PROGRESS REPORT

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

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Executive Summary

This document presents a description and interim findings of applied studies to reduce methyl mercury concentrations in two 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. Although this TMDL has not yet been through the entire approval process, it contains a requirement for the District to prepare this document by December 31, 2009. The District voluntarily agreed to submit this report to the Regional Board by this date.

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 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 voluntarily 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. The portion of the lake untreated by the device produced similar year-over-year concentrations of methyl mercury in the water column, indicating that circulation alone can affect seasonal maximum concentrations of methyl mercury.

Circulation using solar power has immediate environmental benefits; it is carbon neutral in itself (produces as much energy without producing carbon dioxide as the amount of carbon dioxide produced to generate energy used to manufacture the device), requires no infrastructure and operates solely on solar power. The circulation patterns established by the device are intended to deliver oxygenated water to the desired depth by drawing water from the desired depth to the surface, where it is oxygenated by contact with air and then falls back through the water column. In addition, the circulation is expected to reduce blue green algae blooms, which are a main source of organic material that settles to the bottom of the lake and causes anoxia in the hypolimnion.

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;

- 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);

- Oxygenation of the hypolimnion in combination with epilimnetic circulation will accelerate the processes described above in Guadalupe Reservoir;

- 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);

- 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.

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 provide epilimnetic circulation of the entire lake;

- In 2010, a pilot hypolimnetic oxygenation system is scheduled for installation and operation in Guadalupe Reservoir;

- In 2011, a hypolimnetic oxygenation system is scheduled for installation and operation in Calero Reservoir (pending grant funding).

Key findings presented in this progress report are as follows:

- Hypolimnetic circulation significantly reduces seasonal maximum concentrations of methyl mercury in the metalimnion at Lake Almaden;

- Hypolimnetic circulation significantly reduces seasonal maximum concentrations of methyl mercury in the lower hypolimnion of Lake Almaden, but not Almaden Reservoir;

- Operational parameters of the circulators significantly affect the effectiveness of the devices in reducing methyl mercury concentrations;

- 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;

- Changes in blue green algae blooms are difficult to measure or demonstrate.

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 portions of the TMDL applicable to the District. In the TMDL, this progress report from the District regarding these studies is due December 31, 2009. This report covers the reporting period of March 2005 through December 2009. 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 does 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 supports significant wetlands (at its upper end) and 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. Three circulators in Guadalupe Reservoir provide epilimnetic circulation. Three circulators in Lake Almaden provide hypolimnetic circulation and one circulator provides epilimnetic 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 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 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 (a form of biodilution).

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) 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 in two of the reservoirs and in Lake Almaden.

Study Descriptions

Theoretical Basis

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

- Can anoxia in the hypolimnion can 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. The District is operating under an energy-conservation policy to remain carbon-neutral with its operations. The use of solar-powered circulators was selected primarily for this reason.

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. Several approaches may be considered (such as periodically harvesting large fish) that might shift the balance of fish populations from what now seems to be a relatively small number of large fish to populations dominated by large numbers of small fish. Alternatively, measures that might result in the elimination of species that are efficient accumulators (such as largemouth bass) could be contemplated, although actual achievement of these results is problematic.

In this study, the solar-powered circulators 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 devices suggests that circulation of the epilimnion eliminates the competitive advantage of Cyanobacteria (blue-green algae) over green algae and diatoms. How this competitive advantage is achieved is unclear. One hypothesis is that the competitive advantage of the former is control of buoyancy, so they can move faster toward nutrients (usually downward) and upward toward sunlight. However, if this advantage is removed, the green algae and diatoms have a greater advantage because they reproduce faster and therefore utilize nutrients faster than the Cyanobacteria. Another hypothesis is that circulation promotes more favorable conditions for zooplankton. A large standing crop of grazing cladocerans such as *Daphnia pulicaria* provides high rates of phytoplankton grazing and allow for some grazing of Cyanobacteria before their densities can reach nuisance proportions (Reinikainen et al. 1995). Others have suggested that artificial mixing may control Cyanobacteria through light limitation (Huisman et al. 2004). Others have suggested that artificial mixing may limit Cyanobacteria by promoting natural infections of viruses (cyanophage), viral particles, and other bacteria of the Cyanobacteria (Safferman and Morris 1964; Honjo et al. 2006; Middleboe et al. 2008). Regardless of the precise mechanism, artificial circulation appears to promote considerable control over Cyanobacteria, even in nutrient-rich environments (Hudnell et al. 2010).

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, and this is why late season blooms of Cyanobacteria are common, because the ammonia is near the thermocline and, using buoyancy control, the Cyanobacteria can take advantage of this nutrient source. 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.

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. It is expected that changes in fish tissue concentrations of methyl mercury in adult fish will temporally lag those in age-1 fish, since age-1 fish are a significant portion of the diet of larger fish.

Oxygenation of the hypolimnion in conjunction with circulation of the epilimnion may accelerate the digestion of accumulated organic material at the bottom sufficiently to allow the desired effects of circulation to be achieved sooner. This technique may be useful 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. This may accelerate the achievement of seasonal maximum concentrations of methyl mercury in the hypolimnion that approach target concentrations, and fish tissue concentrations that approach water quality objectives.

Hypotheses Tested

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

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).

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. A pilot scale solar-powered oxygenation system was designed in 2009 and is scheduled for deployment in April 2010.

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 these actions, 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 (see below). The second device was installed in March 2007; the other two devices were installed in January 2009.

Materials and Methods

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.

Lake Monitoring Sites

The bathymetry of Lake Almaden has not been surveyed, but a bathymetry 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 at the outlet of the lake.

Details of Monitoring

Field data collected at the reservoir outlets (beginning 2008) with a Horiba U-10 Water Quality Checker 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 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. On several occasions, 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” technique 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);
- 0.5-liter volume glass or 0.25-liter polypropylene containers preserved with HCL for low level total mercury analyses (epilimnion, hypolimnion and inlet/outlet only) and unpreserved for low level dissolved mercury analyses (epilimnion, hypolimnion and outlet at Almaden Reservoir only).

