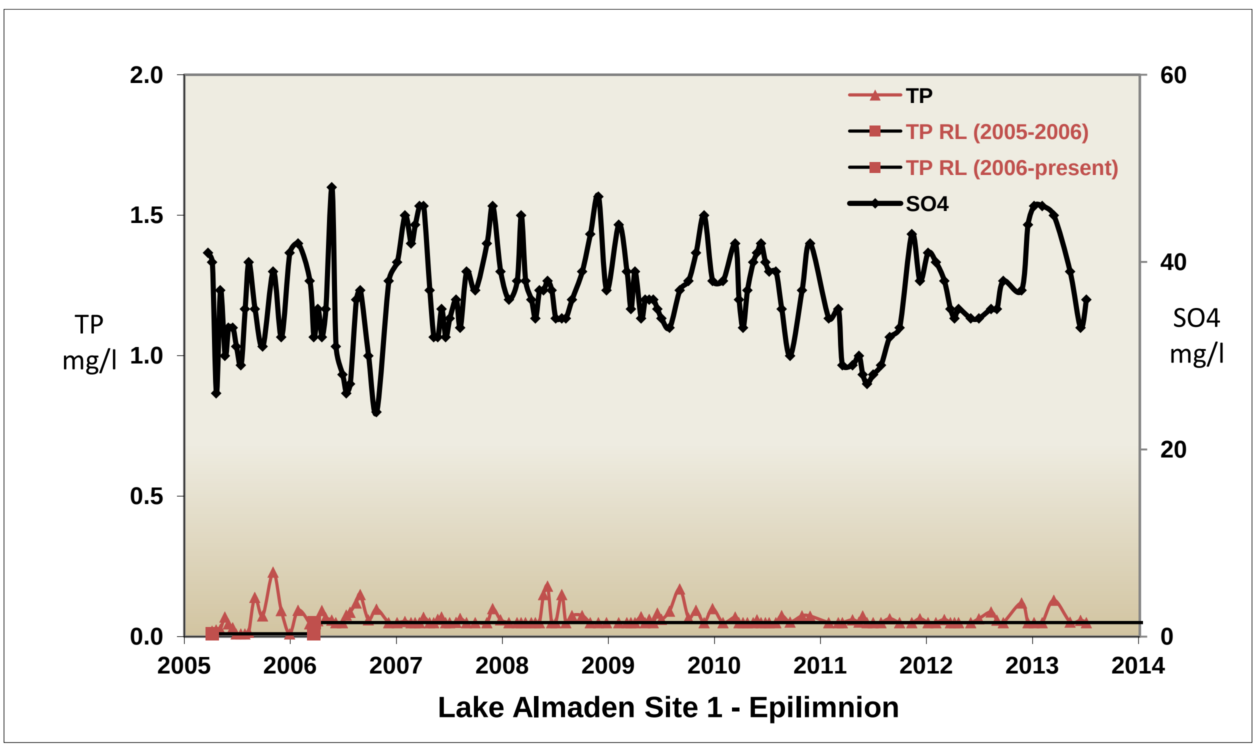
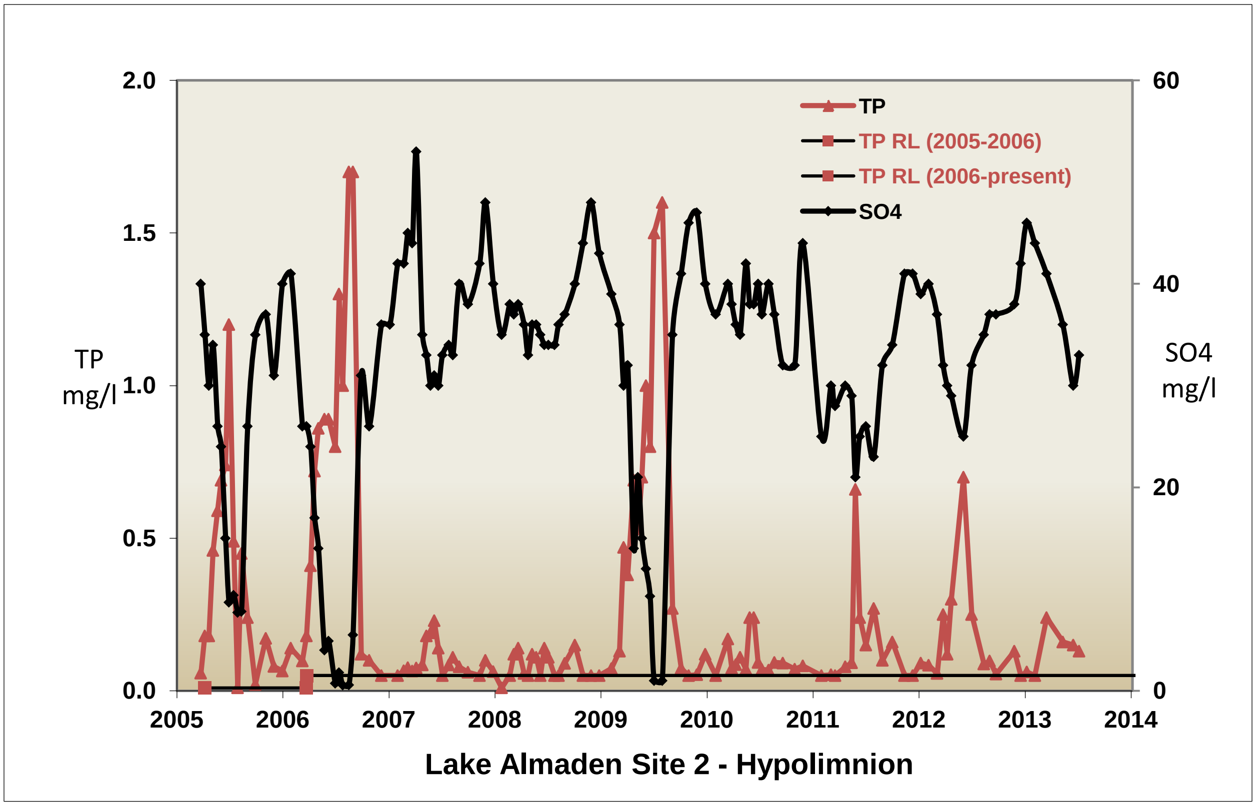


Figure 15: Total Phosphorus (TP) and Sulfate (SO_4) Concentrations in Lake Almaden (Site 1)



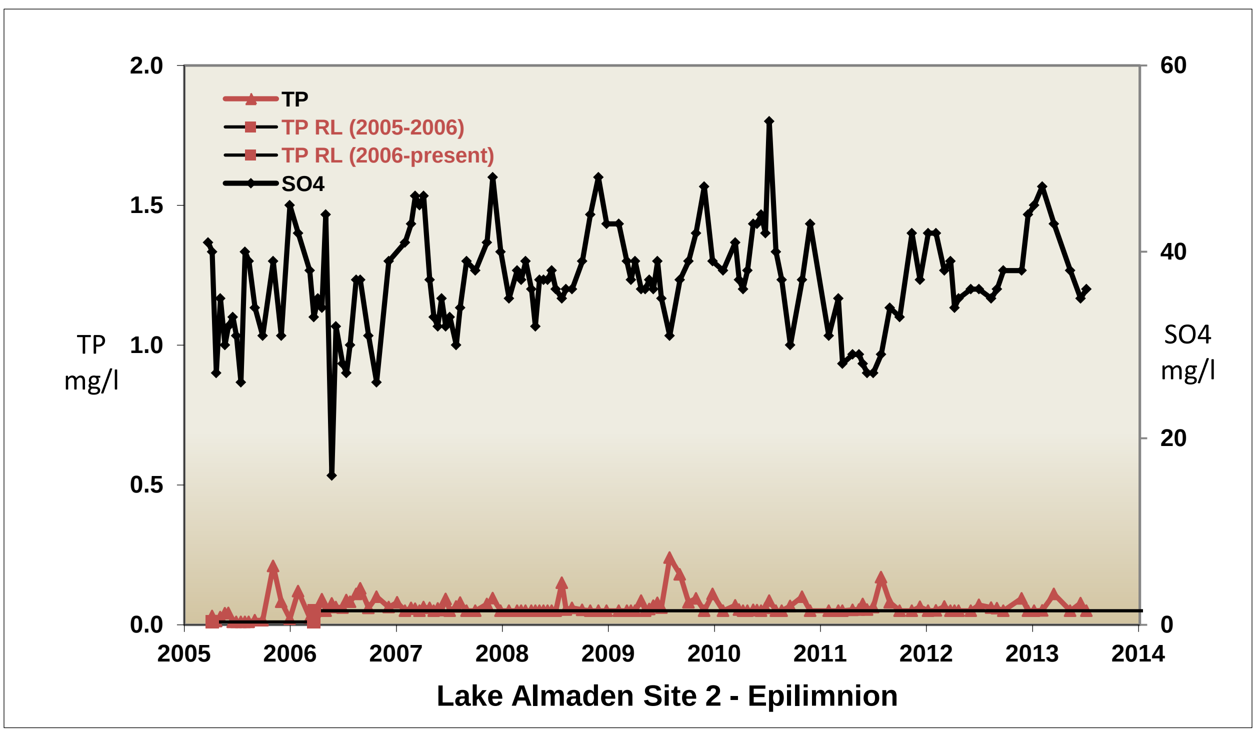


Figure 16: Total Phosphorus (TP) and Sulfate (SO_4) Concentrations in Lake Almaden (Site 2)

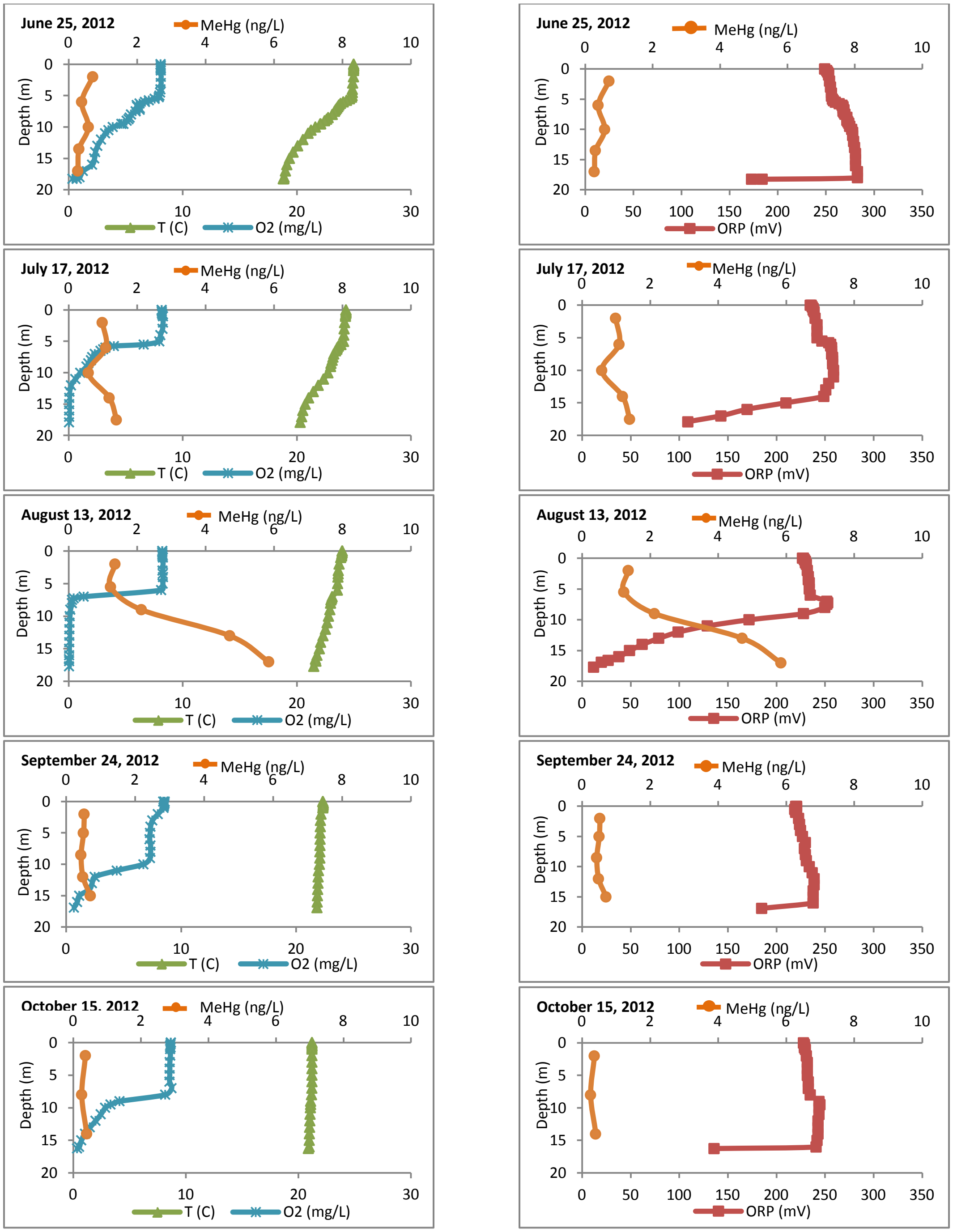


Figure 17: Unfiltered Methyl Mercury (Total MeHg) 2012 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Almaden Reservoir

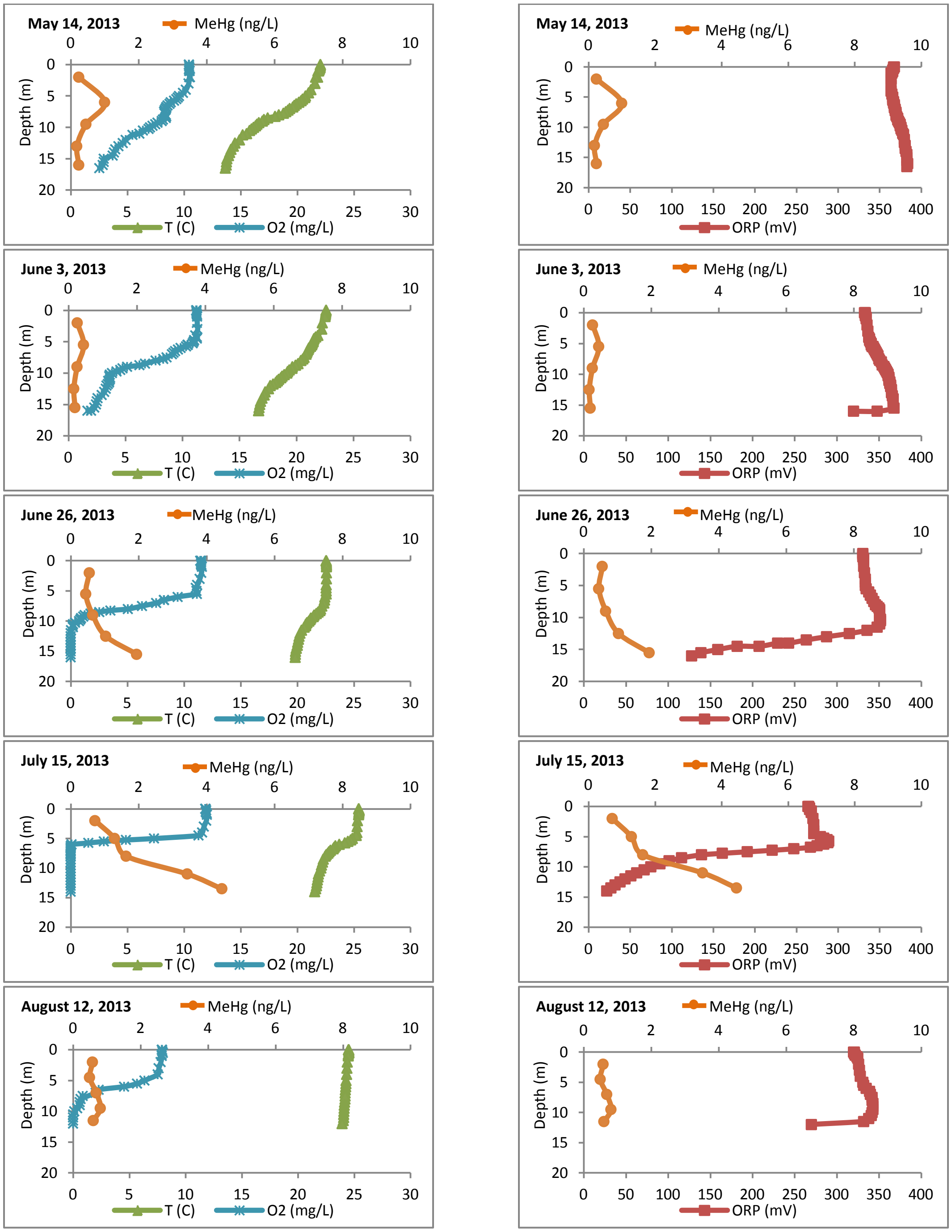


Figure 18: Unfiltered Methyl Mercury (Total MeHg) 2013 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Almaden Reservoir