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 for most samples; some samples were analyzed with Reporting Limits of 0.25 mg/l and 0.50 mg/l.

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 0.50 mg/l.

Results and Discussion

Nutrient Cycling

Nitrogen

Nutrients required for living cells, in order of abundance, include carbon, hydrogen, oxygen, nitrogen and phosphorous (Horne). Nitrate (NO3) 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 (NH4) 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 4 through 8),

In Almaden Reservoir (Figure 4), excursions of Nitrate concentrations above the laboratory analysis reporting limit are short-lived (one month) and related to inflows, and appear simultaneously in the epilimnion and hypolimnion. Ammonia concentrations in both the epilimnion and hypolimnion remain near the laboratory analysis reporting limit throughout the year.

In Guadalupe Reservoir (Figure 5), seasonal Nitrate concentrations above the laboratory reporting limit occur over one to two months and are related to inflows in the epilimnion; however, 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. Ammonia concentrations in the epilimnion remain near the reportable limit throughout the year, except for one event in October 2008.

In Calero Reservoir (Figure 6), seasonal Nitrate concentrations above the laboratory analysis reporting limit in the epilimnion and hypolimnion were prolonged over the winter of 2006 and in the hypolimnion in the spring of 2008. Ammonia concentrations in the epilimnion were near the reportable limit except for two occasions (spring of 2006 and summer of 2009), while a small seasonal pattern was exhibited in the hypolimnion in the fall of 2008 and summer of 2009.

Concentrations of Ammonia and Nitrate in Lake Almaden (Figure 7 and 8) were significantly higher than those measured in the three reservoirs. Nitrate concentrations exhibited strong seasonal patterns in the epilimnion and hypolimnion at both sampling sites. Ammonia concentrations exhibited strong seasonal patterns in the epilimnion and 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). Ammonia concentrations in the epilimnion remained near the laboratory analysis reporting limit year-round at both sites.

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 do not appear to have had any effect on nitrogen concentrations in the reservoirs (Almaden and Guadalupe).

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). It is naturally occurring in sediment and most of this form is organic and inert. The usable phosphorus is the organic form of phosphorus (PO_4). 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 phosphorus is released from the sediment into the hypolimnion.

Sulfate (SO_4) 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 9), Sulfate concentrations vary in a narrow range (+/- 3 mg/l) throughout the year, with maxima occurring during the winter, 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 winter of 2005 and the fall of 2009. In the hypolimnion, Total Phosphorus concentrations vary within a narrow range near the reporting limit (+/- 0.1 mg/l), exhibiting a summer seasonal effect, particularly in 2006 and 2007, which appears muted in 2008 and 2009.

In Guadalupe Reservoir (Figure 10), 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. 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, with some notable occurrences in the winter of 2006 and the summer of 2009. In the hypolimnion, Total Phosphorus concentrations vary within a narrow range near the reporting limit (+/- 0.1 mg/l), exhibiting a summer seasonal effect.

In Calero Reservoir (Figure 11), 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.

Concentrations of Sulfate and Total Phosphorus in Lake Almaden (Figures 12 and 13) were significantly higher than those measured in the three reservoirs. 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.

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. The circulators do not appear to have had any effect on Sulfate or Total Phosphorus concentrations in the reservoirs (Almaden and Guadalupe).

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.

Almaden Reservoir

Methyl mercury concentrations measured in Almaden Reservoir (Figure 14) show a production season that lasts approximately six months from June through November annually. Annual maximum concentrations in the hypolimnion were 10 ng/l or less, and seasonal average concentrations were usually less than 2 ng/l (Figure 15). Mid-depth seasonal maximum concentrations were usually less than 5 ng/l, and seasonal average concentrations were less than 1.5 ng/l. Epilimnion seasonal maximum concentrations were less than 2 ng/l and seasonal average concentrations were less than 1 ng/l.

Guadalupe Reservoir

Methyl mercury concentrations measured in Guadalupe Reservoir (Figure 16) show a production season that lasts from seven to nine months from April through November annually. Annual maximum concentrations in the hypolimnion were above 50 ng/l in 2005 and 2006, about 22 ng/l in 2007 and 2008, and 29 ng/l in 2009 (Figure 17). Seasonal average concentrations in the hypolimnion range from 9 to 17.5 ng/l over this time period. Mid-depth seasonal maximum concentrations range from 1 to 13 ng/l, and seasonal average concentrations range from 0.5 to 3.5 ng/l. Epilimnion seasonal maximum concentrations range from 0.7 to 2.7 ng/l. Epilimnion seasonal average concentrations were 0.9 and 1.5 ng/l in 2005 and 2006, but were less than 0.7 ng/l in 2007-2009.

Calero Reservoir

Methyl mercury concentrations measured in Calero Reservoir (Figure 18) show a production season that lasts approximately four months from May through September annually. Annual maximum concentrations in the hypolimnion were 13 ng/l or less, and seasonal average concentrations were less than 3.5 ng/l (Figure 19). Mid-depth seasonal maximum concentrations were less than 9 ng/l, and seasonal average concentrations were less than 3.1 ng/l. Epilimnion seasonal maximum concentrations were less than 0.5 ng/l, except for 2005 (1.75 ng/l) and seasonal average concentrations were less than 0.7 ng/l in all years.

Lake Almaden

Methyl mercury concentrations measured in Lake Almaden at Site 1 (Figure 20) show a production season that lasts approximately seven months from April through November annually. 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 21). In 2005-2007 the maximum concentration in the hypolimnion was about 70 ng/l; in 2008 and 2009, the maximum concentration was 30 and 18 ng/l, respectively. Seasonal average concentrations in the hypolimnion decreased each year from about 30 ng/l in 2005 and 2006 to 20 ng/l in 2007, 13 ng/l in 2008 and to 10 ng/l in 2009. Mid-depth seasonal maximum concentrations were immediately affected by the circulator following installation in 2006. The maximum concentration at mid-depth in 2005 was 140 ng/l; in 2006-2009 the maximum concentration was 5, 4.5, 14, and 7 ng/l, respectively. Seasonal average concentration at mid-depth was 32 ng/l in 2005, and range from 3.5 to 5.3 ng/l in subsequent years. Epilimnion seasonal maximum concentration was 5.5 ng/l in 2005 and range from 2.3 to 4.3 ng/l in subsequent years; and seasonal average concentrations were about 1.5 ng/l in all years.

Methyl mercury concentrations measured in Lake Almaden at Site 2 (Figure 22) show a production season that lasts approximately seven months from April through November annually. 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 23) 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. Seasonal average concentration in the hypolimnion was 59 ng/l in 2005 and 71 ng/l in 2006; in 2007 and 2008, the seasonal average concentration was 3 and 4.5 ng/l, respectively, and in 2009 it was 36 ng/l. Mid-depth seasonal maximum concentration was immediately affected by the circulator following installation in 2007, but did not suffer from the malfunction. The maximum concentration at mid-depth in 2005 and 2006 was 78 and 112 ng/l, respectively; in 2007-2009 the maximum concentration was 4.7, 18, and 4.4 ng/l, respectively. Seasonal average concentration at mid-depth was 21 ng/l in 2005 and 2006, and range from 1.2 to 4.5 ng/l in subsequent years. Epilimnion seasonal maximum concentration in 2005 and 2006 was 8.2 and 3.5 ng/l, respectively, and range from 2.9 to 6 ng/l in subsequent years.

Methyl mercury concentrations measured in Lake Almaden at Site 5 (Figure 24) show a production season that lasted six months in 2009 from May to November. Only a partial background season of data were obtained at this site in 2008. In 2008 the maximum concentration measured in the hypolimnion was 38 ng/l. In 2009, the maximum concentration measured in the hypolimnion was 7.6 ng/l, and the seasonal average concentration for 2009 was 4.5 ng/l.

Summary-Methyl Mercury

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 5), as described above. 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 2 and near Site 5 is 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. The circulators do not appear to have had any effect on methyl mercury concentrations in the reservoirs (Almaden and Guadalupe).

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 and 2008, 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 25, 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 26, 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 (approximately 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 26) are essentially the same.

As shown in Figure 27, 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 28, the inlet and outlet concentrations of methyl mercury for Lake Almaden indicate that the lake is a sink for methyl mercury (discharges less methyl mercury than it receives).

Phytoplankton

In 2009, the District collected samples from the epilimnion of each of the water bodies for laboratory analyses of algae counts. One sampling location was used for each of the reservoirs, while two sampling sites were used at Lake Almaden (Site 1 and Site 4, Figure 3). The following discussion is primarily the result of a personal communication from Joseph Eilers, SolarBee, Inc. (Prof. Hydrologist-WQ and Certified Lake Manager Bend, Oregon).

Almaden Reservoir exhibited a notable increase in Cyanobacteria in July 2009, followed by a decrease and then a major bloom in October and November, 2009 (Figure 29). This bloom was dominated by *Aphanizomenon*, although *Microcystis* represented nearly one-fourth of the Cyanobacteria density in October. Diatoms were a minor portion of the phytoplankton community only during the winter months in Almaden Reservoir (Figure 29). Guadalupe Reservoir exhibited much lower densities of Cyanobacteria compared to Almaden Reservoir (Figure 30). The greatest densities of Cyanobacteria in Guadalupe Reservoir occurred during the cool months of December 2008 and October 2009. Calero Reservoir exhibited a very different pattern in Cyanobacteria abundance compared to Almaden and Guadalupe Reservoirs in that the greatest densities of Cyanobacteria occurred largely during the summer months (Figure 31). Diatom densities in Calero Reservoir remained low throughout the year, but were highest in the fall. Patterns in Cyanobacteria and diatoms were similar between the two sampling sites in Lake Almaden (Figures 32 and 33). Lake Almaden showed an increase in diatoms (largely *Fragilaria*) from April to June, but in July the Cyanobacteria became dominant and showed a substantial, but apparently short-lived bloom in August 2009.

A spring increase (bloom) of diatoms is typical of many temperate lakes and in general is a positive phenomenon because it provides food for the zooplankton that graze these phytoplankton. Most diatoms are suitable sources of food for crustacean zooplankton such as the cladoceran, *Daphnia*. In turn, the large cladocerans (or sometimes large copepods such as *Epischura*) are critical food sources for many young-of-the-year fish or even larger trout and omnivores. In contrast, the Cyanobacteria are a poor food source for the zooplankton because the filaments often clog the mouthparts of the zooplankton, thus interfering with feeding. The Cyanobacteria are also of less value from a nutritional standpoint compared to most diatoms. Having a Cyanobacteria pulse in the winter is generally not a major problem for the zooplankton, because these populations are usually low in the winter. However, having the Cyanobacteria pulse in the spring is highly detrimental to the zooplankton and the rest of the lake trophic groups. Thus, the phytoplankton pattern observed in Calero Reservoir is the least favorable from an ecological viewpoint, however because the density of Cyanobacteria was relatively low in Calero Reservoir its effect was probably minimal. The diatom pulses in the spring at Lake Almaden are probably the most favorable among this group of water bodies with regard to providing a suitable food supply for the zooplankton. The similarity of the phytoplankton results for the two sites in Lake Almaden indicates that there appears to be little patchiness of the phytoplankton (the system seems to be well-mixed) and some cost savings could be achieved by sampling at just one location in the lake.

Another way to examine the data across the water bodies is to re-plot the data by taxonomic group among reservoirs. This shows very quickly that only two reservoirs with appreciable Cyanobacteria present during the data window are Almaden Reservoir and Lake Almaden (Figure 34). This also shows that the only reservoirs with appreciable populations of diatoms are Almaden Reservoir (February 2009) and Lake Almaden in the spring (Figure 35).