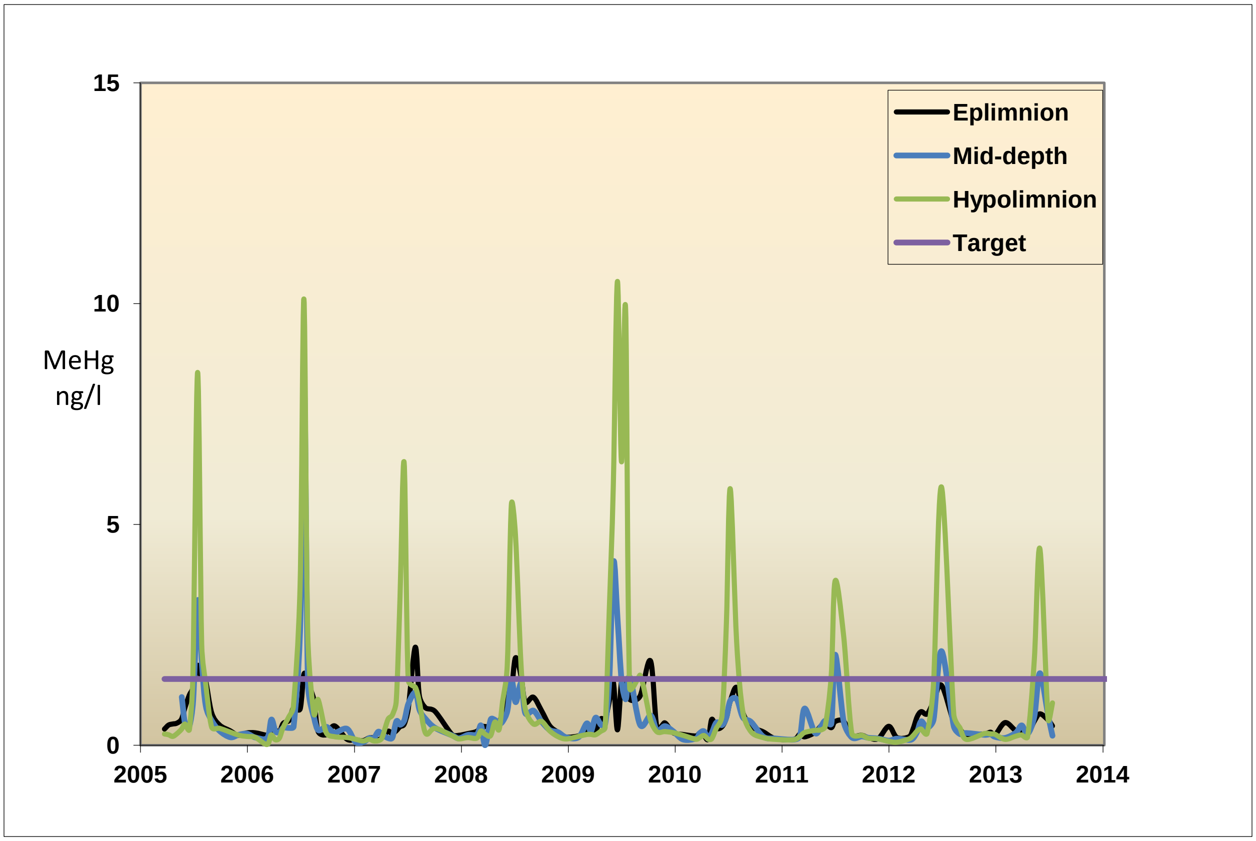
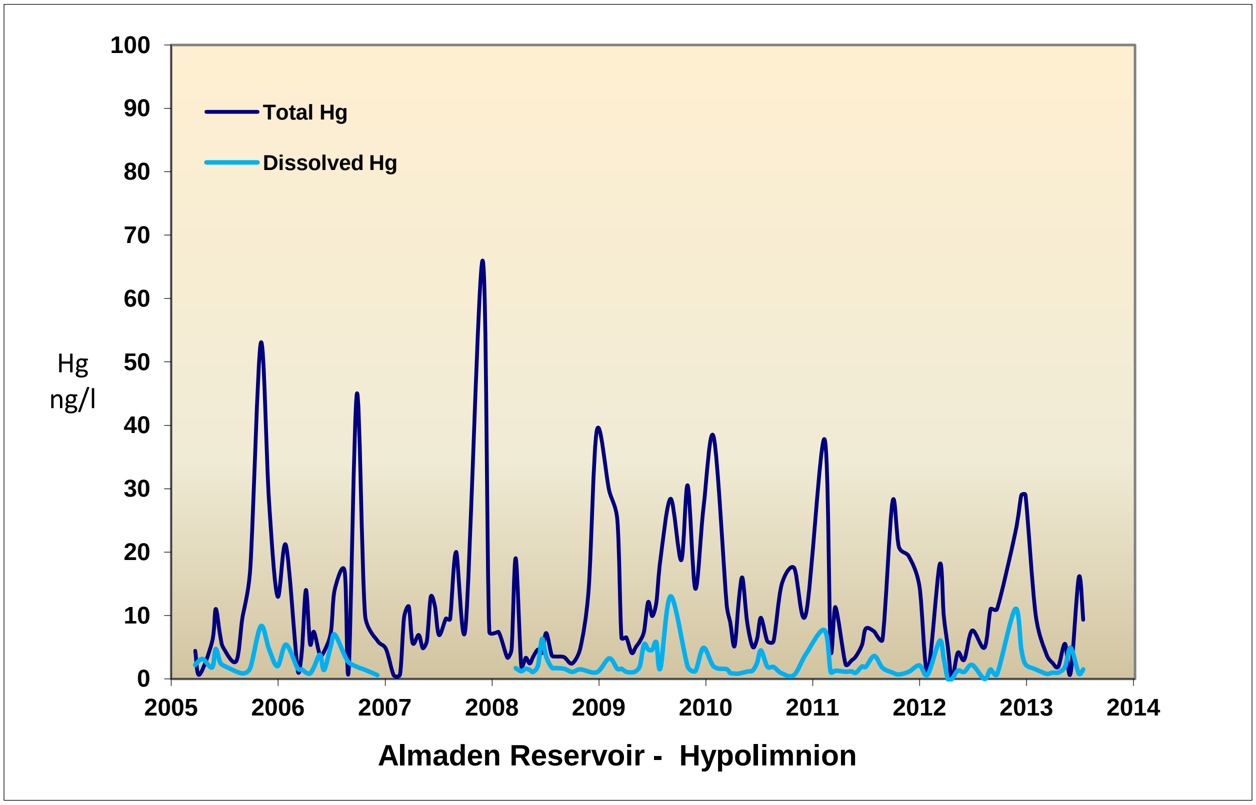


Figure 19: Unfiltered Methyl Mercury (Total MeHg) Concentrations in Almaden Reservoir



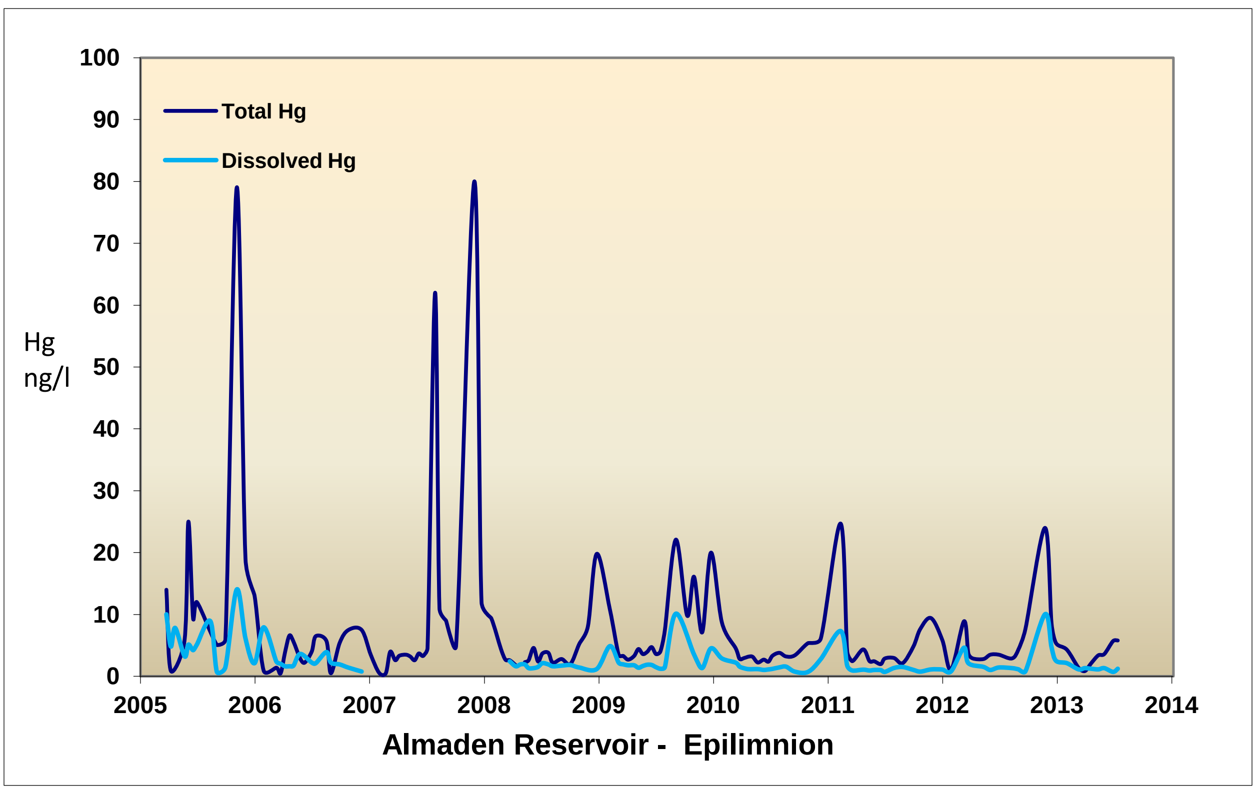


Figure 20: Unfiltered (Total) and Filtered (Dissolved) Mercury (Hg) in Almaden Reservoir

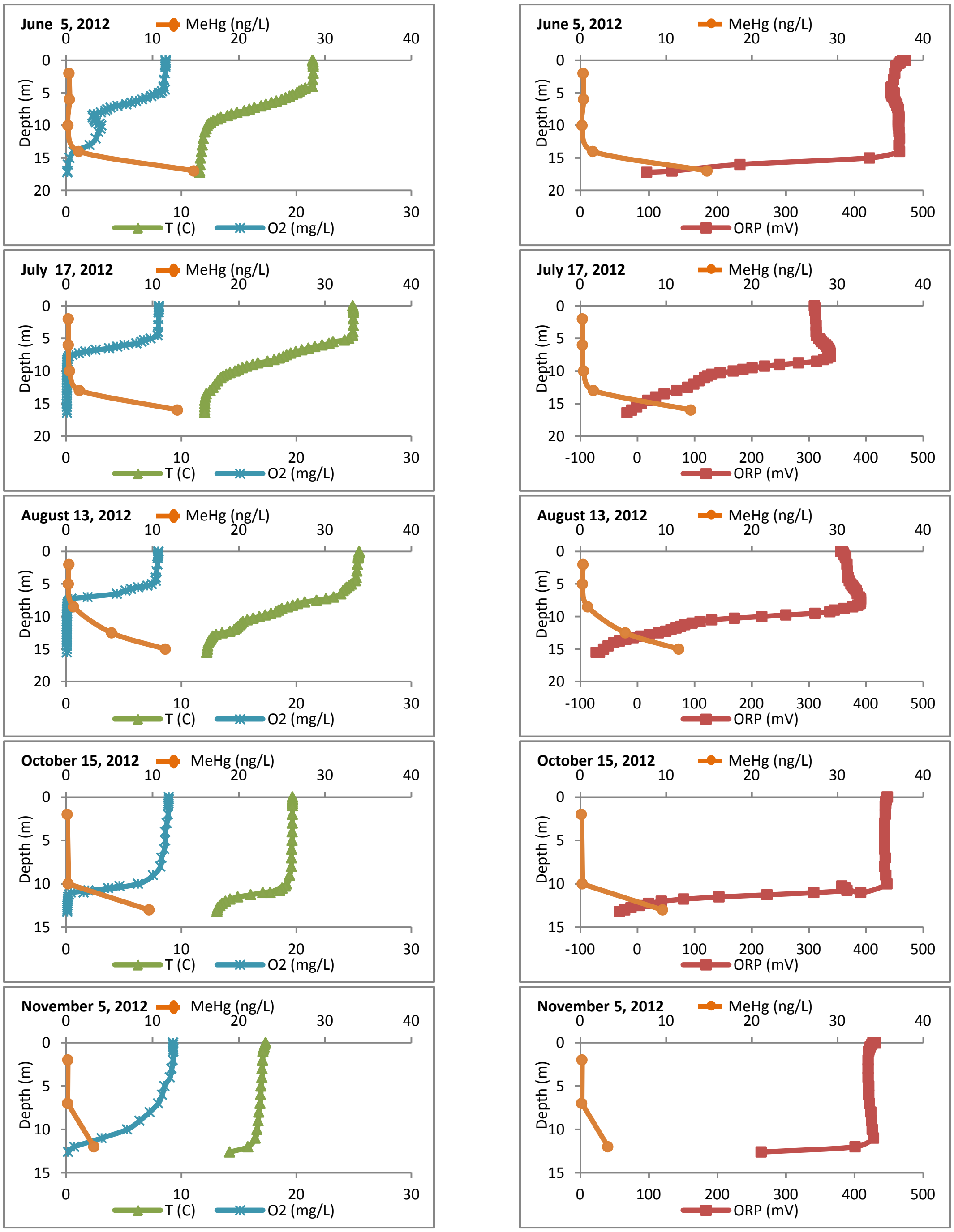


Figure 21: Unfiltered Methyl Mercury (Total MeHg) 2012 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Guadalupe Reservoir

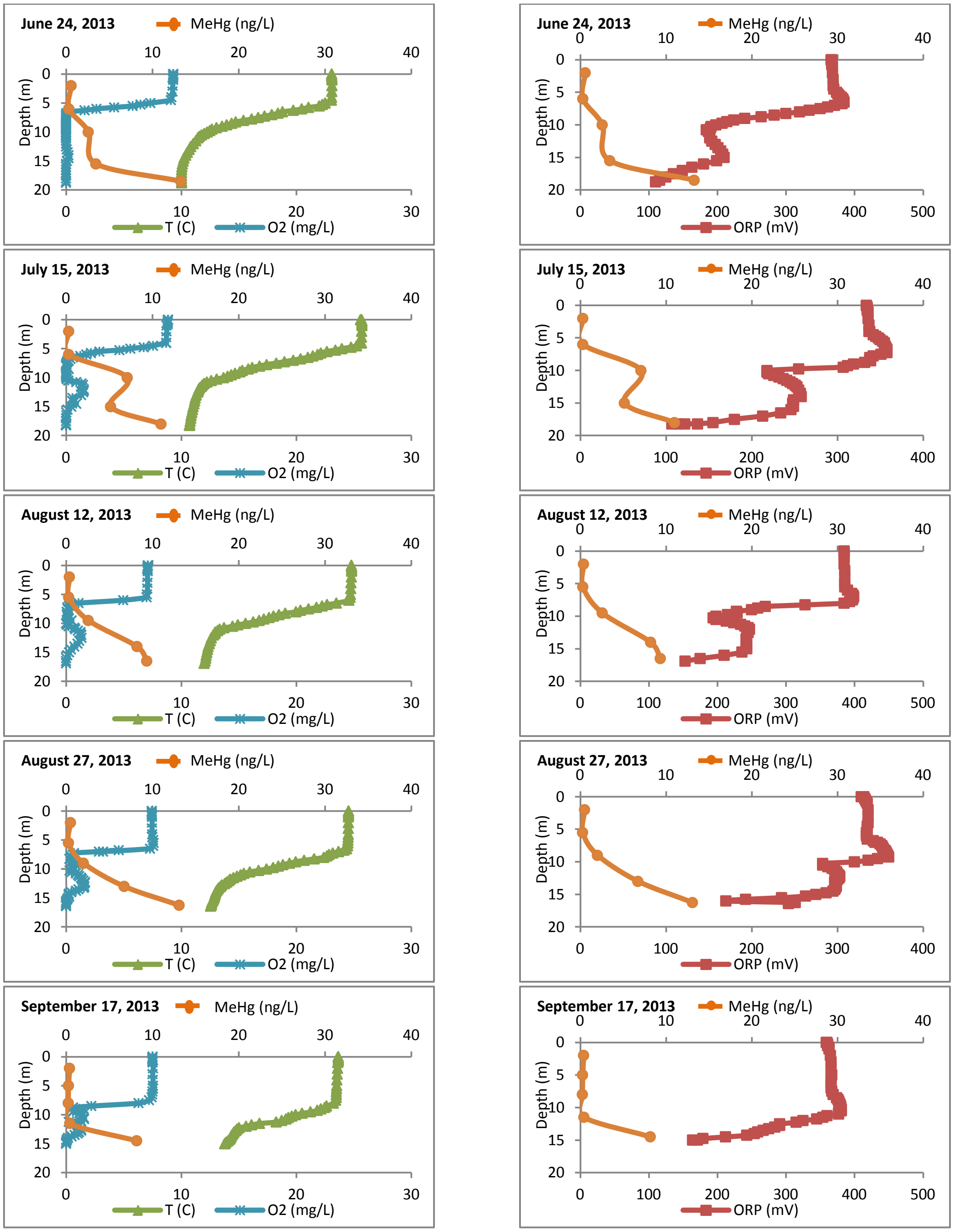


Figure 22: Unfiltered Methyl Mercury (Total MeHg) 2013 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Guadalupe Reservoir

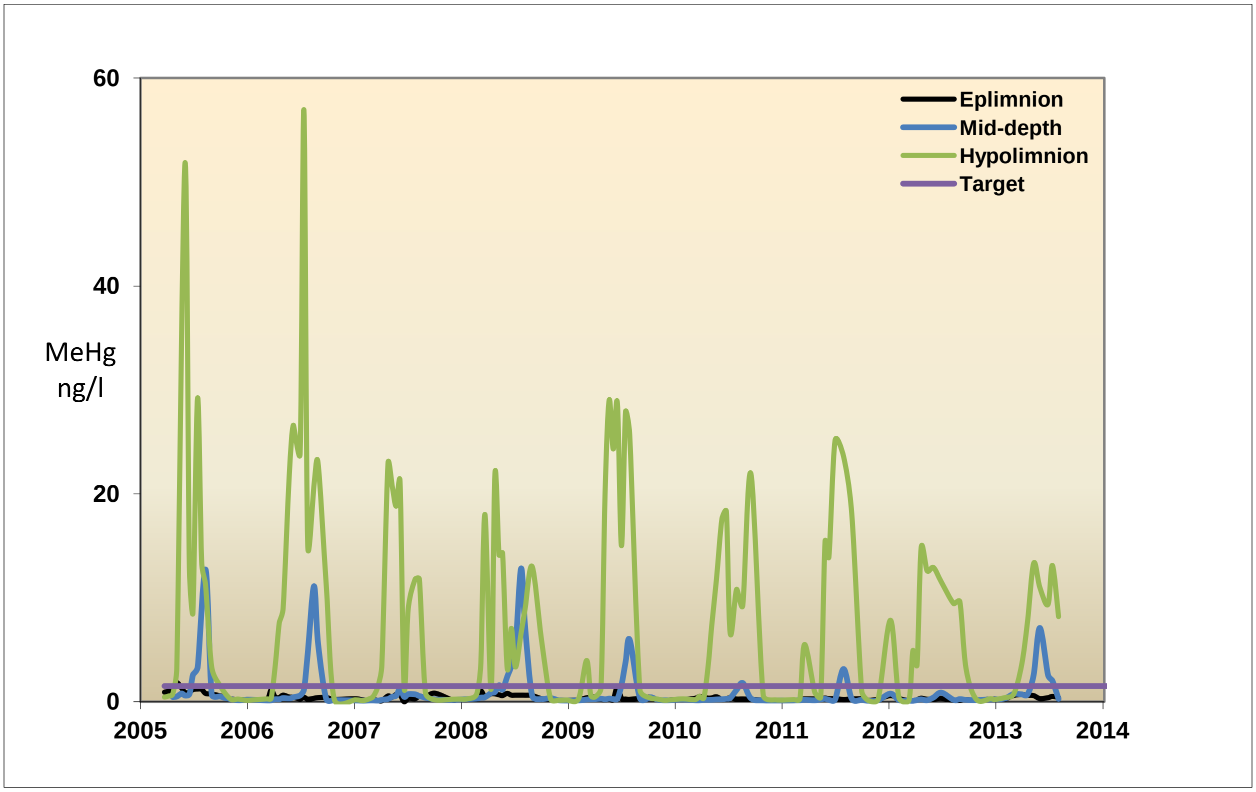
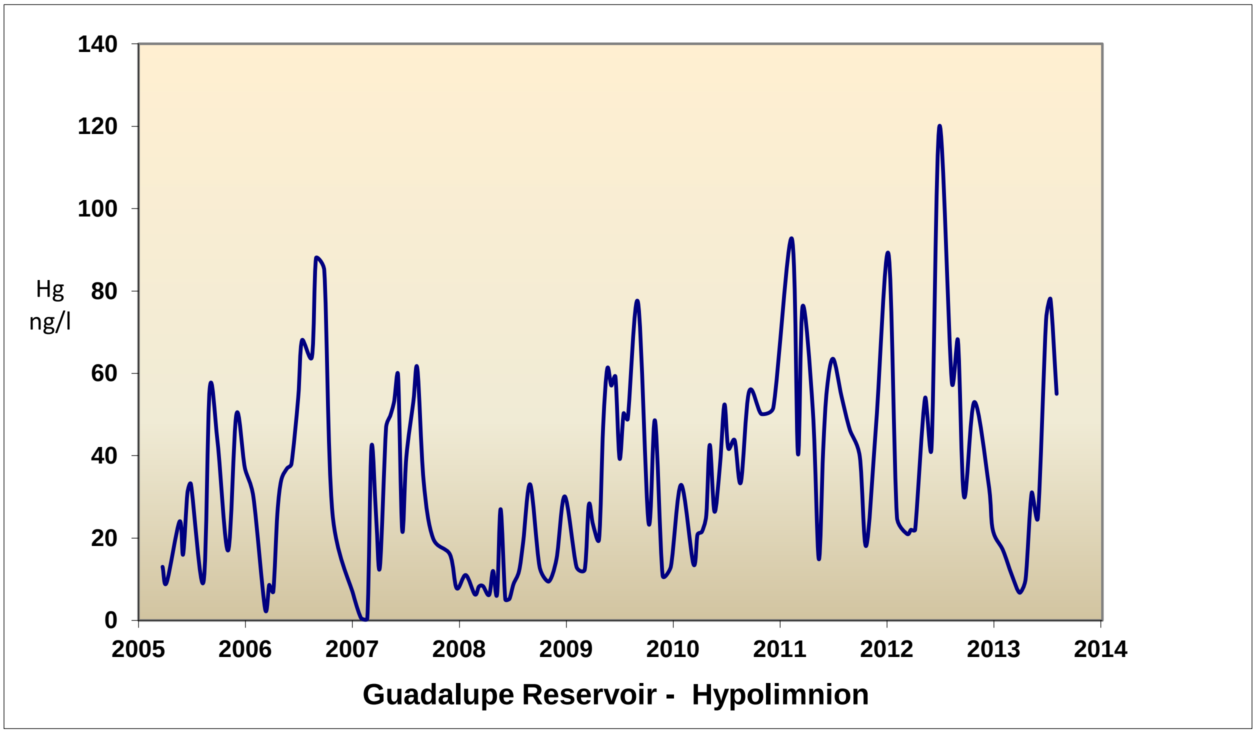