Examination of the genera of phytoplankton taxa provides additional insight regarding differences and similarities of the water bodies. The first distinction to note is that the increase in Cyanobacteria in Almaden Reservoir in the winter is attributed to a major pulse of *Microcystis*. This genus, unlike *Aphanizomenon* and *Anabaena*, is not capable of fixing atmospheric nitrogen (N-fixation). Instead, it must acquire nitrogen from inorganic N (ammonia or nitrate). Therefore, the pulse of *Microcystis* in Almaden Reservoir in December strongly suggests that there was an influx of ammonia or nitrate that enabled this population to flourish for one to two months. This inorganic N could have been derived from watershed inputs or from mixing of hypolimnetic waters enriched with ammonia. *Microcystis* almost always produces microcystin and thus control of the nitrogen source would be helpful in reducing this risk. The dominant Cyanobacteria taxon in Guadalupe Reservoir is *Aphanizomenon,* which is present only in low to modest numbers. *Aphanizomenon* seldom produces cyanotoxins, and the major blooms that occurred in Lake Almaden and Almaden Reservoir were both dominated by *Aphanizomenon* and likely were of low risk with respect to human health concerns. Calero Reservoir and Almaden Reservoir are the only two reservoirs with substantial quantities of *Anabaena* present. *Anabaena* can produce both microcystins and anatoxins.

The genera of diatoms present are typical of lakes with some degree of nutrient enrichment. A reasonable expectation is that the *Asterionella* is *A. formosa* and that the *Fragilaria* taxon is *F. crotonensis*. *Melosira* has been renamed and is now called *Aulocoseira* and a possibility for the species is *A. distans.* Almost all of the dinoflagellates were *Peridinium*, a taxon that is widespread and can achieve bloom densities in highly productive waters. *Oocystis*, which was present in low densities in Almaden Reservoir and Lake Almaden, is non-motile green algae. *Pandorina* is flagellated, colonial green algae, a common species being *P. morum*. *Trachylomonas,* found in all of the reservoirs except Lake Almaden, is a Euglenophyta and is usually associated with enriched waters, often organically enriched waters. A count of 8000 cells/ml of some unidentified algae was noted for Calero Reservoir. In summary with respect to minor taxa, the current densities of potential nuisance-causing diatoms in the District water bodies are not a cause for concern. Currently, densities of *Peridinium, Pandorina*, and *Trachylomonas* are low, but significant increases in abundance of these taxa would indicate increased nutrient input.

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. In 2009, the District applied for grant funding to assess the feasibility of restoring Alamitos Creek to bypass Lake Almaden as an alternative to treatment methods of addressing methyl mercury issues in this water body. If received, this study could be completed as early as June 2011.

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 are no background data for comparison, so it is not possible to determine if the circulators have had any effect on the blue green algae blooms. The data indicate that there has been no effect of circulation on hypolimnetic anoxia or water column concentrations of methyl mercury.

The second Hypothesis being tested for Guadalupe Reservoir is

> *Oxygenation of the hypolimnion in combination with epilimnetic circulation will accelerate the processes described above in Guadalupe Reservoir*.

A pilot oxygenation system is being installed for operation in calendar year 2010. To date, there are no data available to test this hypothesis.

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. Seasonal blooms of Cyanobacteria were visually observed annually each November, indicating that the epilimnetic circulation has not yet substantially affected the composition of phytoplankton in the reservoir.

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.*

In 2009, the District applied for grant funding to purchase an oxygenation system for Calero Reservoir. If the funding is received, this system could be installed as early as the spring of 2011. Data from the pilot system to be installed in Guadalupe Reservoir (see above) will be used in the design of the system for Calero Reservoir. If funding is not received, there is no time frame for installation of a system in Calero Reservoir.

Implementation Timeline

To date, the District has conducted the following activities:

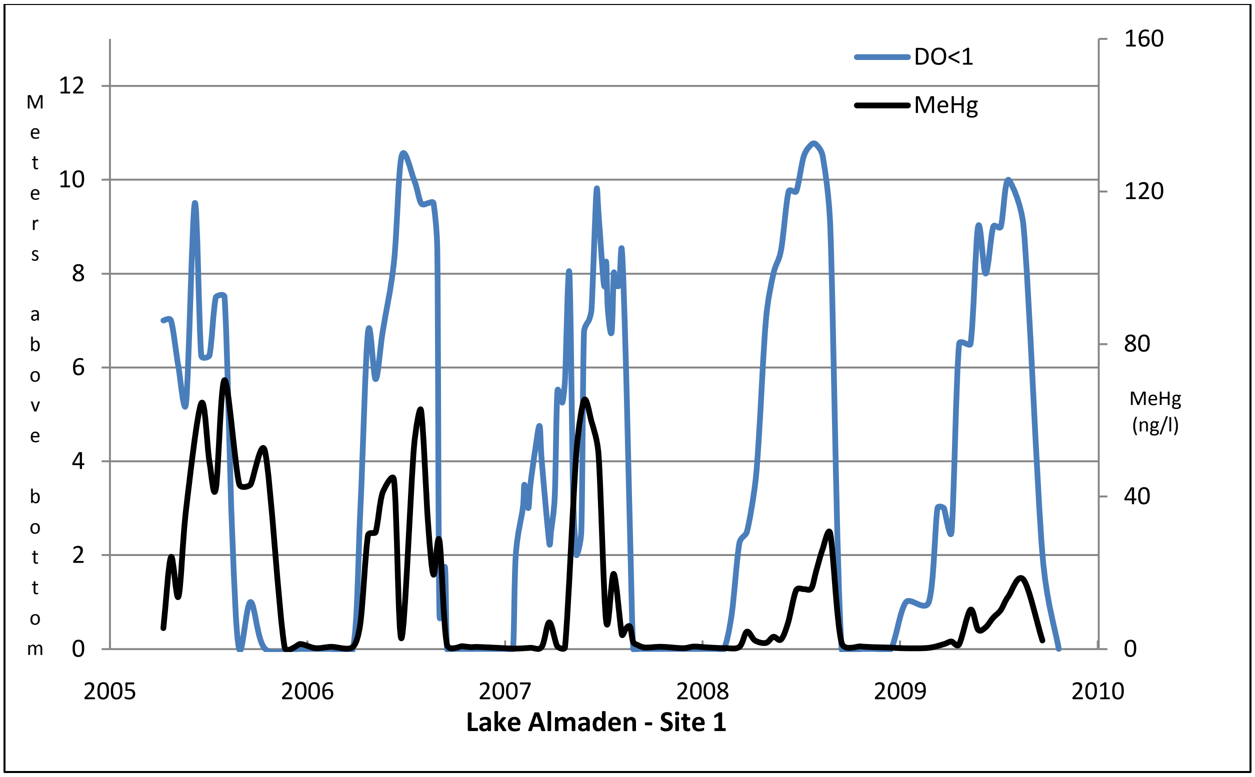
2003-2009	Source removal on all known source areas on District-owned property on Alamitos Creek.
2005-present	Monitoring and Sampling Program for three reservoirs and one lake.
2006-present	Installation and operation of a circulator at Site 1 in Lake Almaden, with modifications to deployment in 2008.
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	Installation and operation of two additional circulators in Lake Almaden; lease of pilot scale oxygenation system for Guadalupe Reservoir; 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.

Planned activities for the next reporting period:

2010-2011	Monitoring and Sampling Program for three reservoirs and one lake, continued operation of existing circulators.
2010	Pilot oxygenation system operation in Guadalupe Reservoir.
2010-2011	Pending grant funding: installation and operation of oxygenation system in Calero Reservoir; completion of feasibility study for Alamitos Creek Restoration/Lake Almaden Bypass; source reduction on private property on Alamitos Creek.

APPENDIX A

FIGURES



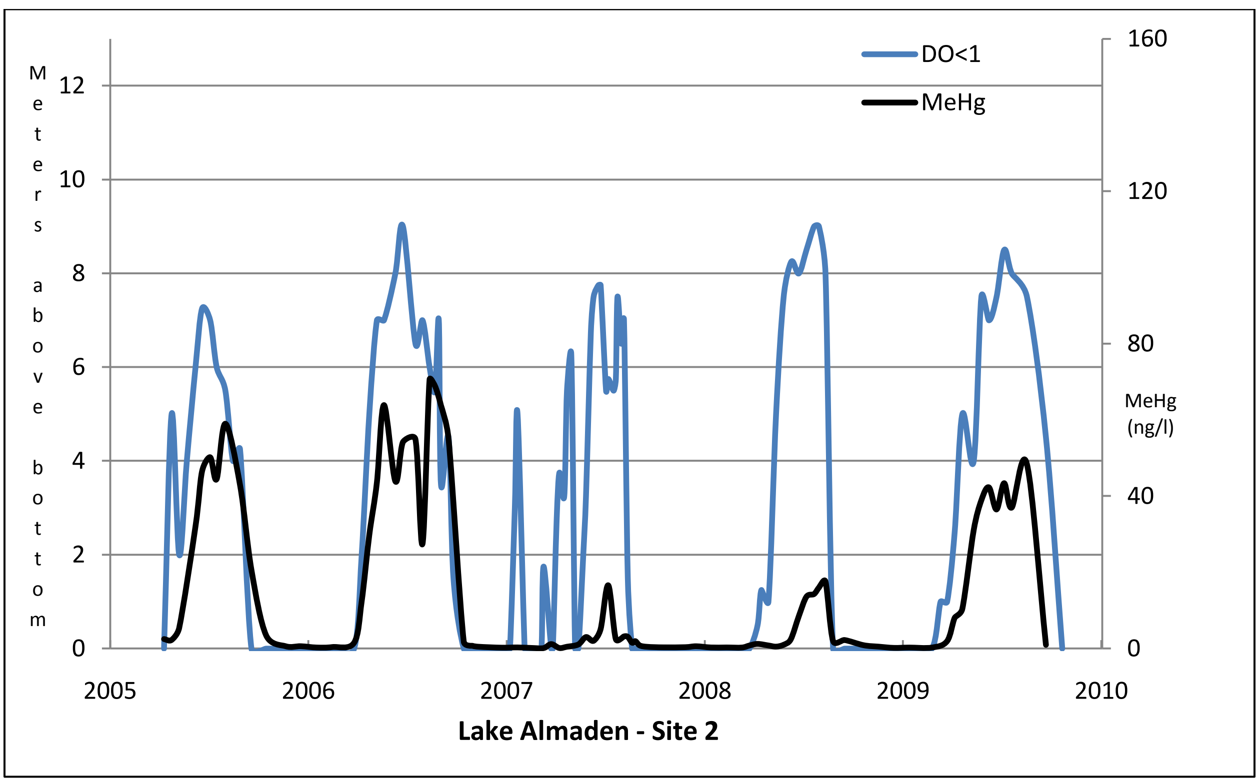


Figure 1 Annual coincidence of methyl mercury production with seasonal anoxia in Lake Almaden