Figure 23: Unfiltered Methyl Mercury (Total MeHg) Concentrations in Guadalupe Reservoir



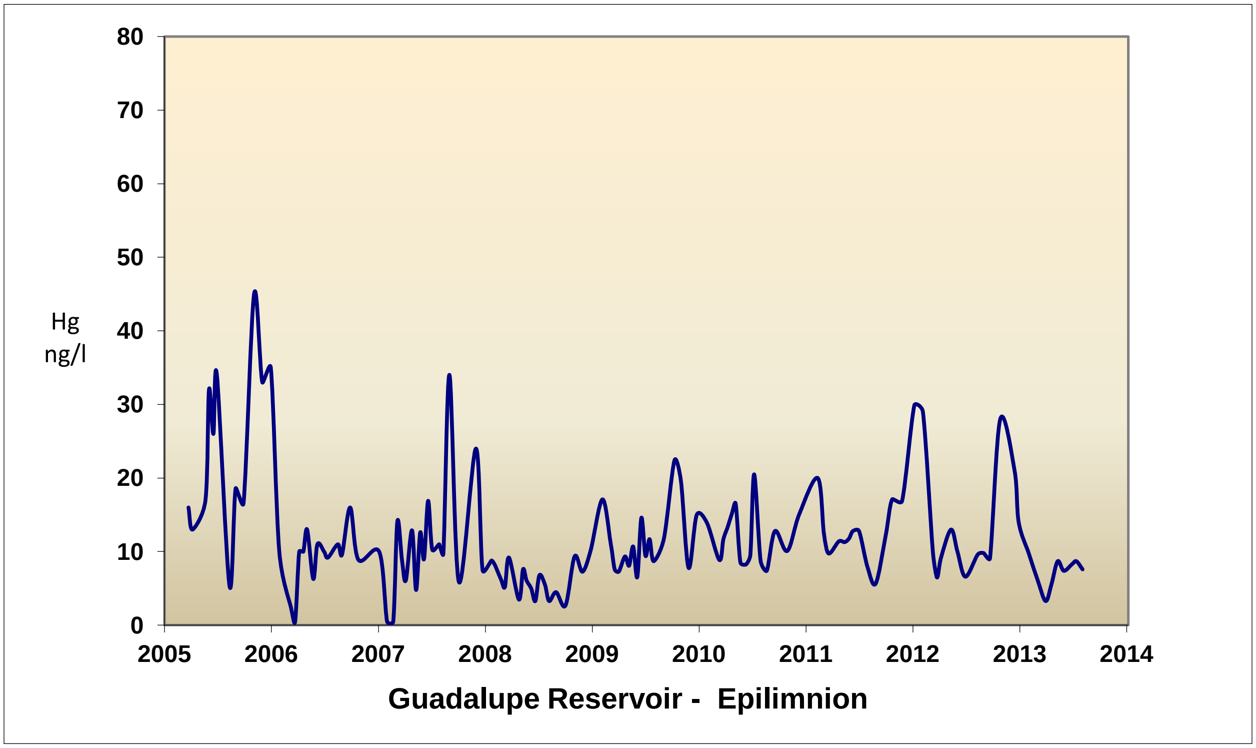


Figure 24: Unfiltered Mercury (Total Hg) Concentrations in Guadalupe Reservoir

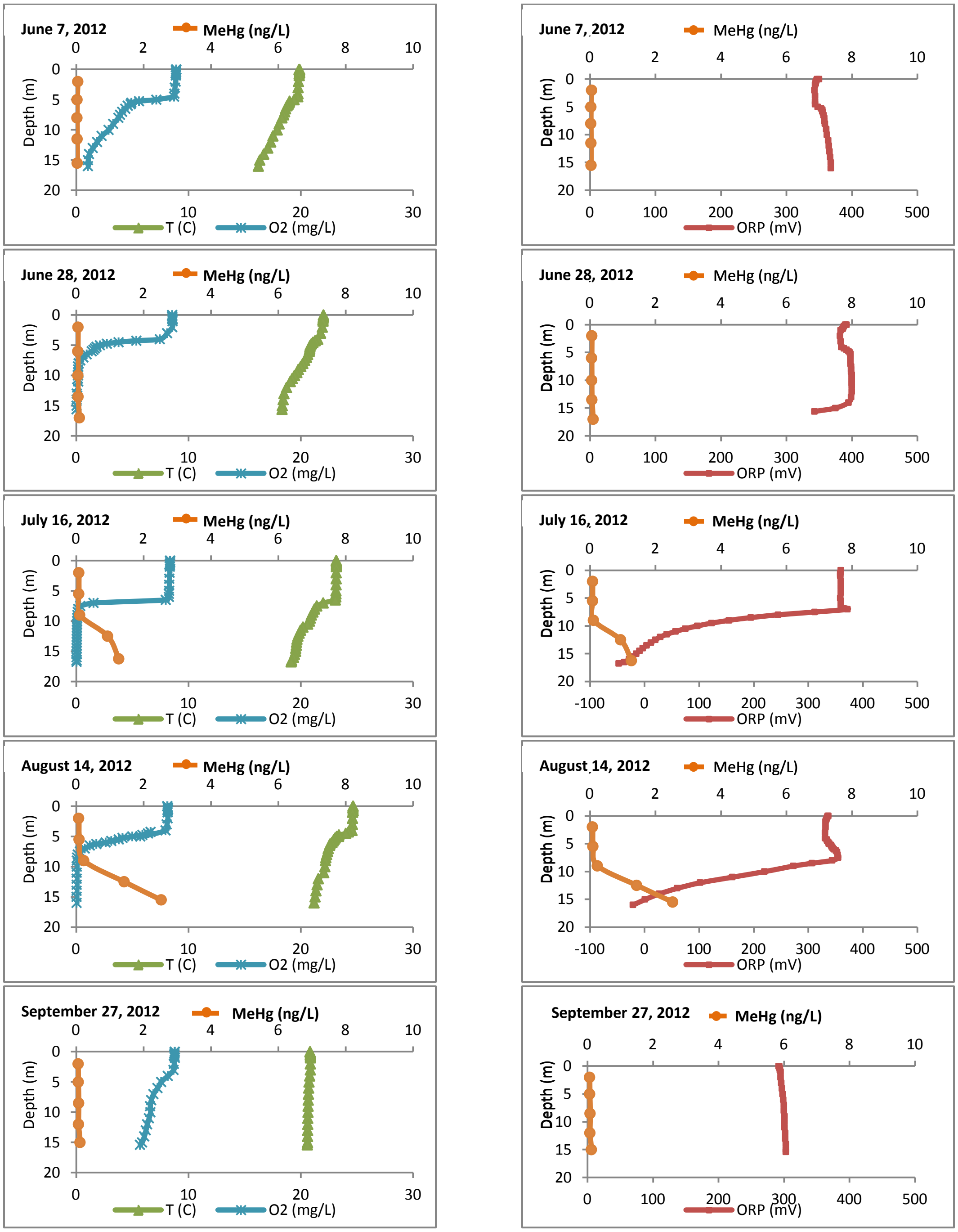


Figure 25: Unfiltered Methyl Mercury (Total MeHg) 2012 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Calero Reservoir

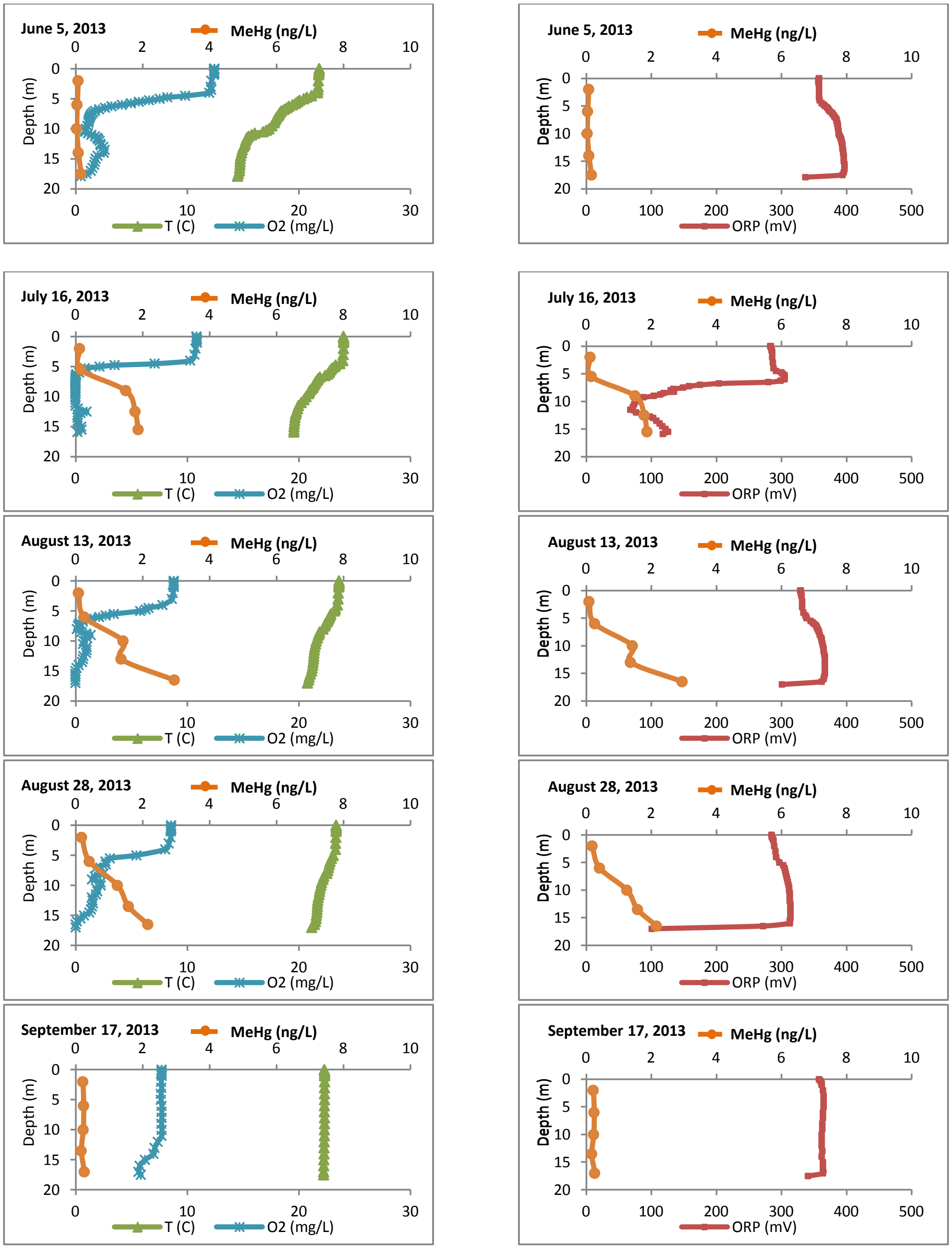


Figure 26: Unfiltered Methyl Mercury (Total MeHg) 2013 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Calero Reservoir

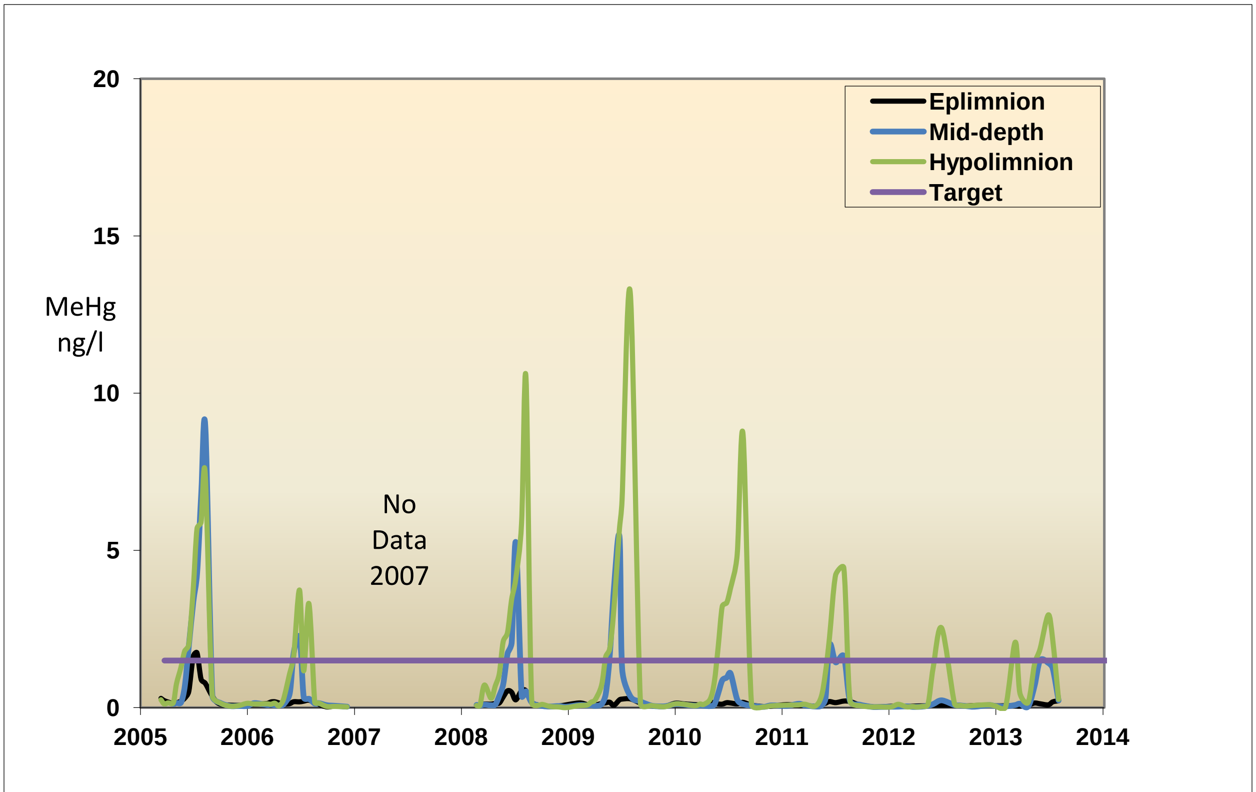
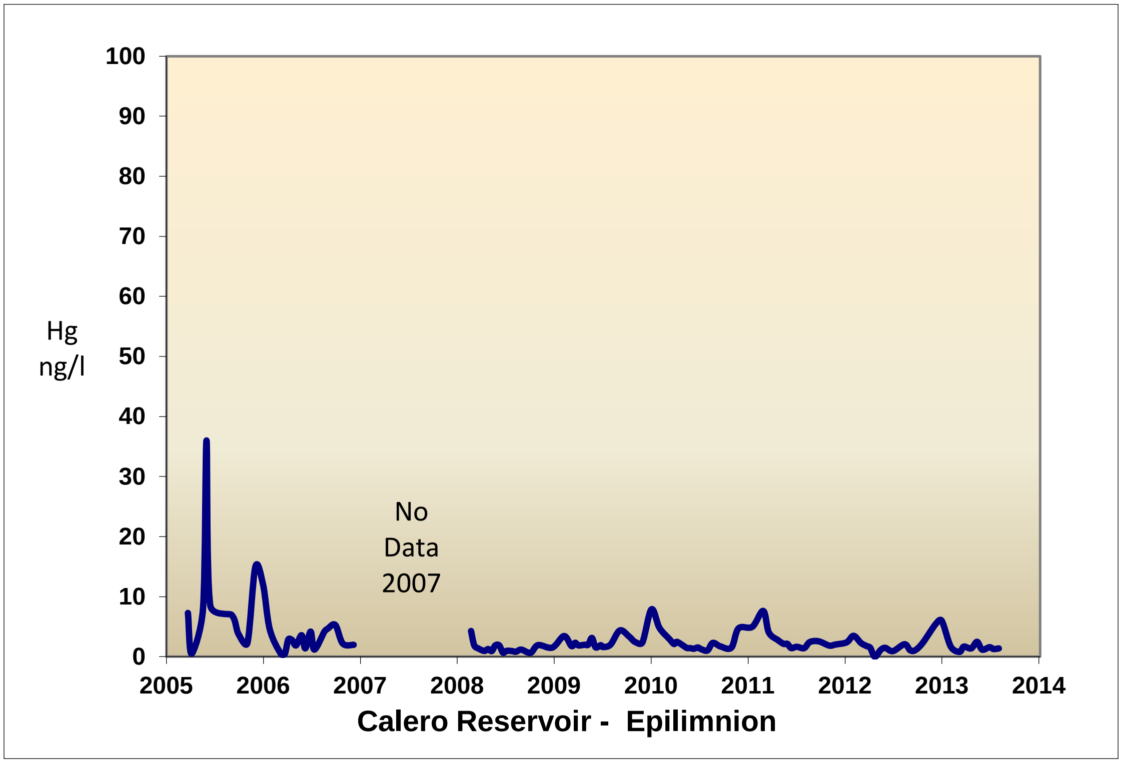


Figure 27: Unfiltered Methyl Mercury (Total MeHg) Concentrations in Calero Reservoir



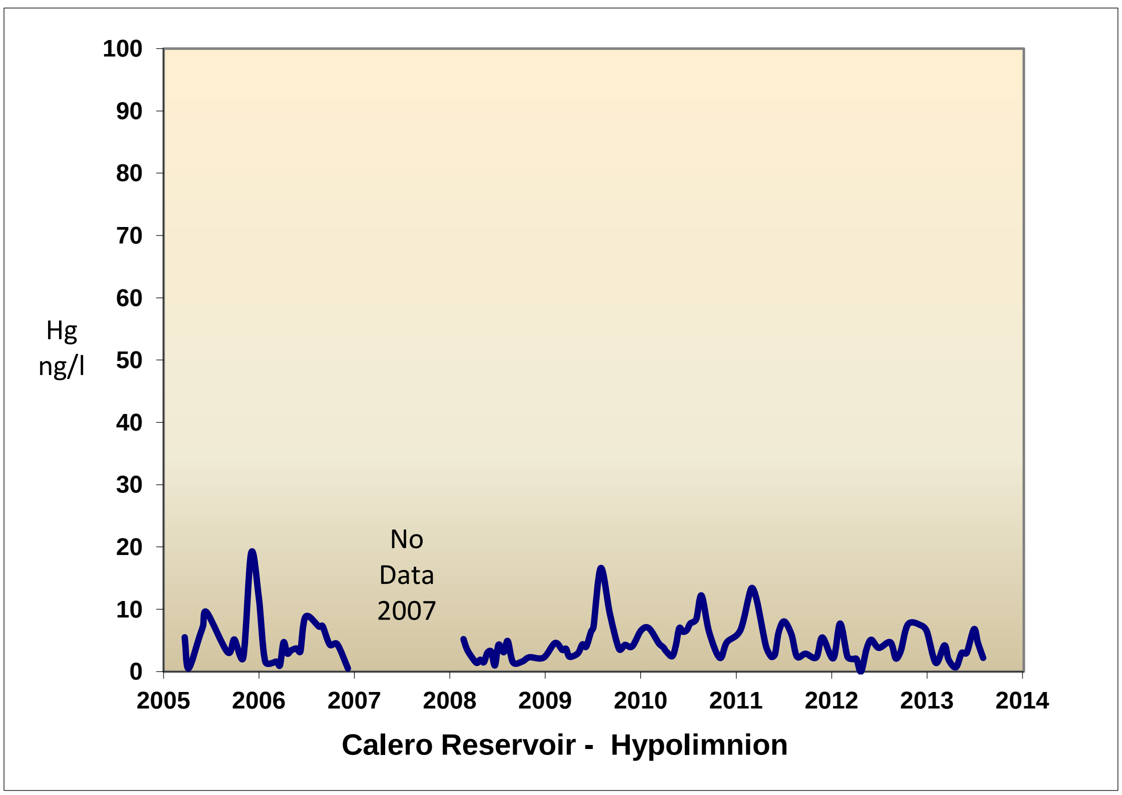


Figure 28: Unfiltered Mercury (Total Hg) Concentrations in Calero Reservoir

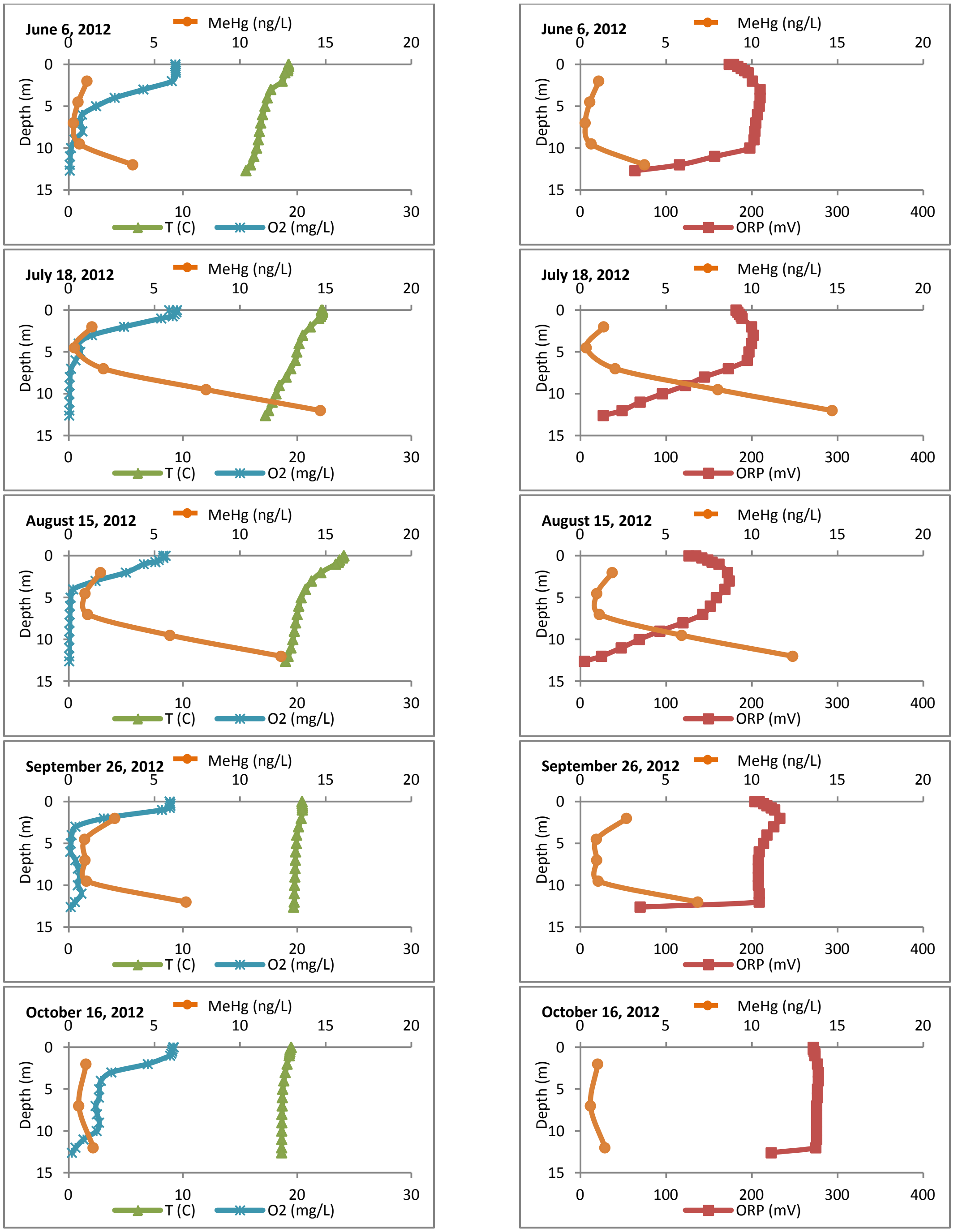


Figure 29: Unfiltered Methyl Mercury (Total MeHg) 2012 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Lake Almaden (Site 1)

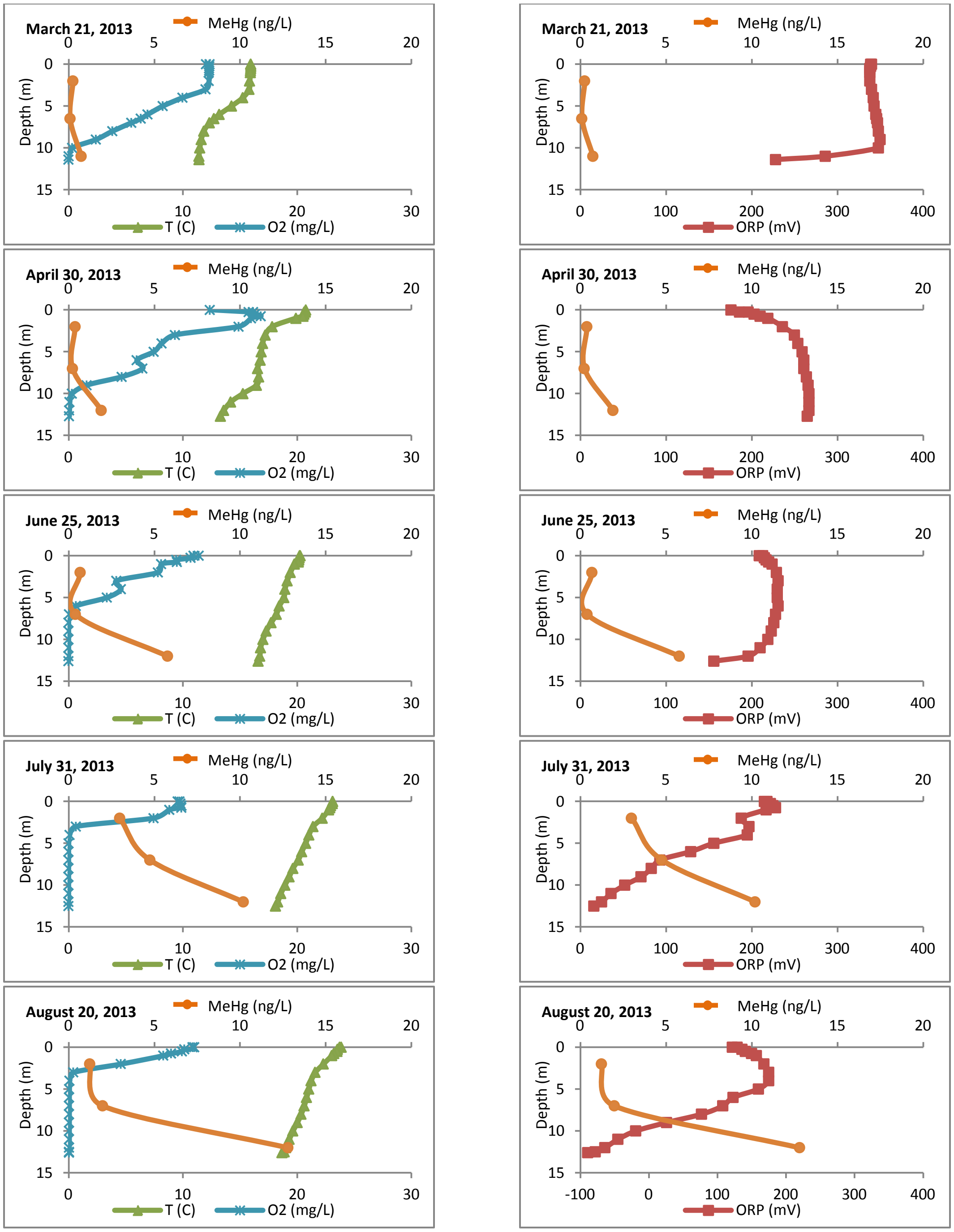


Figure 30: Unfiltered Methyl Mercury (Total MeHg) 2013 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Lake Almaden (Site 1)

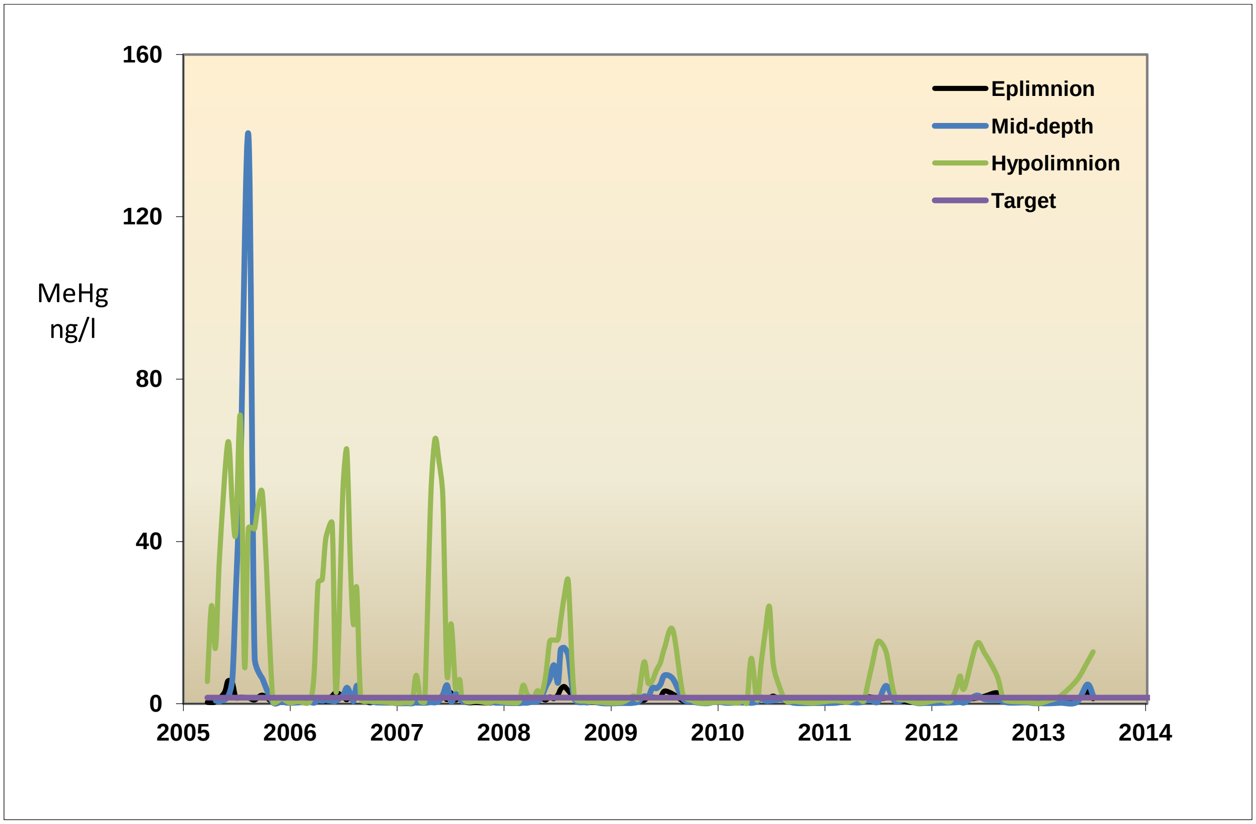
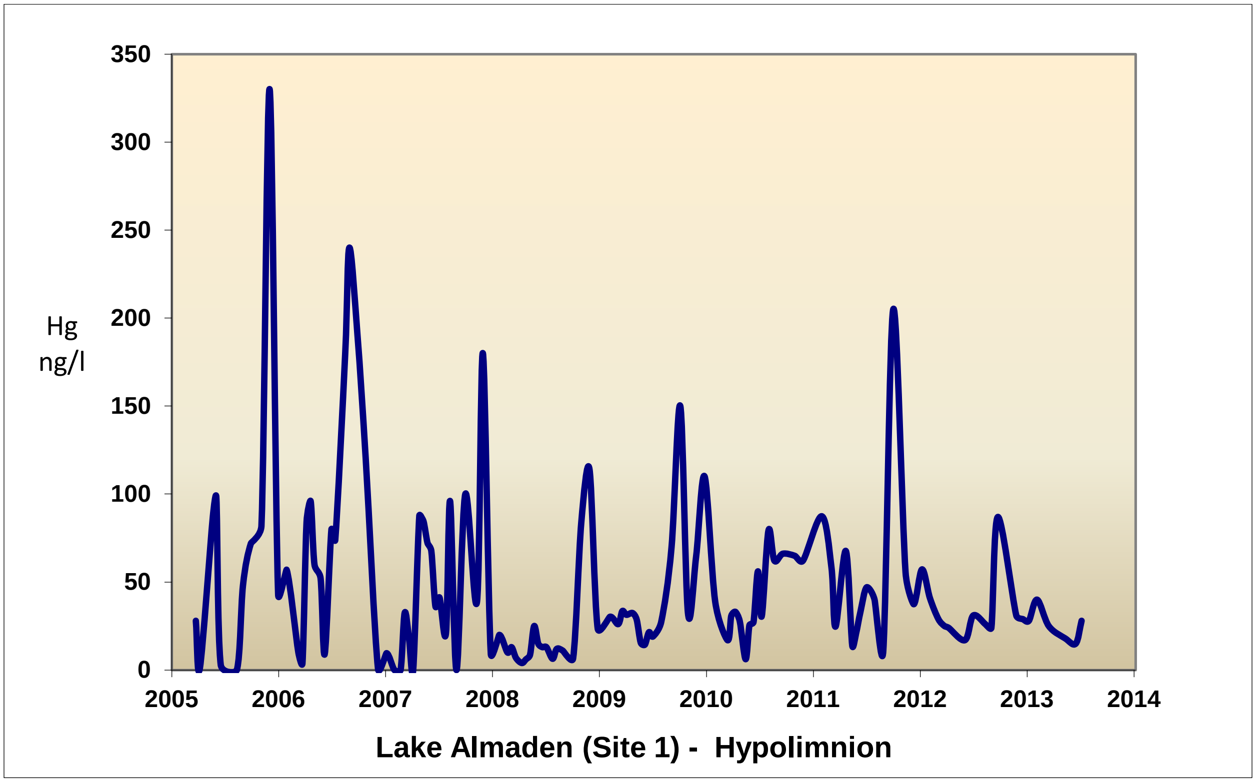


Figure 31: Unfiltered Methyl Mercury (Total MeHg) Concentrations in Lake Almaden (Site 1)



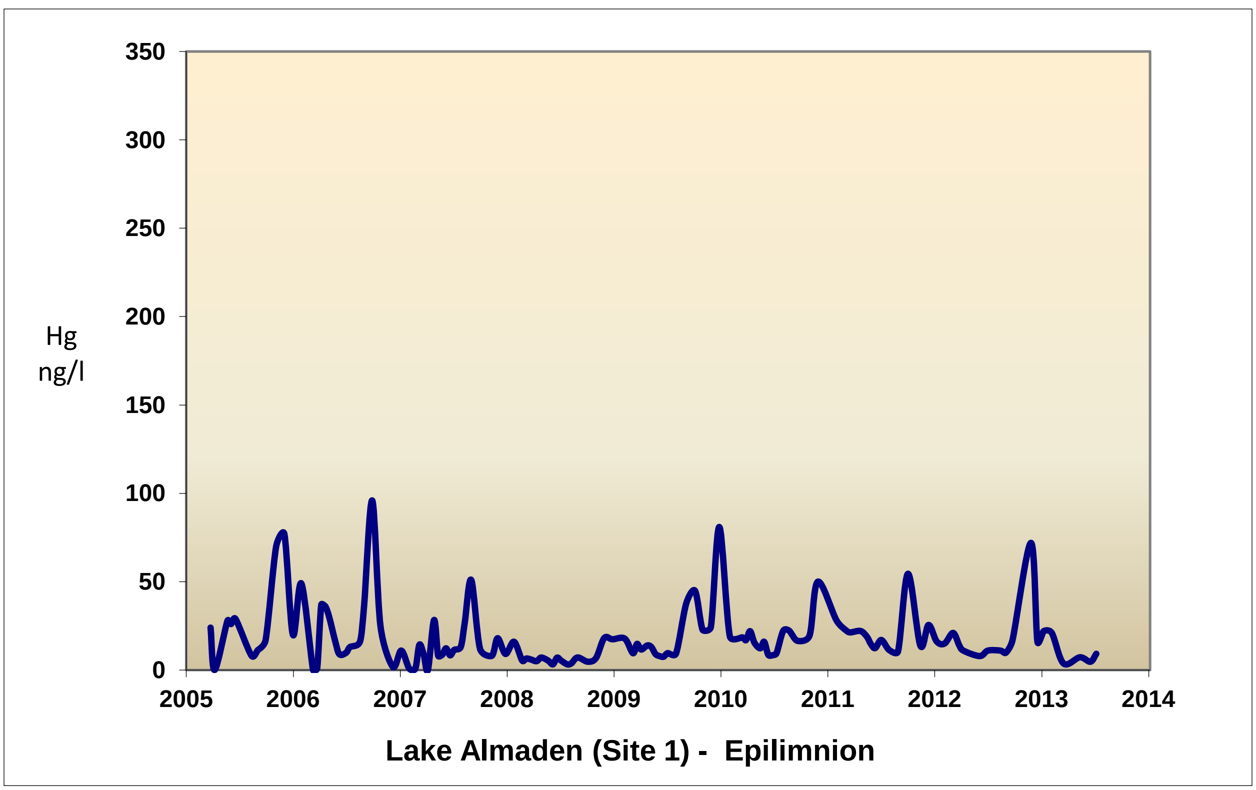


Figure 32: Unfiltered Mercury (Total Hg) Concentrations in Lake Almaden (Site 1)