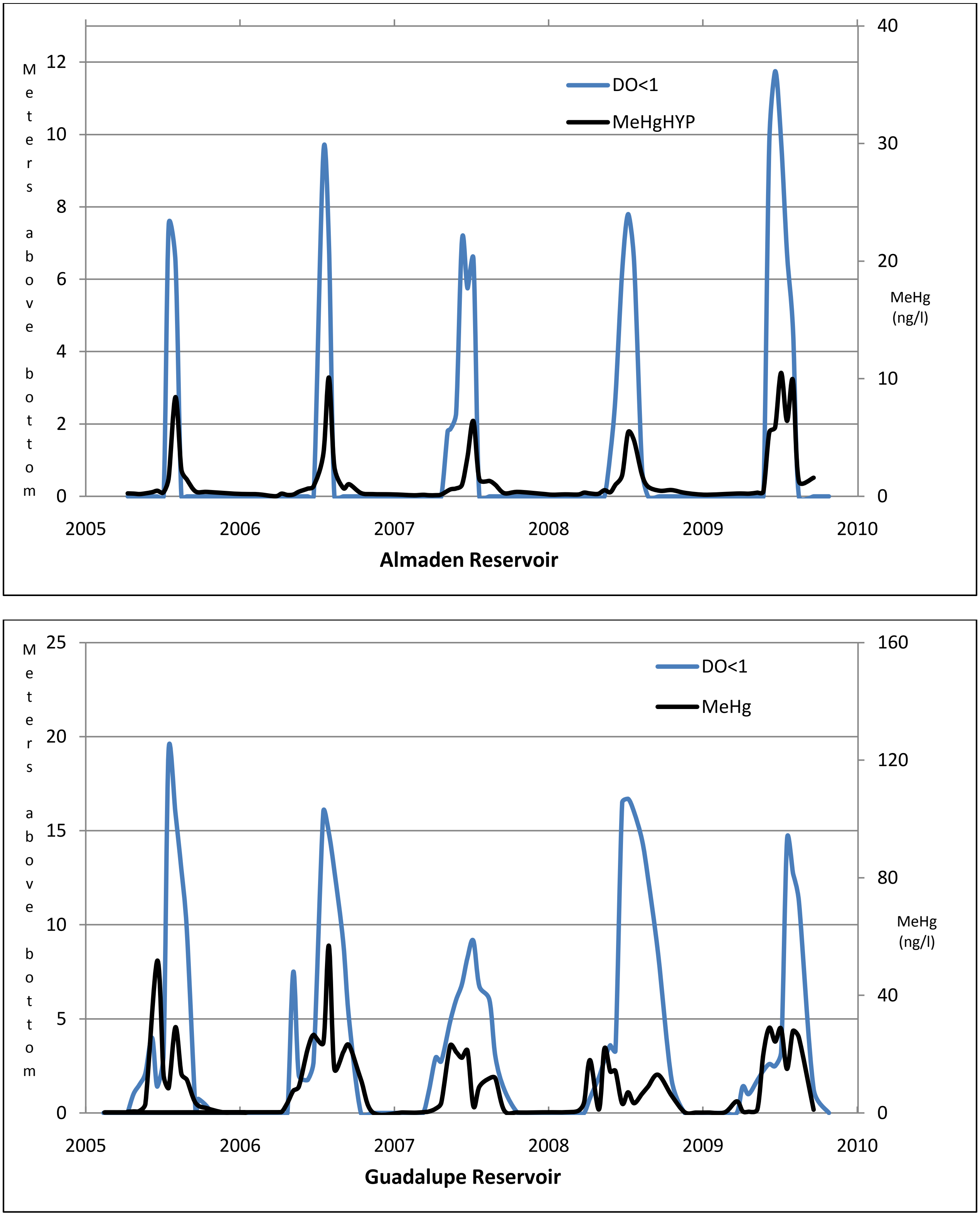


Figure 2: Annual coincidence of methyl mercury production with seasonal anoxia in two Reservoirs

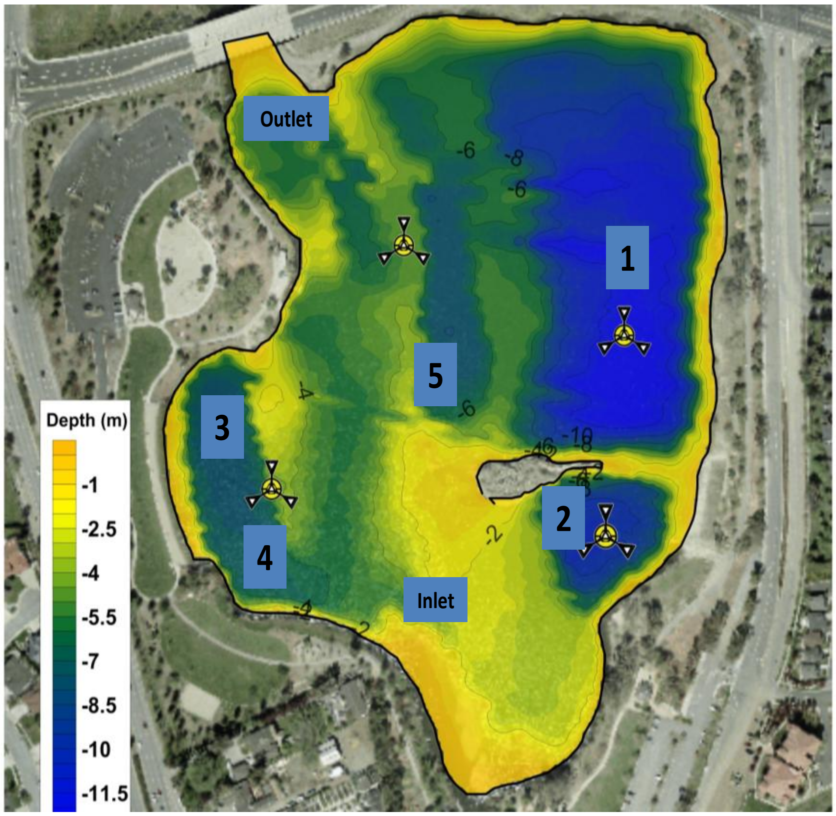
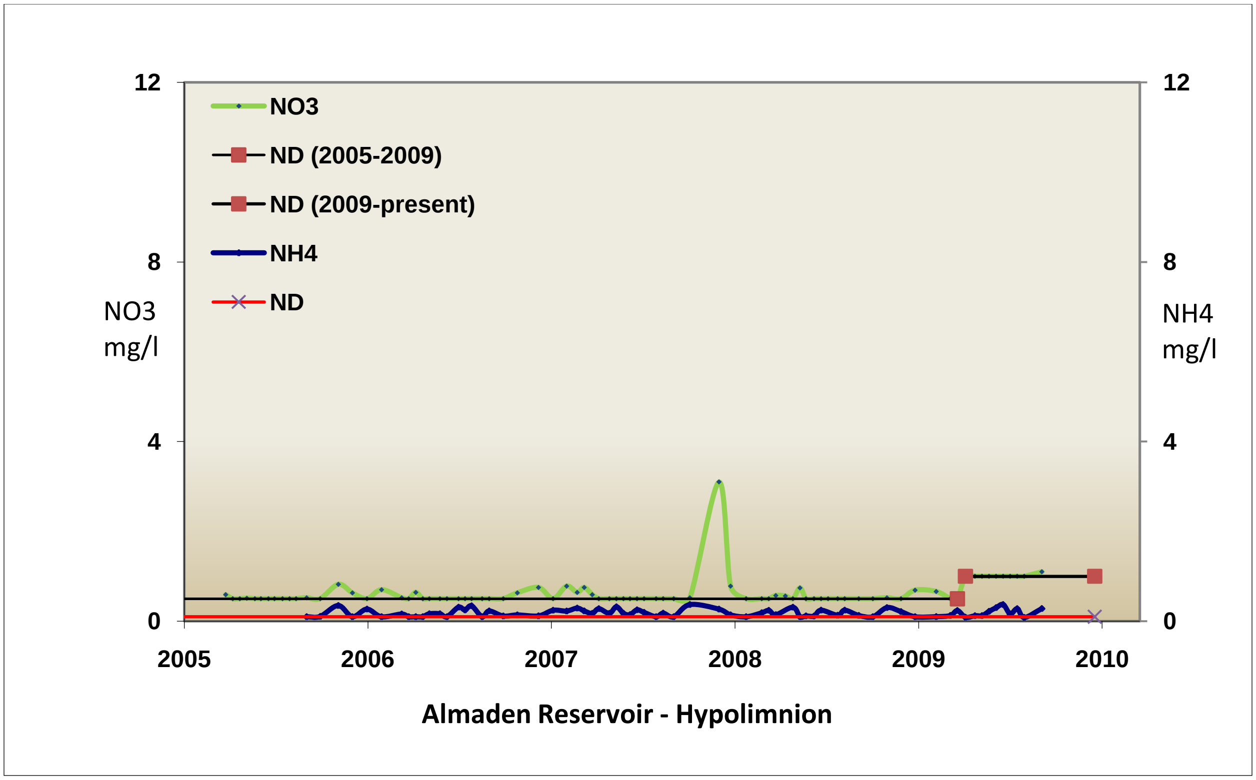