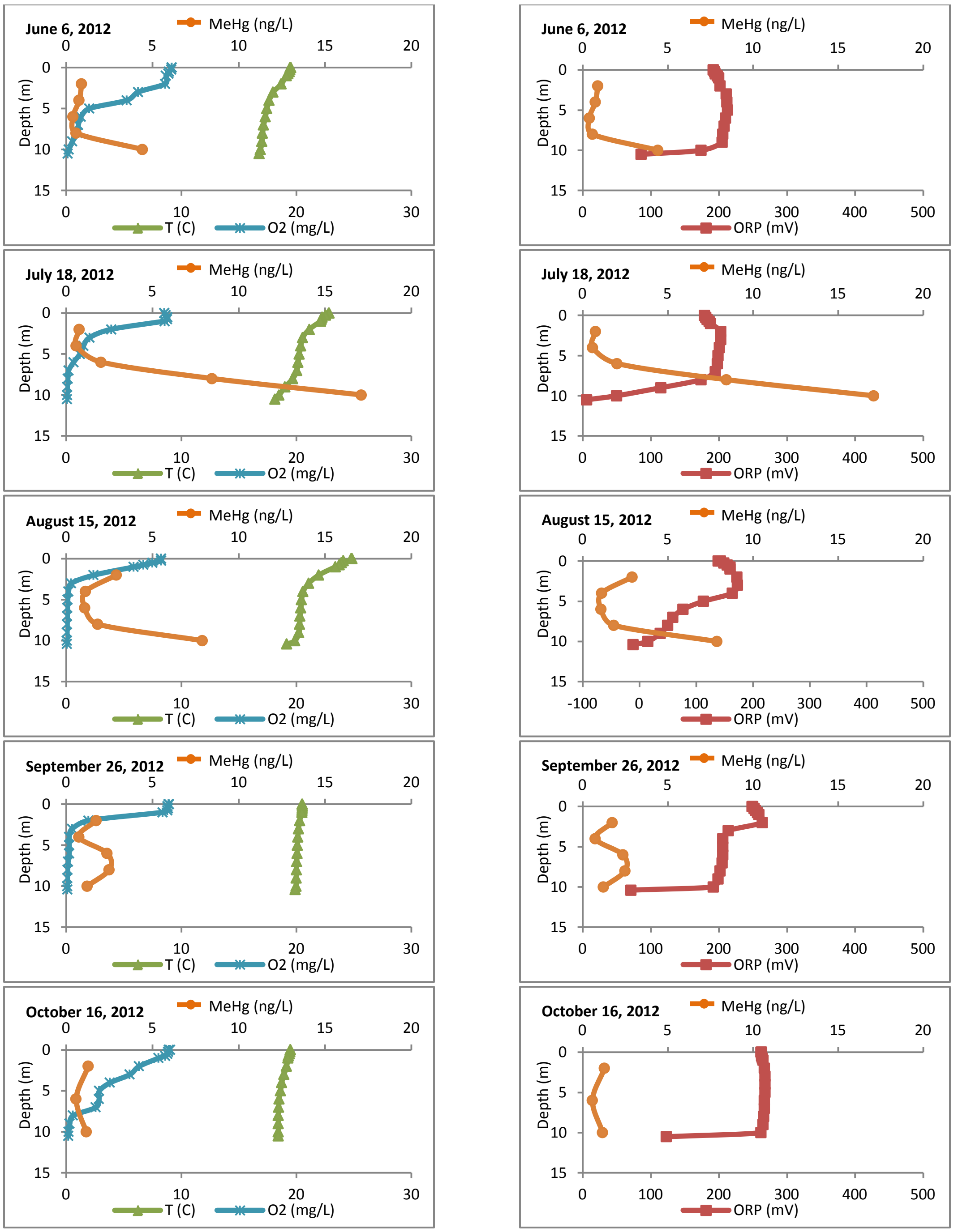


Figure 33: Unfiltered Methyl Mercury (Total MeHg) 2012 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Lake Almaden (Site 2)

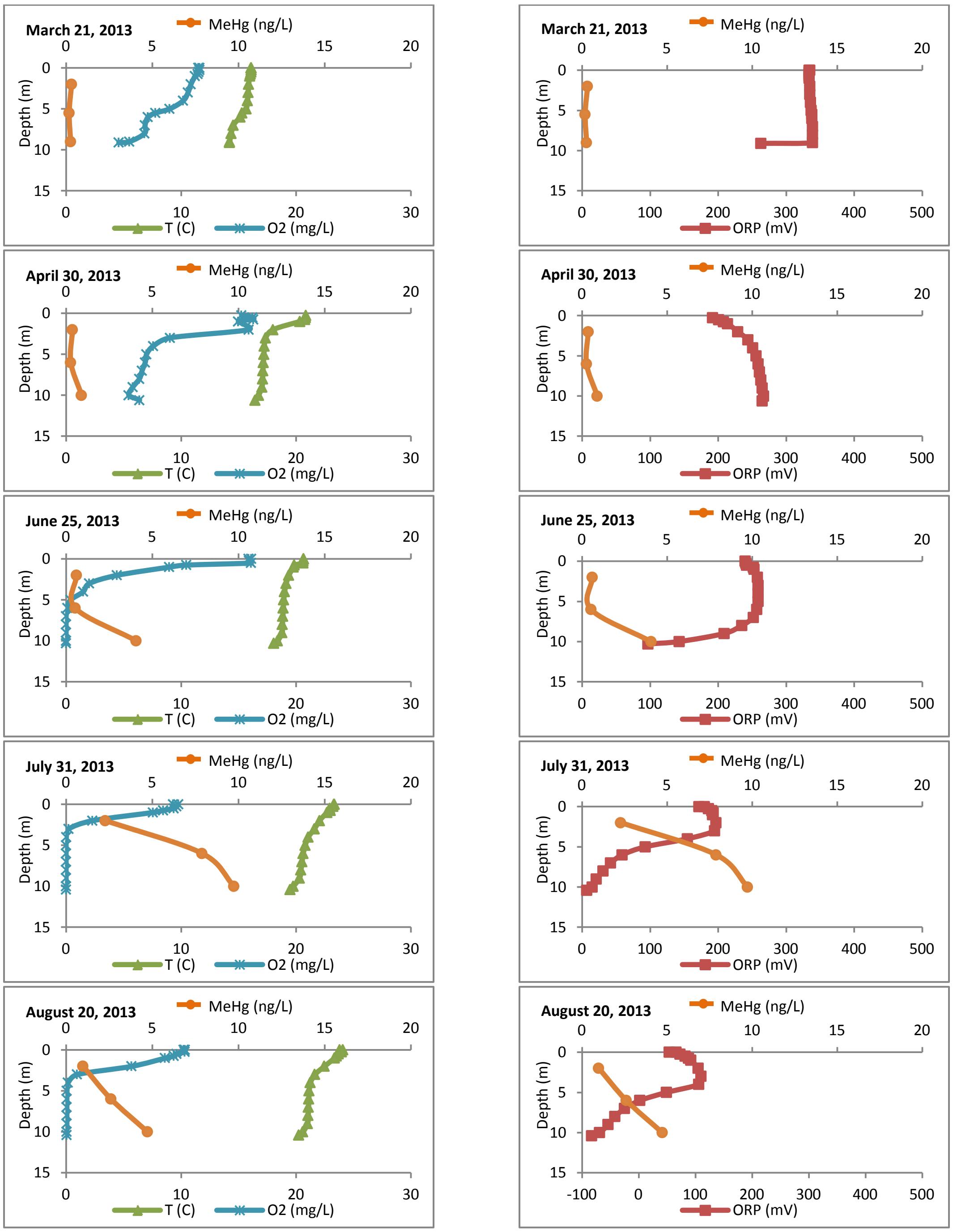


Figure 34: Unfiltered Methyl Mercury (Total MeHg) 2013 Production Season Relation to Stratification (left) and Oxidation Reduction Potential [ORP] (right) in Lake Almaden (Site 2)

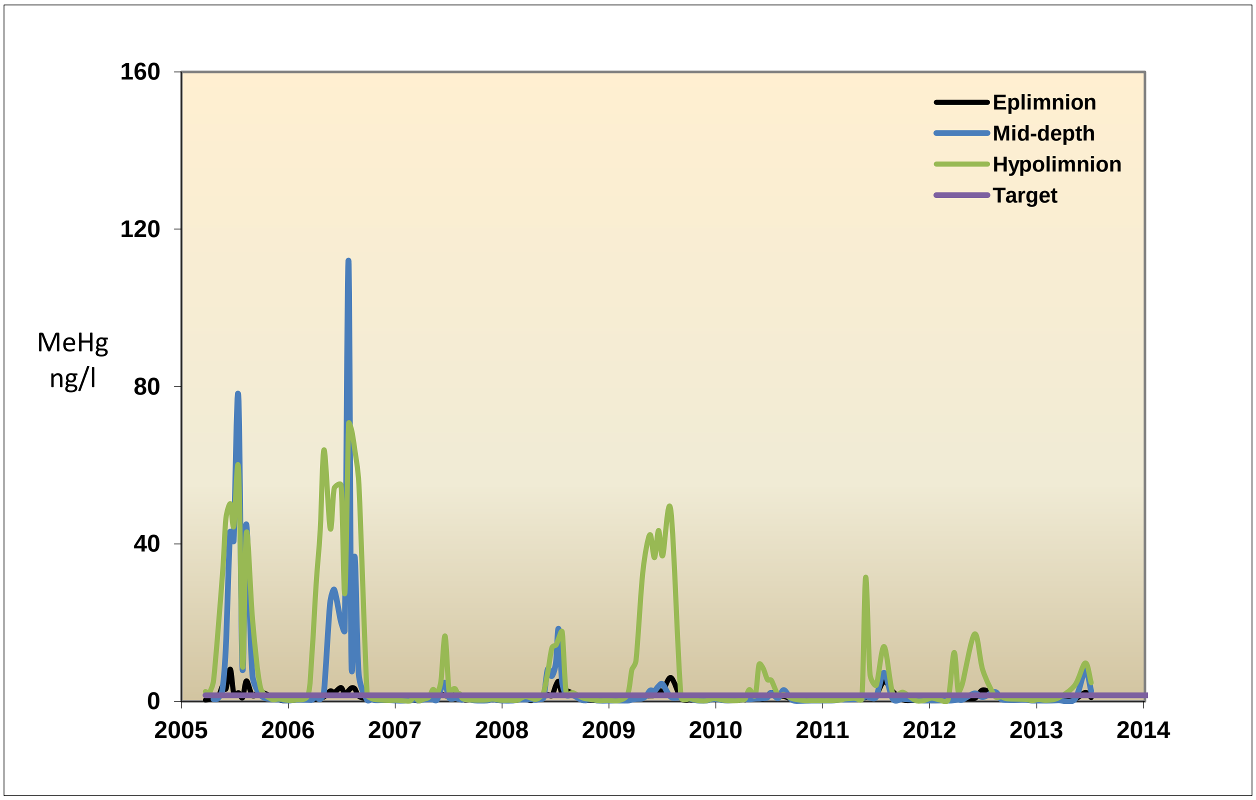
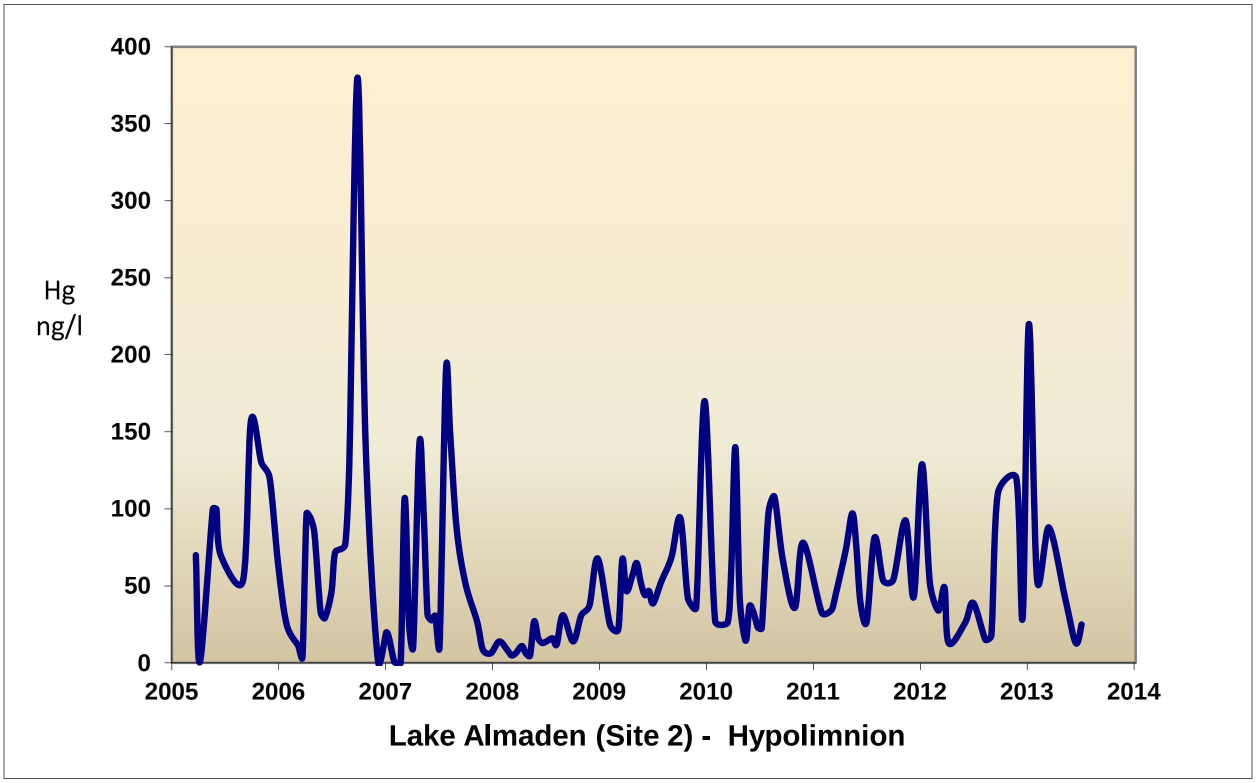


Figure 35: Unfiltered Methyl Mercury (Total MeHg) Concentrations in Lake Almaden (Site 2)



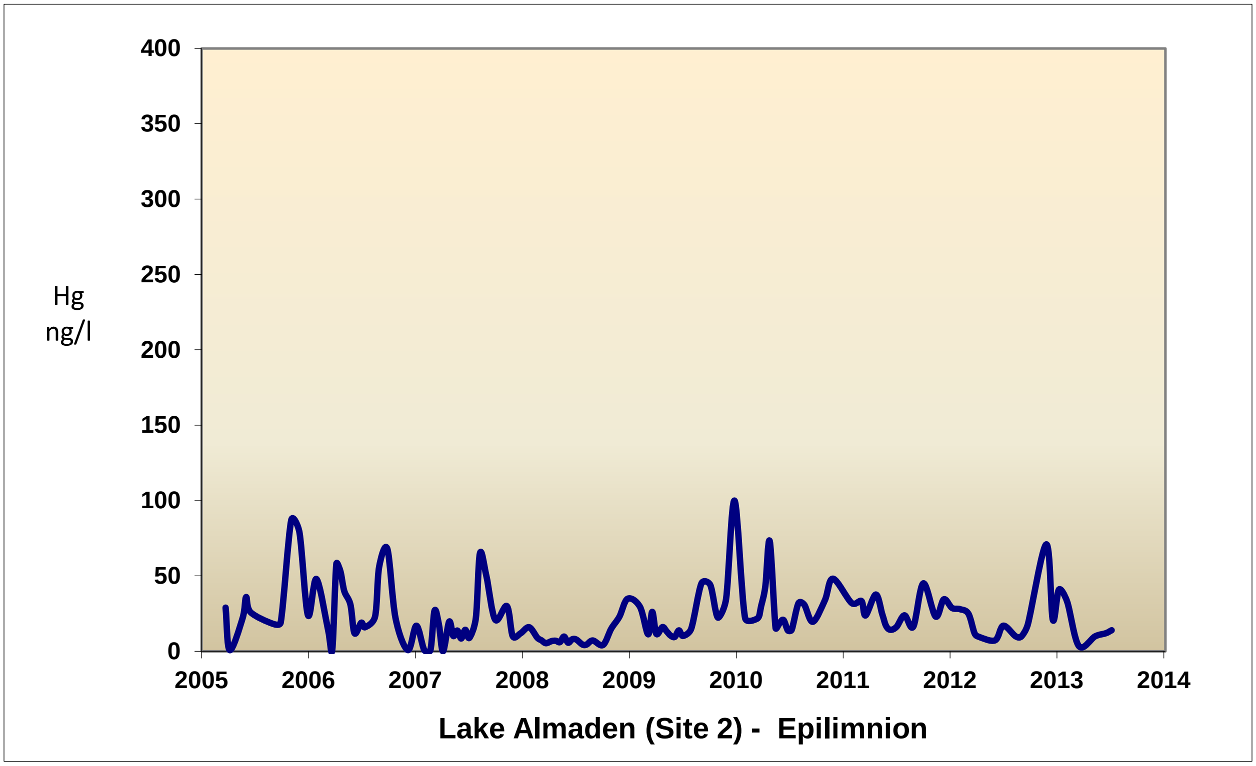
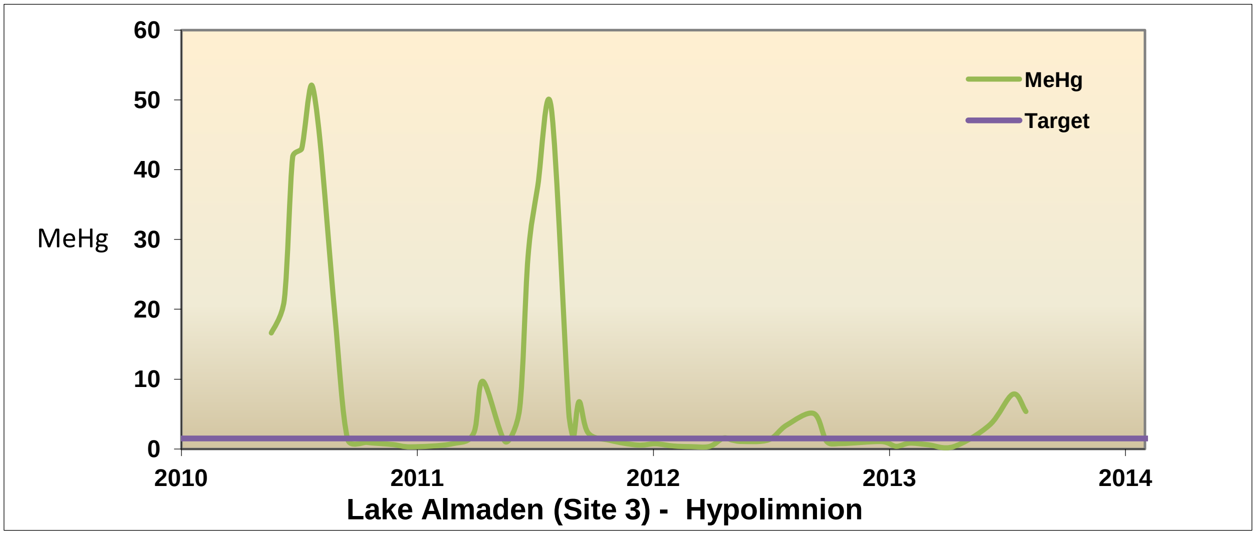
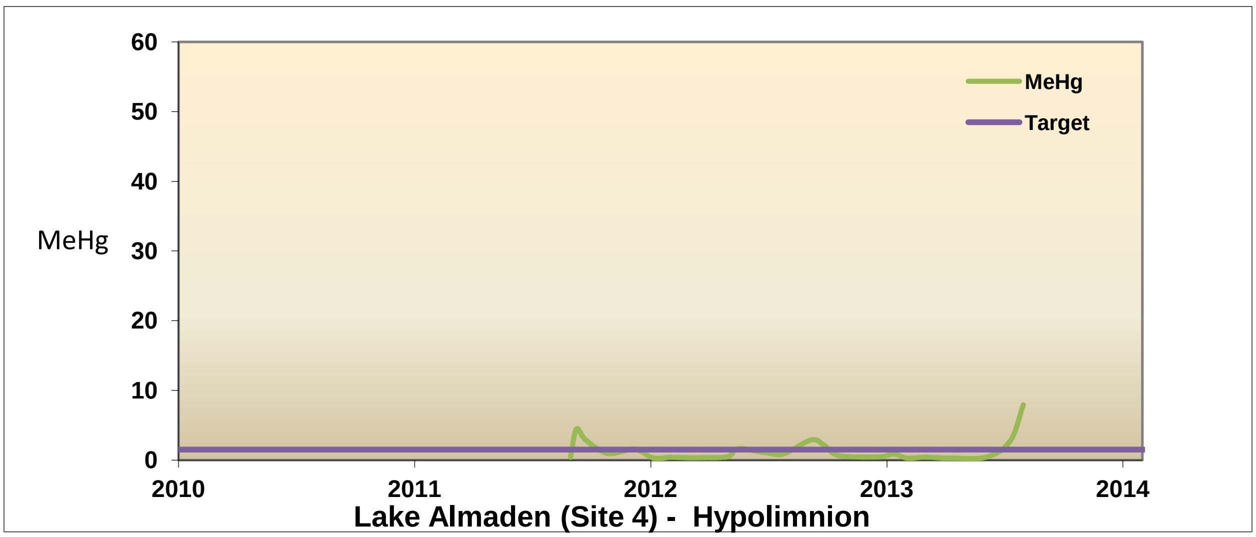