Figure 3: Lake Almaden Bathymetry and Site Map

Inlet = Sampling/Monitoring Location

 = Solar-powered Circulator Location



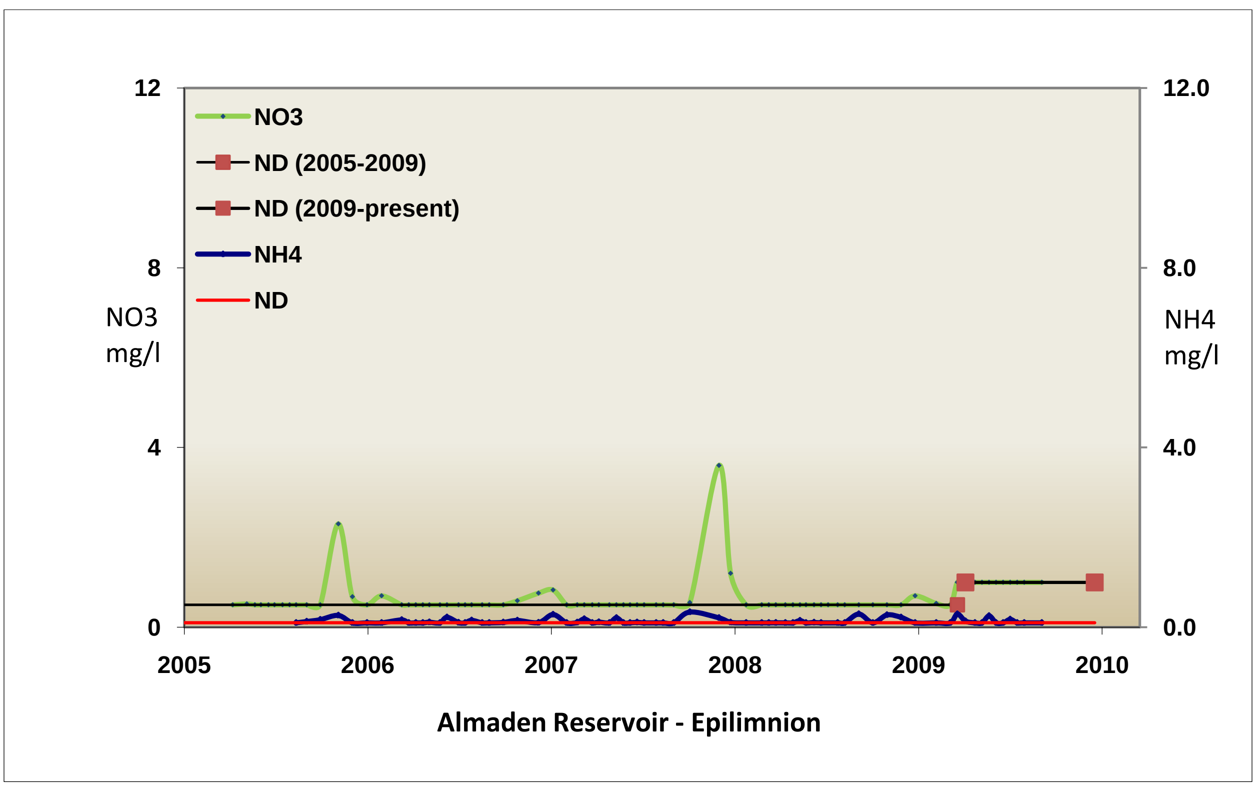
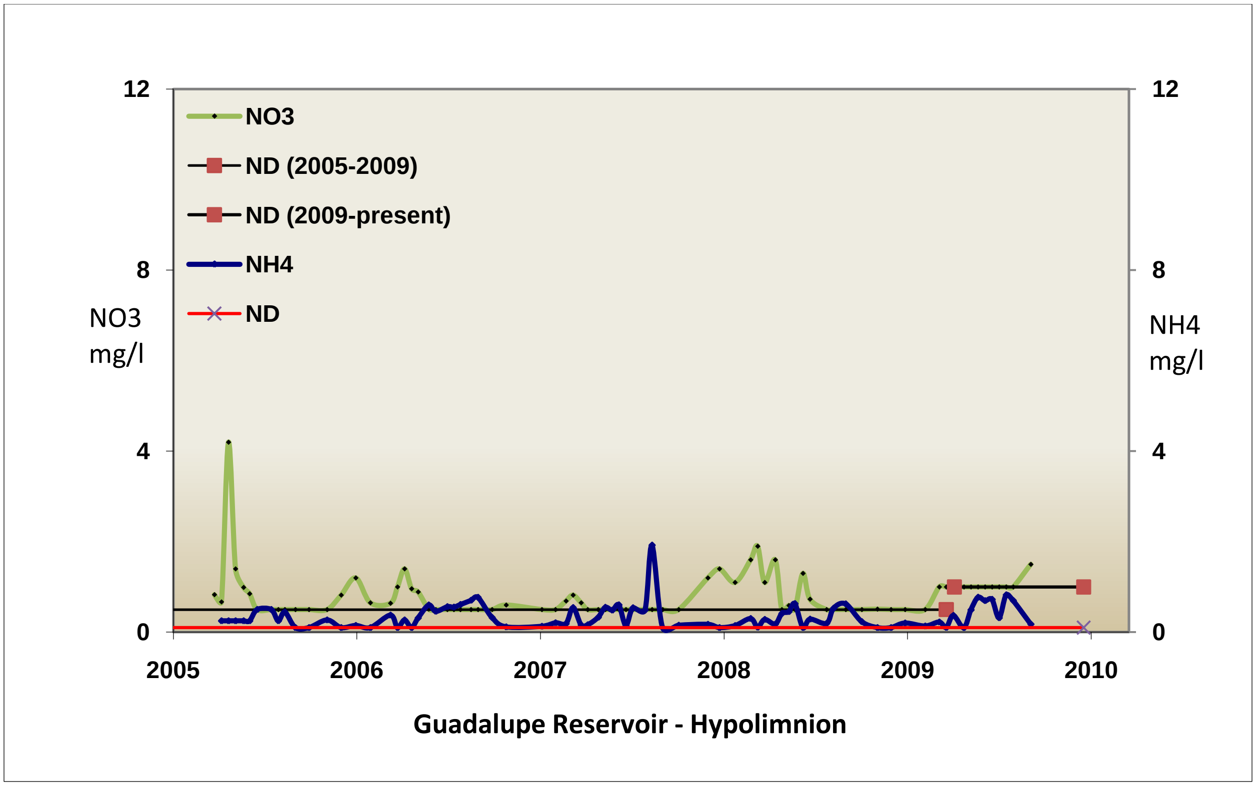