Figure 36: Unfiltered Mercury (Total Hg) Concentrations in Lake Almaden (Site 2)





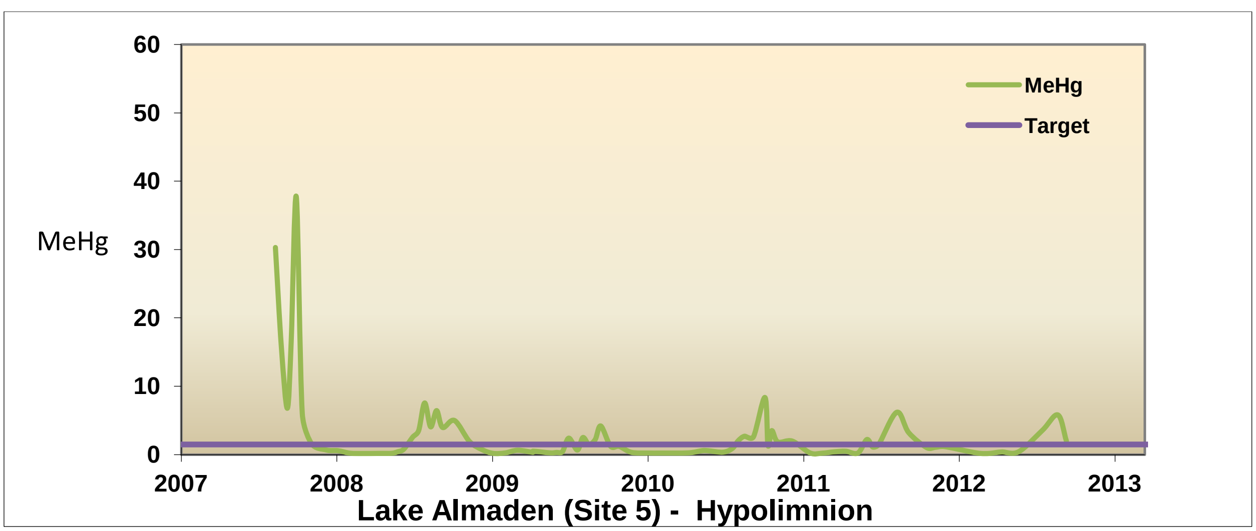


Figure 37: Unfiltered Methyl Mercury (Total MeHg) Concentrations in Lake Almaden (Sites 3, 4, 5)

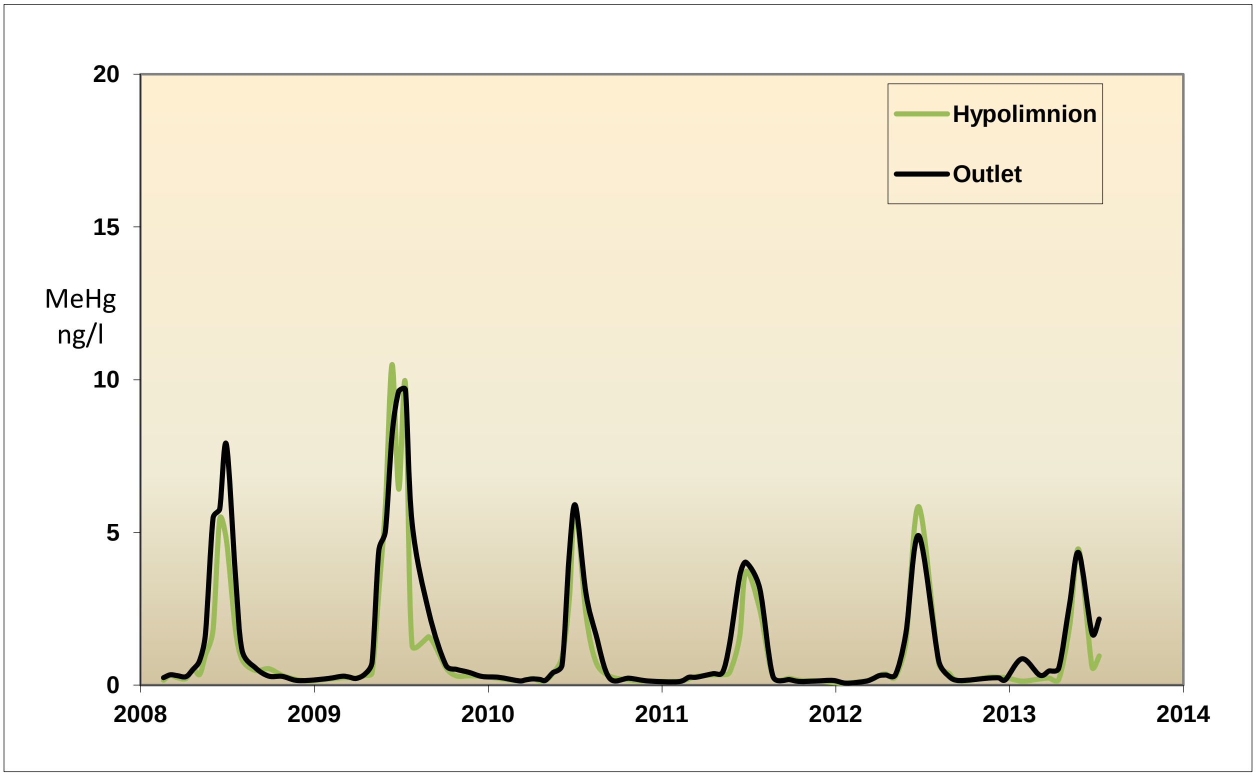


Figure 38: Comparison of Hypolimnion and Outlet Unfiltered Methyl Mercury (Total MeHg) Concentrations in Almaden Reservoir

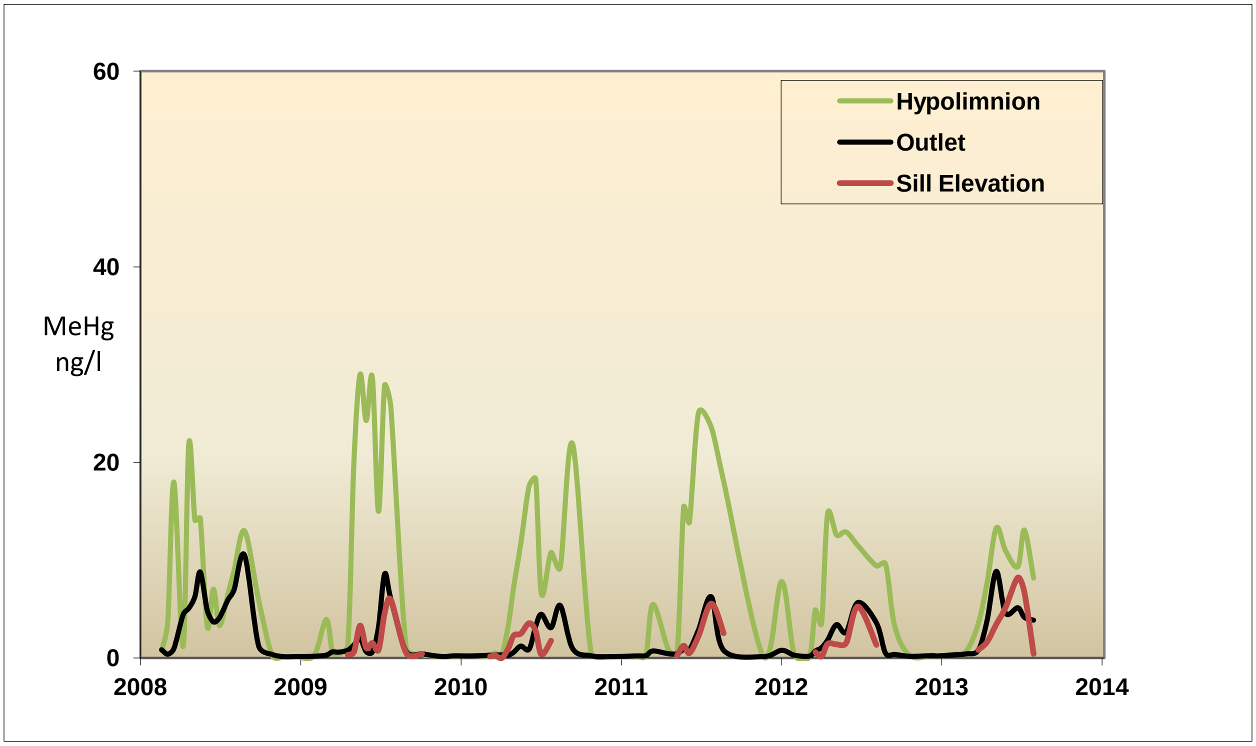


Figure 39: Comparison of Hypolimnion, Sill Elevation, and Outlet Unfiltered Methyl Mercury (Total MeHg) Concentrations in Guadalupe Reservoir

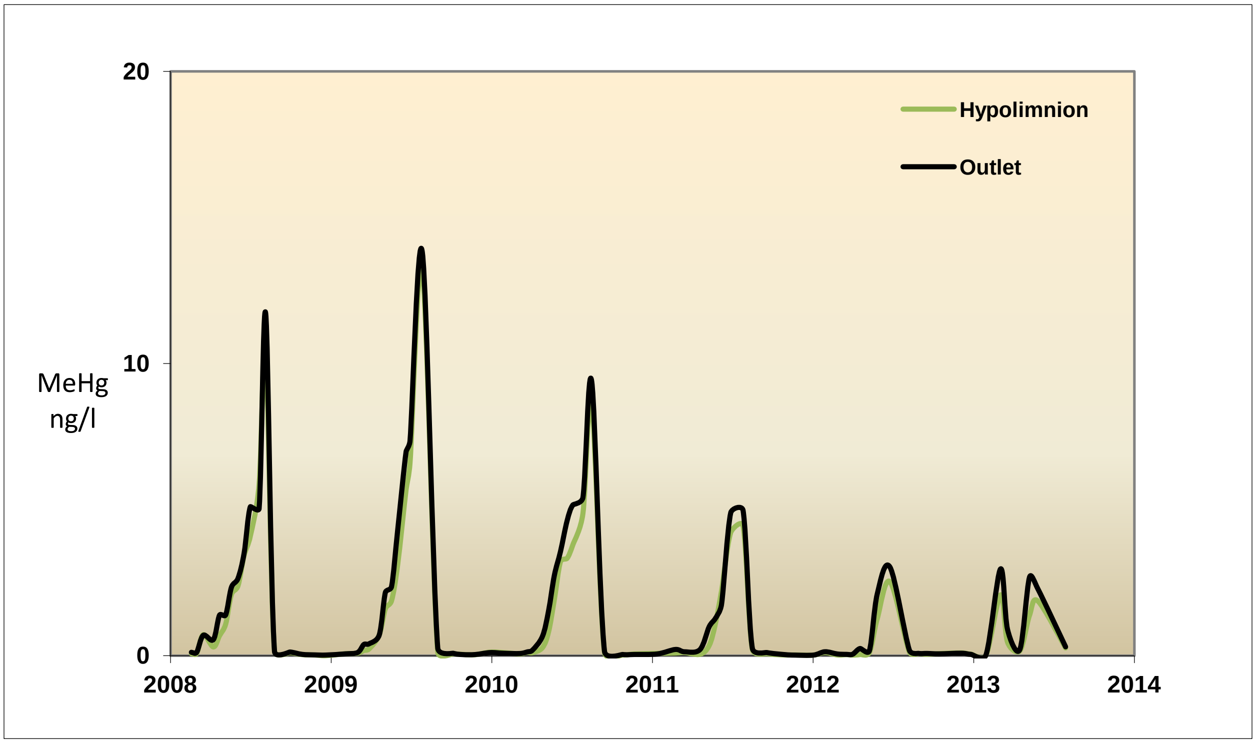
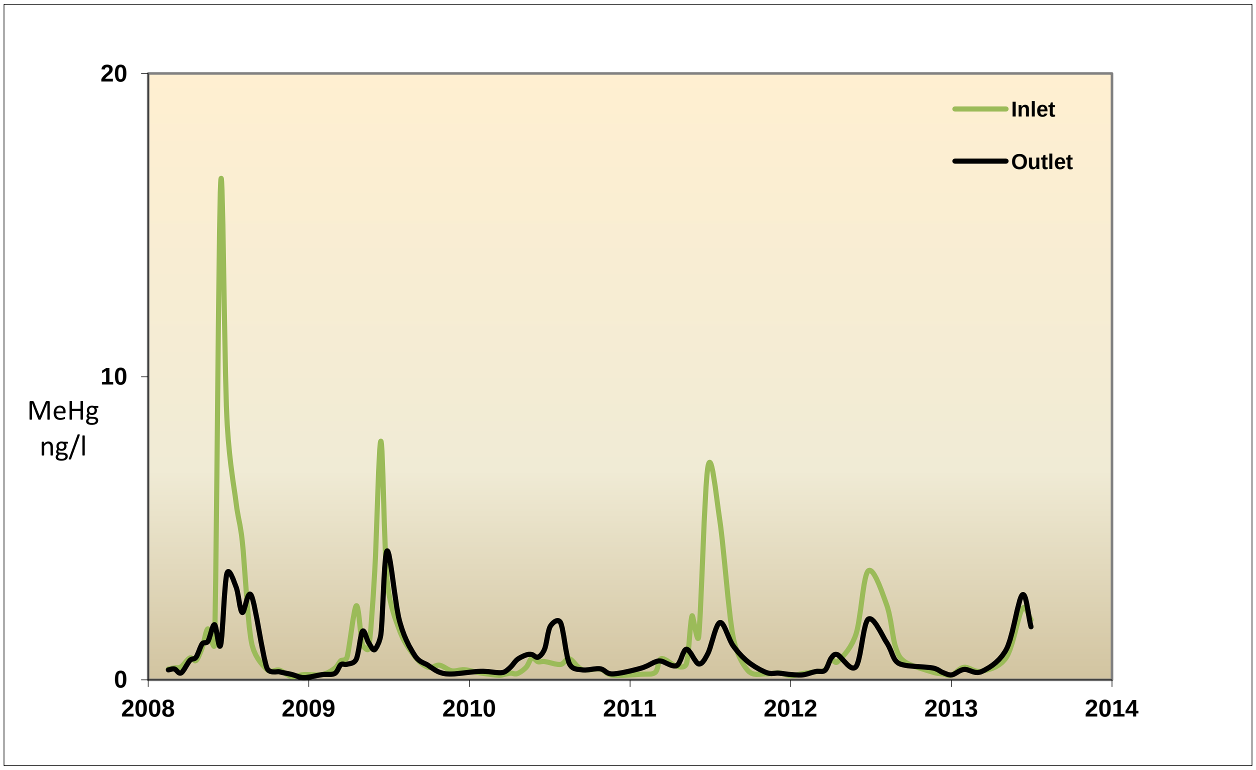


Figure 40: Comparison of Hypolimnion and
Outlet Unfiltered Methyl Mercury (Total MeHg) Concentrations in Calero Reservoir



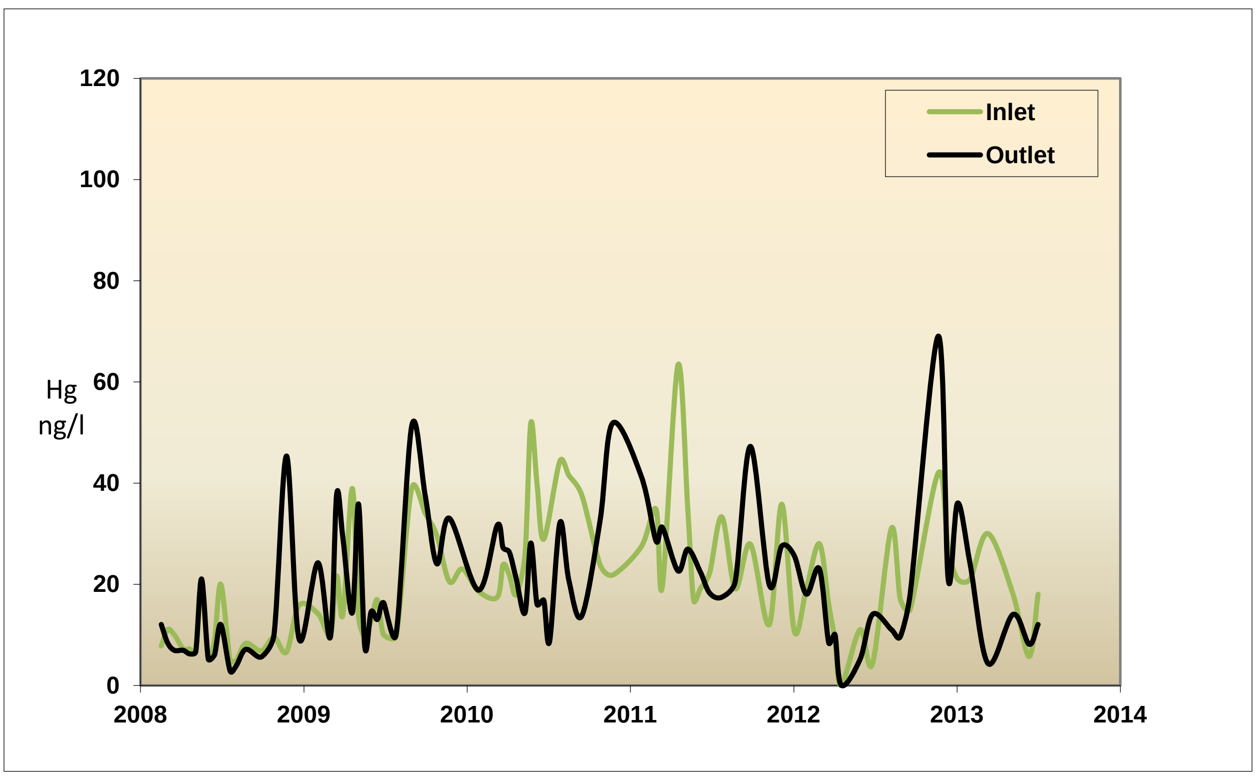


Figure 41: Comparison of Inlet and Outlet Unfiltered Methyl Mercury (Total MeHg) [Top] and Unfiltered Mercury (Total Hg) [Bottom] Concentrations in Lake Almaden

APPENDIX B

Hypolimnetic Oxygenation Systems Installation

HYPOLIMNETIC OXYGENATION SYSTEMS INSTALLATION AT CALERO RESERVOIR (CHERRY ROAD) AND GUADALUPE RESERVOIR (HICKS ROAD), SANTA CLARA COUNTY

Jason Graham, EIT

Graduate Student Intern, Santa Clara Valley Water District

SYSTEMS DESCRIPTION

In 2011 and 2013, respectively, the Santa Clara Valley Water District contracted the work of Manito Construction and their subcontractor, Mobley Engineering, for the installation of bubble diffuser hypolimnetic oxygenation systems in Calero Reservoir and Guadalupe Reservoir. Both reservoirs were constructed in south San Jose in 1935 (see figure 1), and currently are restricted to approximately half capacity due to seismic concerns. At design capacity, Calero Reservoir has a total reservoir volume of 10,050 acre-ft and is approximately 2.2 miles long. Water levels are often carefully controlled, and the reservoir is typically 50-55 feet deep at its deepest location. Guadalupe Reservoir is much smaller, with a capacity of 3,228 acre-ft, and approximately 1.1 miles of length. The deepest location near the face of the dam typically ranges from 50-75 feet deep. Each site consists of a power source, an oxygen supply facility, supply piping and diffuser lines that deliver oxygen to the reservoir. All components are of corrosion resistant materials.

The supply lines are comprised of two separate piping systems. One line supplies oxygen gas to the reservoir, the other is used to control buoyancy. During installation, the diffusers were assembled on water surface in the geometry and location desired. Anchors, composed of cement filled flower pots, were placed 15 feet apart, to hold the line in position, as shown in Figure 2. The buoyancy pipes were subsequently filled with water to sink the assembly to the bottom at the specified location(s). Under operating conditions, the buoyancy pipe is anchored at the bottom of the reservoir, with approximately three feet of head space between the pipe and bottom. To remove for maintenance, the bouyancy pipe is filled with compressed air.

GUADALUPE RESERVOIR SYSTEM INSTALLATION

The installation of the system at Guadalupe was completed in May of 2013. The oxygen supply system consists of a catalyst based on-site generation system (Oxygen Generating Systems Intl, NY USA) housed in a portable trailer. Temporary power is supplied by 150 watt diesel generator. It is located on the northwest side of the dam face along Hicks Road.

Two separate diffuser lines were installed, as shown in Figure 3. The first is 440 feet of line, configured in a circular shape. This circular diffuser is anchored at the deepest portion of the reservoir, at elevation approximately 10 feet below the penstock intake. The second diffuser line is a straight line measuring 1000 feet in length, and is anchored at the elevation of the penstock intake.

CALERO RESERVOIR SYSTEM INSTALLATION

The installation of the system at Calero was completed in December of 2011. The oxygen supply system also consists of a catalyst based on-site generation system (On Site Gas Systems, Inc. USA) mounted on skids. Temporary power was supplied using a 70 watt diesel generator, but in July of 2013, a permanent electrical connection was supplied by PG&E. The facility sits on the north east side of the dam, just off Cherry Canyon Road.

Using the same methods as described above, a diffuser line 1000 ft in length was installed in a semi-circle around the face of the dam as shown in Figure 4. The line is anchored at the elevation of penstock intake.

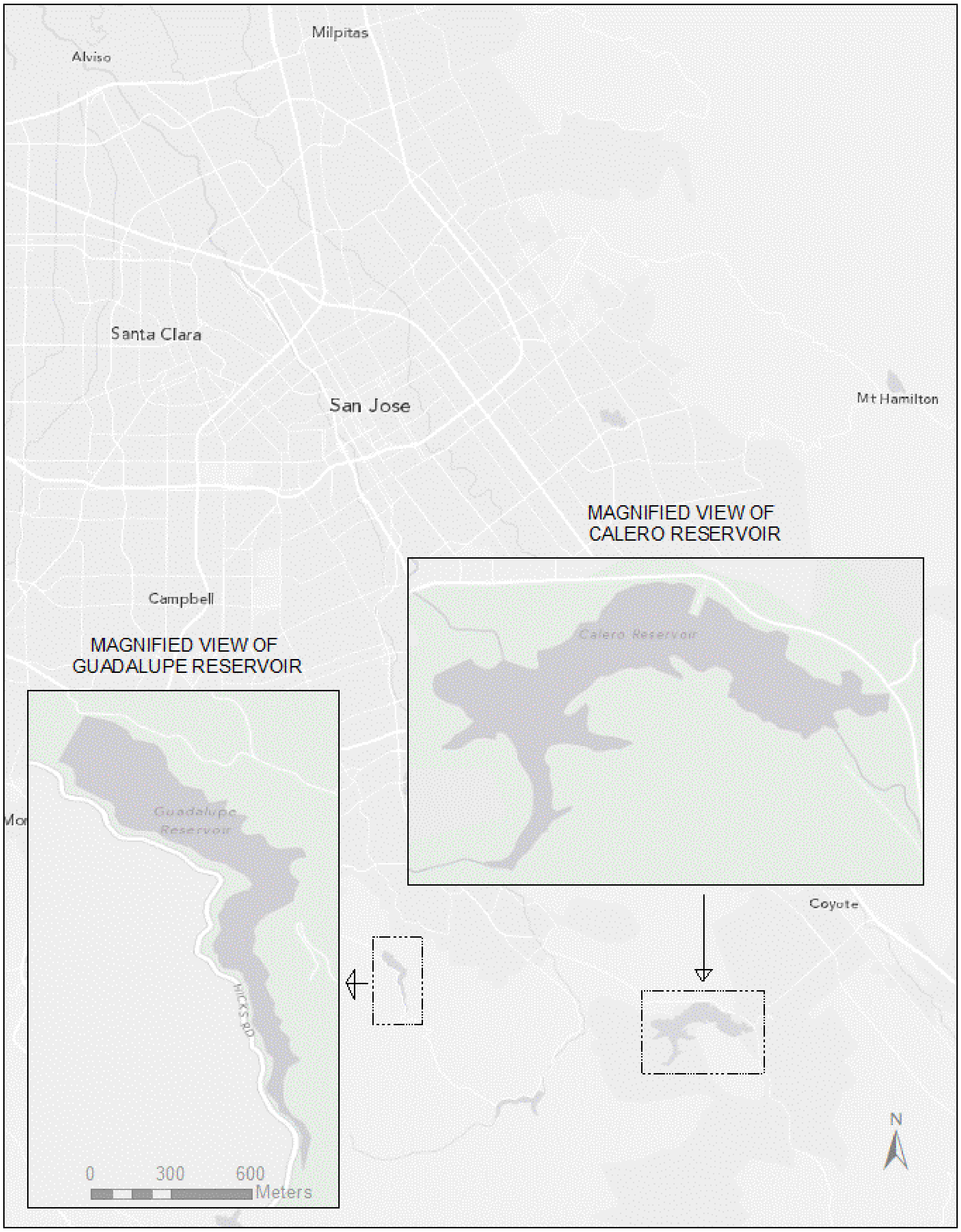


Figure 1: Geographic Locations of Guadalupe and Calero Reservoirs (shown in the dashed lines)

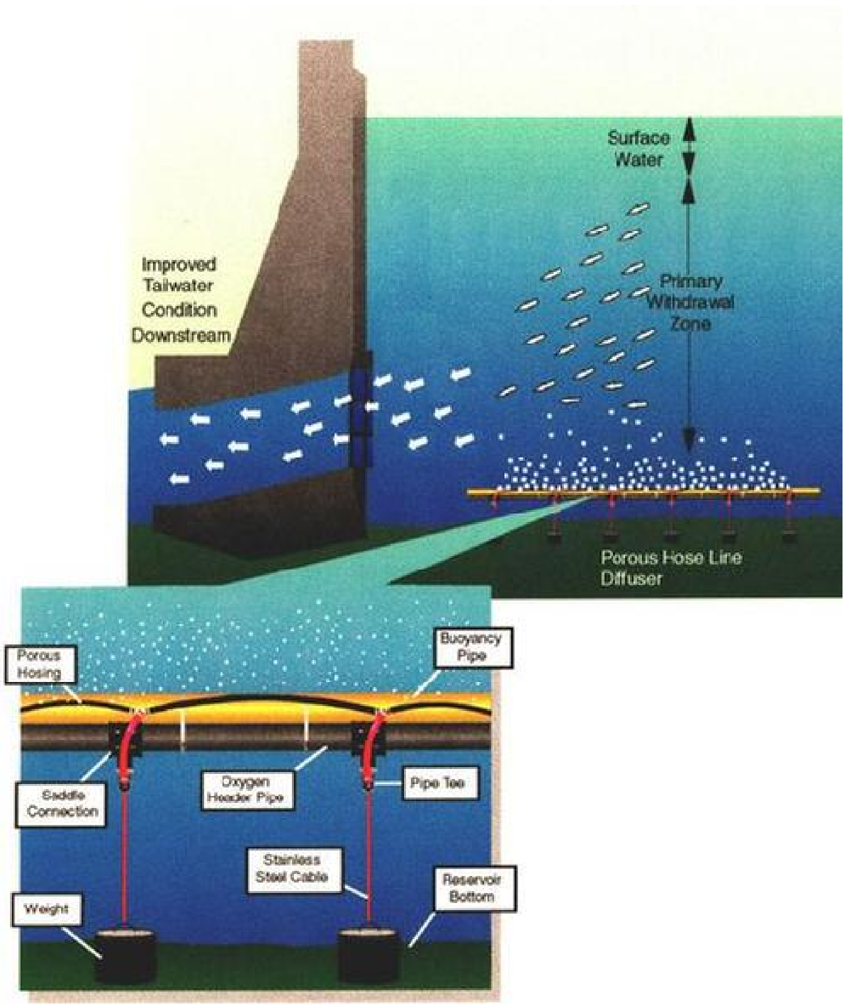


Figure 2: Typical Bubble Line Diffuser System, From www.mobleyengineering.com

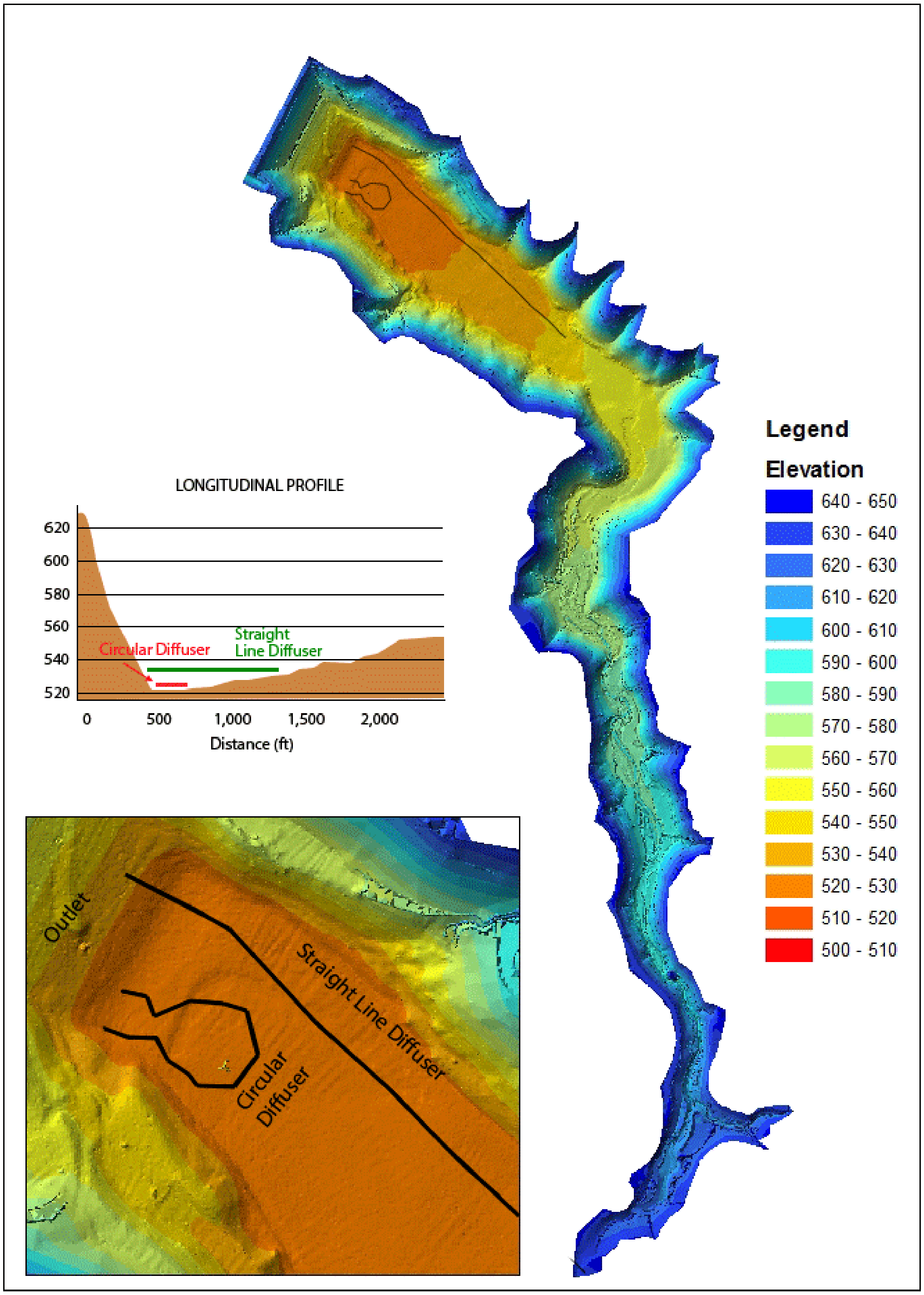


Figure 3: Configuration of Bubble Line Diffusers at Guadalupe Reservoir

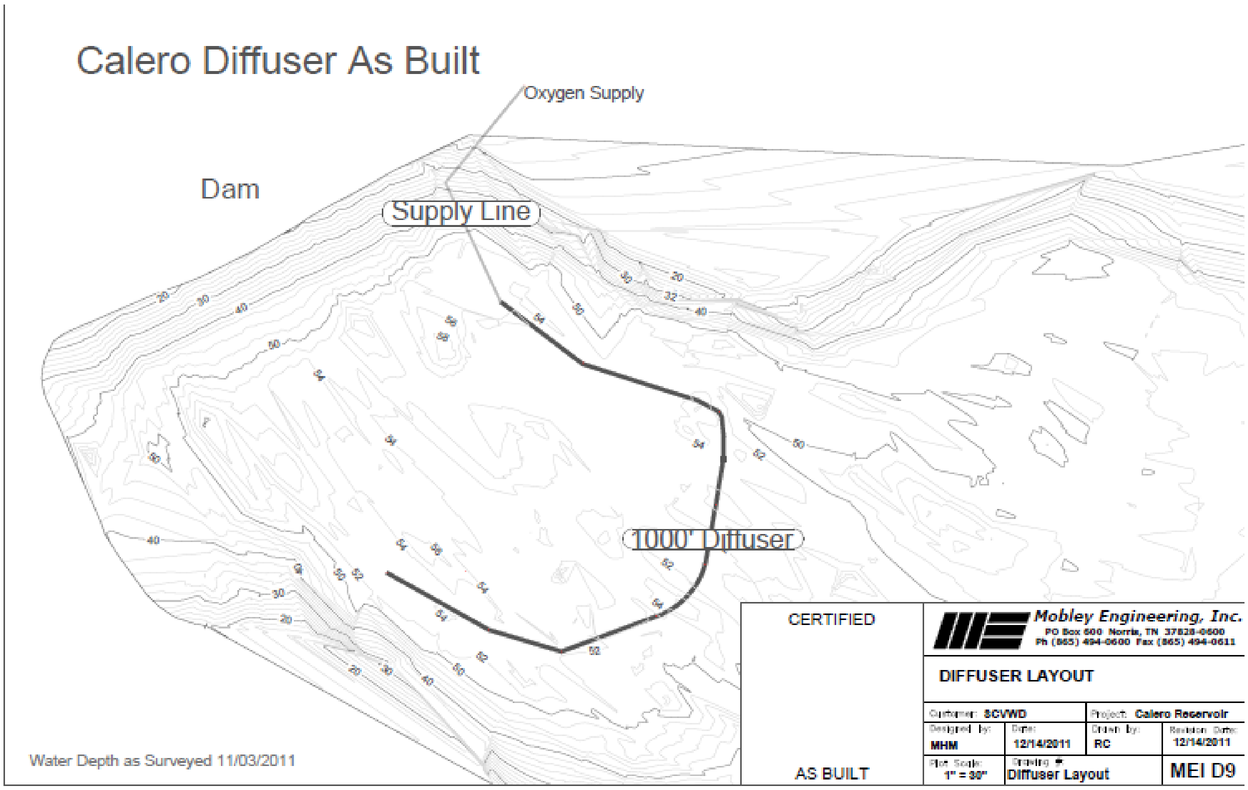


Figure 4: Configuration of Bubble Line Diffuser at Calero Reservoir

APPENDIX C

Fish Sampling

SUMMARY OF FISH SAMPLING ACTIVITIES IN DISTRICT RESERVOIRS IMPACTED BY MERCURY

Jason Nishijima

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INTRODUCTION

As part of the Methyl Mercury Control Study, fish sampling of the reservoirs was undertaken to document the fish assemblages in reservoirs which will be oxygenated as part of the remediation effort to manage legacy mercury pollution. Data is to be collected seasonally over multiple years to document fish assemblages present and relative changes in fish populations over time as treatment regimes are implemented. At the same time, specimens are taken to assess the body burden of mercury levels of target fish species. During 2012 and 2013 fish assemblage data and specimens were collected on Calero and Guadalupe reservoirs. Conditions at Almaden Reservoir limited sampling efforts at the site in 2012 and 2013. The effort reported herein is a summary of the sampling effort including Summer 2013 fish assemblage and relative occurrence data and comparisons with Summer 2012 data. Data on body burden analyses will be reported elsewhere.

METHODS

For each of the reservoirs fish were captured using a Smith-Root Model H electrofishing boat. Settings were 120V DC, in the 360-500 range. Four fetches (stations) were sampled at each reservoir. Sampling was initiated at night shortly after dusk. Stations were located along the shoreline following the lake margin with sampling proceeding in a clockwise direction. Station distances were defined by the amount of shoreline sampled in 15 minute spans with positioning recorded on a Lowrance GPS. At the end of each sampling station, the boat was stopped and anchored away from the shoreline. Fish were then identified to species, measured and counted. Forklength was taken for the first 25 of each species measured at a station. Generally the larger specimens were counted first; as a result the length frequency graphs may generally be skewed toward the larger specimens.

RESULTS

During the summer of 2013 two Santa Clara reservoirs were sampled by electrofishing boat.

Sampling was conducted in Guadalupe Reservoir on June 6, 2012 and July 17, 2013. The 2013 species were the same as those encountered in June of 2012 with the exception of Sacramento sucker, which were encountered in 2012 but not in 2013. No native species of fish were captured in Guadalupe Reservoir in 2013. Catch per unit effort (CPUE) was similar for most fish species when comparing 2012 and 2013 totals, with the exception of largemouth bass which were reduced in 2013 (Tables 1 and 2).

TABLE 1

Electrofishing Captures in Guadalupe Reservoir 6/12/12

Station	Duration (min)	Largemouth Bass	Bluegill	Black Crappie	Common Carp	Sacramento Sucker
	15	98	99	8	1	
2	15	137	160	10	1	
3	15	27	168	21	10	3
4	15	57	200	27		
5	4	22	48	8		
Total	64	341	675	74	12	3
per min		5.33	10.55	1.16	0.19	0.05

TABLE 2

Electrofishing Captures in Guadalupe Reservoir 7/17/13

Station	Duration (min)	Largemouth bass	Bluegill	Black Crappie	Common Carp
1	15	10	111	45	1
2	15	12	130	4	
3	15	13	119	6	4
4	15	9	228	3	2
Total	60	44	588	58	7
per min		0.69	9.19	0.91	0.11

Sampling was conducted in Calero Reservoir on June 28, 2012 and July 31, 2013. The 2013 species were the same as those encountered in June of 2012 with the addition in 2013 of brown bullhead (*Amieurus nebulosus*). One native species, tule perch (*Hysterocarpus traskii*) was captured in Calero Reservoir. (Special note: This species was found in at least two of the accepted morphs and may be a reintroduction to the Guadalupe River system). CPUE in Calero Reservoir varied by species when comparing results in 2012 and 2013. Largemouth bass, black crappie, tule perch, bigscale logperch (*Percina macrolepida*), and inland silverside (*Menidia beryllina*) all showed higher CPUE in 2013. Conversely, bluegill had a notable decrease in presence (Tables 3 and 4).

TABLE 3
Electrofishing Captures in Calero Reservoir 6/28/12

Station	Duration (min)	Largemouth Bass	Bluegill	Black Crappie	Common Carp	Tuleperch	Threadfin Shad	Bigscale Logperch	Prickly Sculpin	Pumpkinseed	Inland Silverside	Golden Shiner
1	15	4	5	6	2	2	19			1	2	2
2	15	28	42	1		2	1	6	1	1	5	
3	15	41	68	1		3	1	6			13	
4	15	29	23	2	1	18	4	2	10	3	12	
Total	60	102	138	10	3	25	25	14	11	5	32	2
per min		1.70	2.30	0.17	0.05	0.42	0.42	0.23	0.18	0.08	0.53	0.03

TABLE 4
Electrofishing Captures in Calero Reservoir 7/31/2013

Station	Duration (min)	Largemouth Bass	Bluegill	Black Crappie	Common Carp	Tuleperch	Threadfin Shad	Bigscale Logperch	Prickly Sculpin	Pumpkinseed	Inland Silverside	Golden Shiner	Brown Bullhead
1	15	51	6	33		81	2	25	1	3	38	3	
2	15	86	7	34	1	37	15	16	3	1	75		
3	15	61	7	8	7	6	8	6	1		12	1	1
4	15	120	4	5		55	103	18			71	1	
Total	60	318	24	80	8	179	128	65	5	4	196	5	1
per min		5.30	0.40	1.33	0.13	2.98	2.13	1.08	0.08	0.07	3.27	0.08	0.02

Due to low water levels in Almaden Reservoir confounding access, the electrofisher boat could not be launched during the summer of 2013. Almaden Reservoir was not sampled by boat electrofishing in the summer of 2013. During the summer of 2012 excessive vegetation in Almaden Reservoir caused a malfunction in the electrofishing unit limiting collection to a single station.

DISCUSSION

Year to year abundance and size distribution of largemouth bass varied in the reservoirs (Figure 1). The CPUE for largemouth bass in Guadalupe Reservoir was much lower in 2013 when compared with 2012. This was largely attributable to an apparent lack of production of young of the year largemouth bass in 2013 (Figure 2). One possible explanation for a lack of largemouth bass spawning success is a rapid drop in reservoir elevation in April and May which can dewater nests and kill bass eggs and fry or expose emerging fry to additional predation risk as the parent fish move off to deeper water. Due to a lack of late seasonal rain in Santa Clara County, surface water elevation dropped rapidly in Guadalupe Reservoir in Spring 2013 (Figure 4). Rainfall in Spring 2012 maintained reservoir elevations later in the year and bass production did not seem to be impacted. Almaden and Calero Reservoirs did not exhibit rapid elevation drops in April and May and young of the year bass were common when the reservoirs were sampled. When sampled in 2012, Guadalupe Reservoir had few largemouth bass in the size range expected for 1 and 2 year old fish (Figure 2). This may be due in part to surface elevation changes in Guadalupe Reservoir in 2011 (Figure 4). Another possible explanation is that lower reservoir surface elevations in spring, per the drought, may not have dewatered the nests directly but instead may have yielded littoral habitat conditions that were not as conducive to spawning at that time: e.g. steeper banks and proximal cover elements at the formerly deep edge, may have produced poorer spawning substrate and/or allowed additional predation on emerging fry.

Based on this information largemouth bass reproduction may be partially controlled based on reservoir operation strategy and surface elevation stability in spring/early summer. Largemouth bass are notable predators on many fish and amphibian species, including native species with protected status. However, attempts to manipulate fish populations in reservoirs through shifting reservoir releases should be balanced against the downstream application of augmented flow for water supply and environmental flows since storage in these reservoirs is small, typically one dry season of streamflow.

Young of the year largemouth bass were more common in Calero Reservoir in 2013 when compared with 2012 (Figure 3). This difference may be due to 2013 sampling occurring approximately a month later in the season in 2013. More young of the year bass would be expected as emergence may continue through the spring and early summer and larger young-of-year specimens (captured later in the early growth period) may be more susceptible to capture.

It was interesting that while several fish species increased in Calero Reservoir in 2013, bluegill CPUE decreased. This may be a competition effect with other fish species feeding at similar trophic levels. One such competitor may be the tule perch. It is assumed that tule perch were initially introduced to Calero Reservoir via pipeline transfer of water. The number of tule perch encountered in 2013 was greater than the previous year (Figure 7). The size frequency is consistent with a tule perch population with young of the year and one year old fish. Based on the size distribution it appears that tule perch may have established a reproducing population in Calero Reservoir.

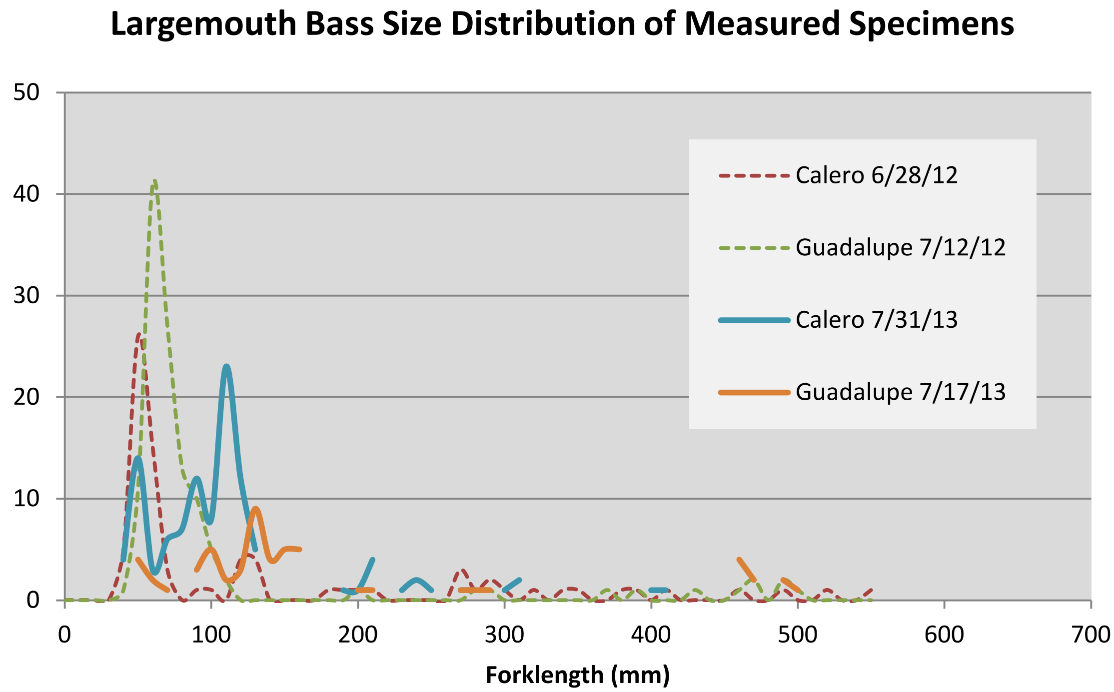

Figure 1. Largemouth bass forklength.

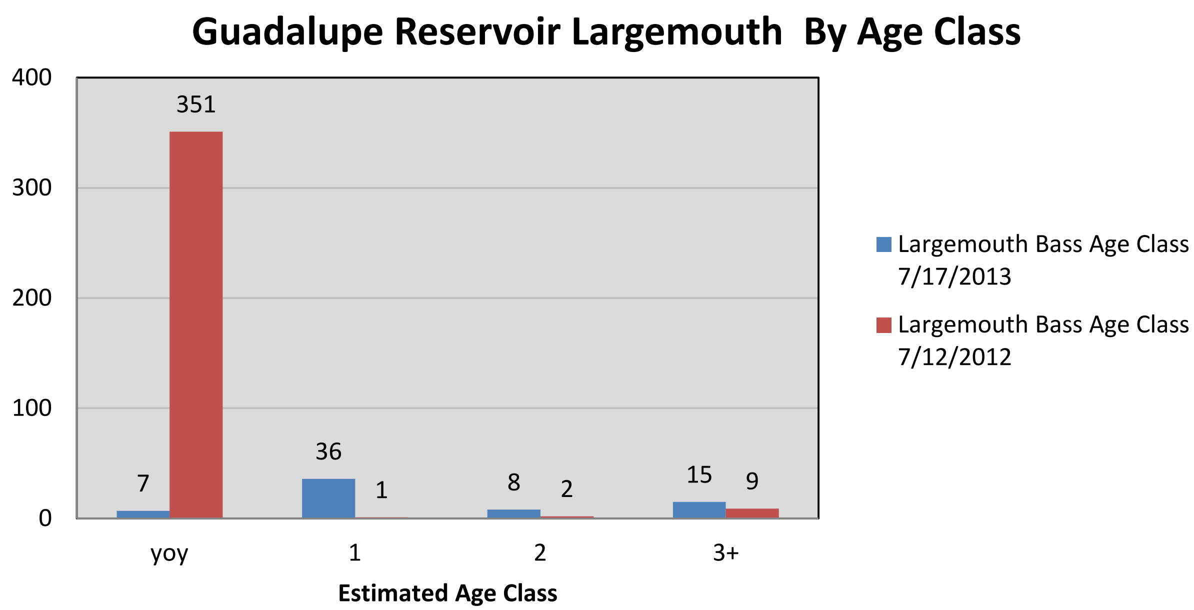

Figure 2. Estimated age distribution of largemouth bass in Guadalupe Reservoir based on forklength at the time of capture.

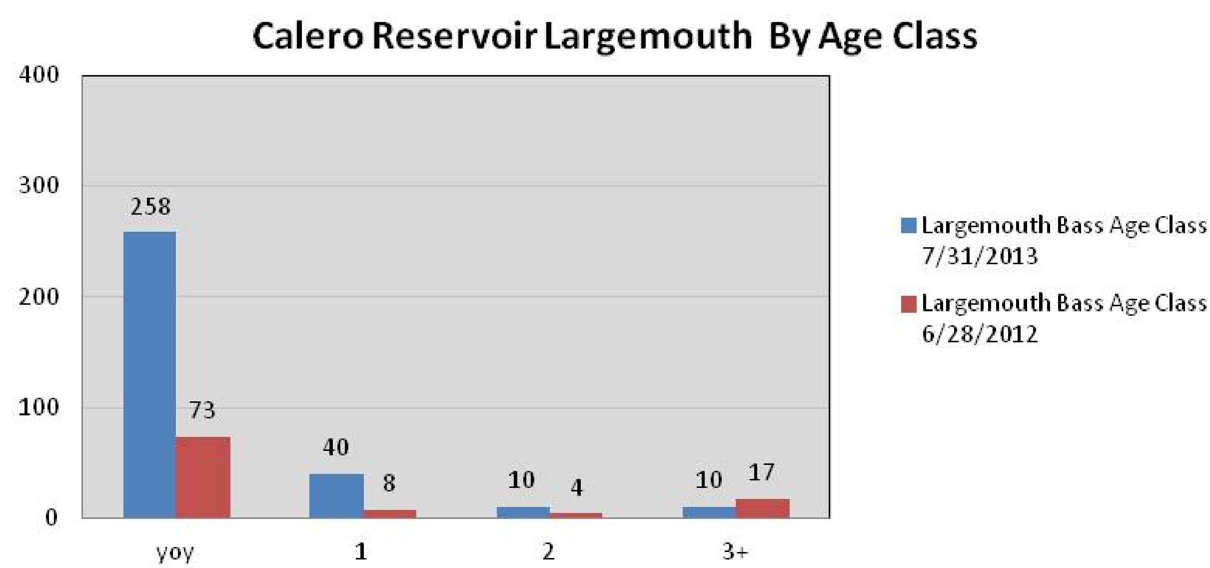

Figure 3. Estimated age distribution of largemouth bass in Calero Reservoir based on forklength at the time of capture.

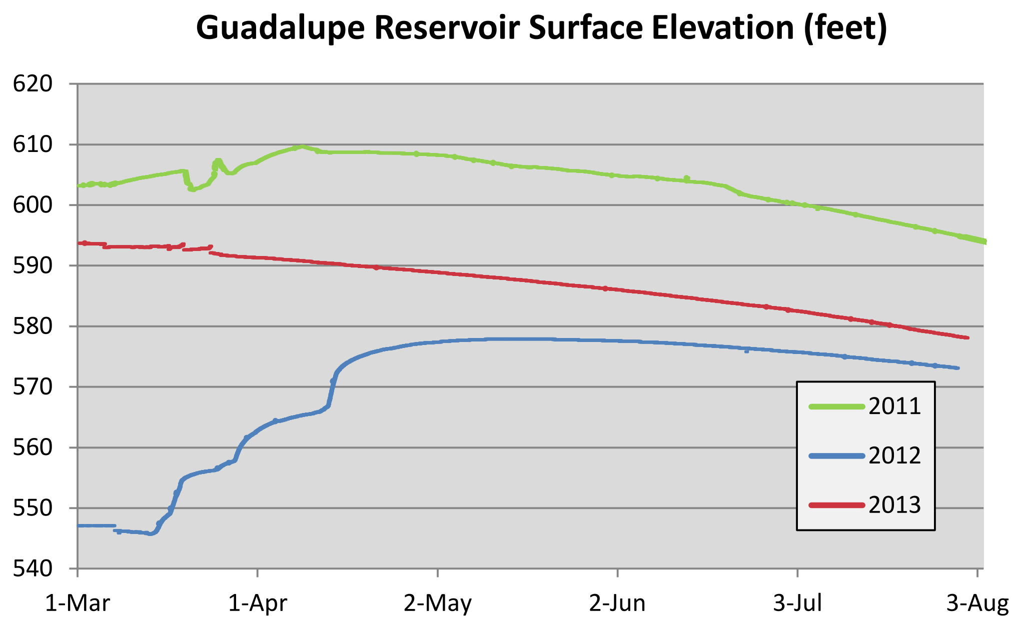

Figure 4. Surface elevation changes in Guadalupe Reservoir.

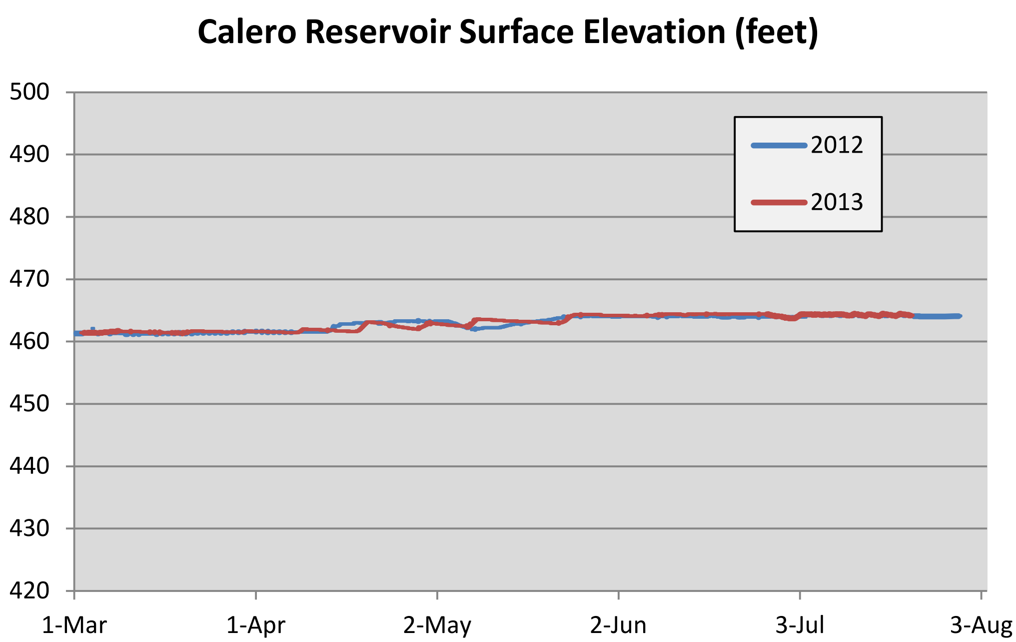

Figure 5. Surface elevation changes in Calero Reservoir.

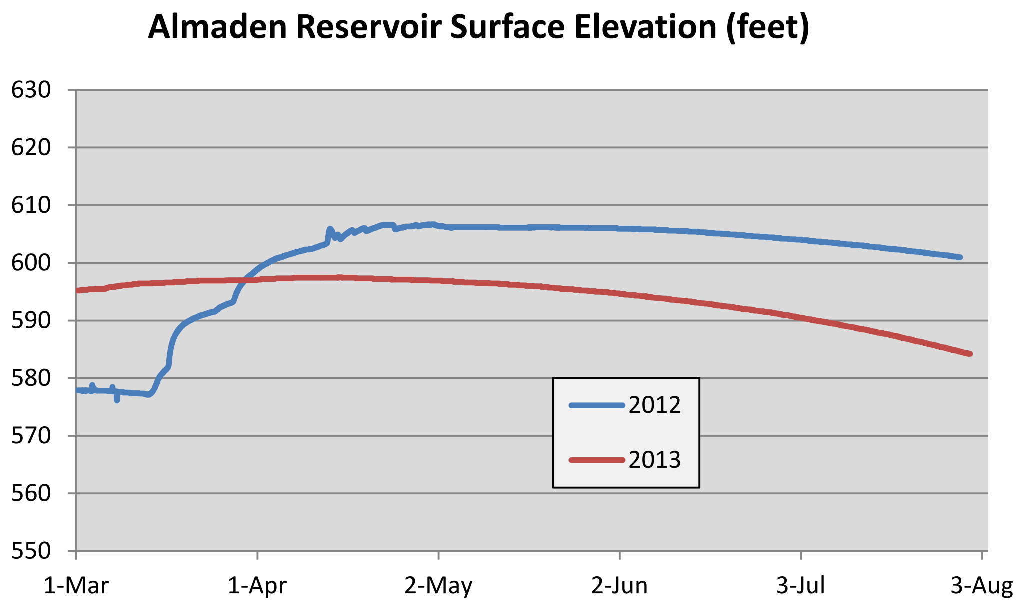

Figure 6. Surface elevation changes in Almaden Reservoir.

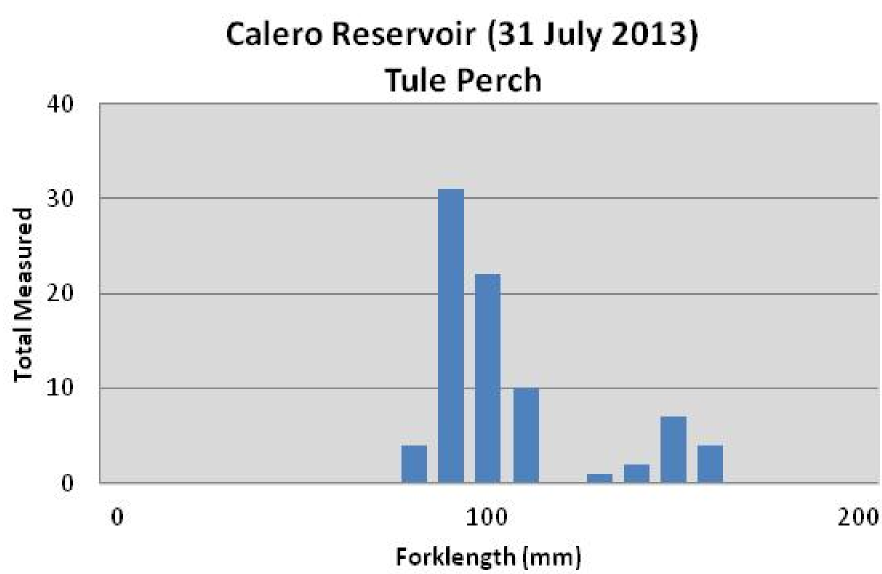

Figure 7. Length distribution of Tule Perch in Calero Reservoir.