Figure 4: Seasonal Nitrate (NO3) and Ammonia (NH4) Concentrations in Almaden Reservoir



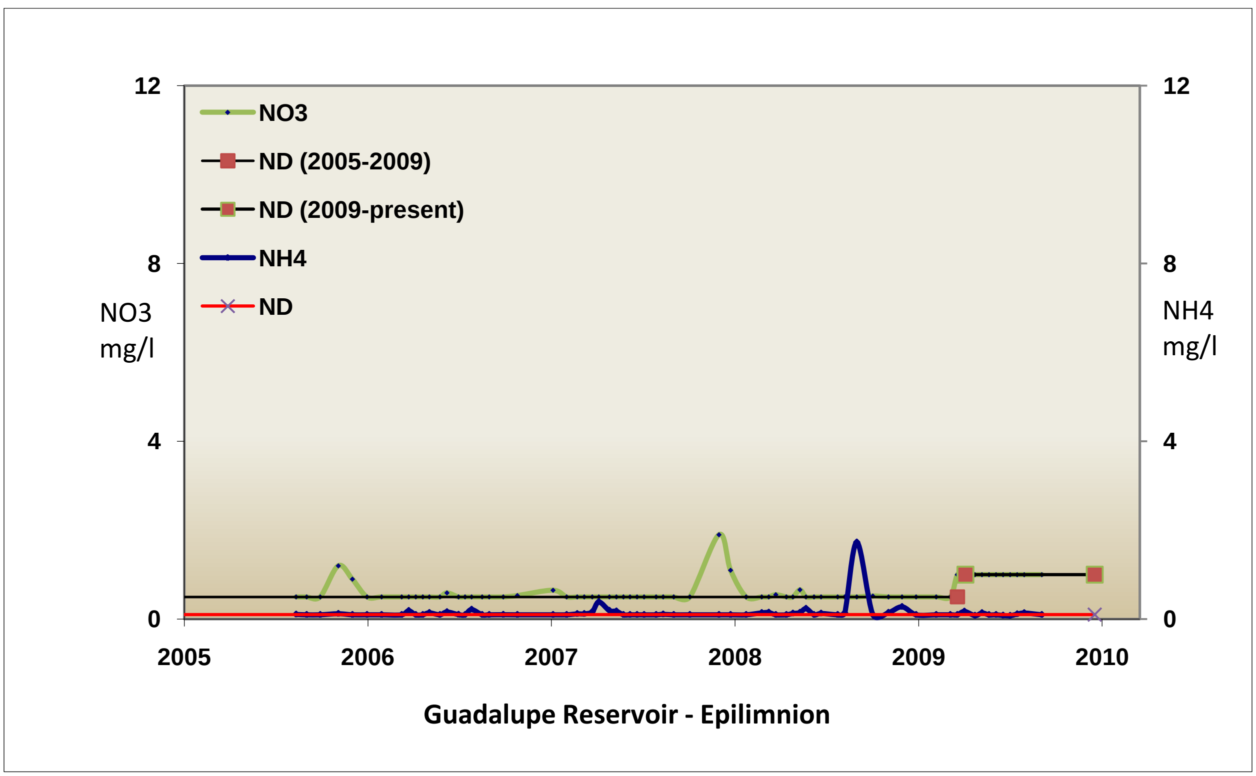
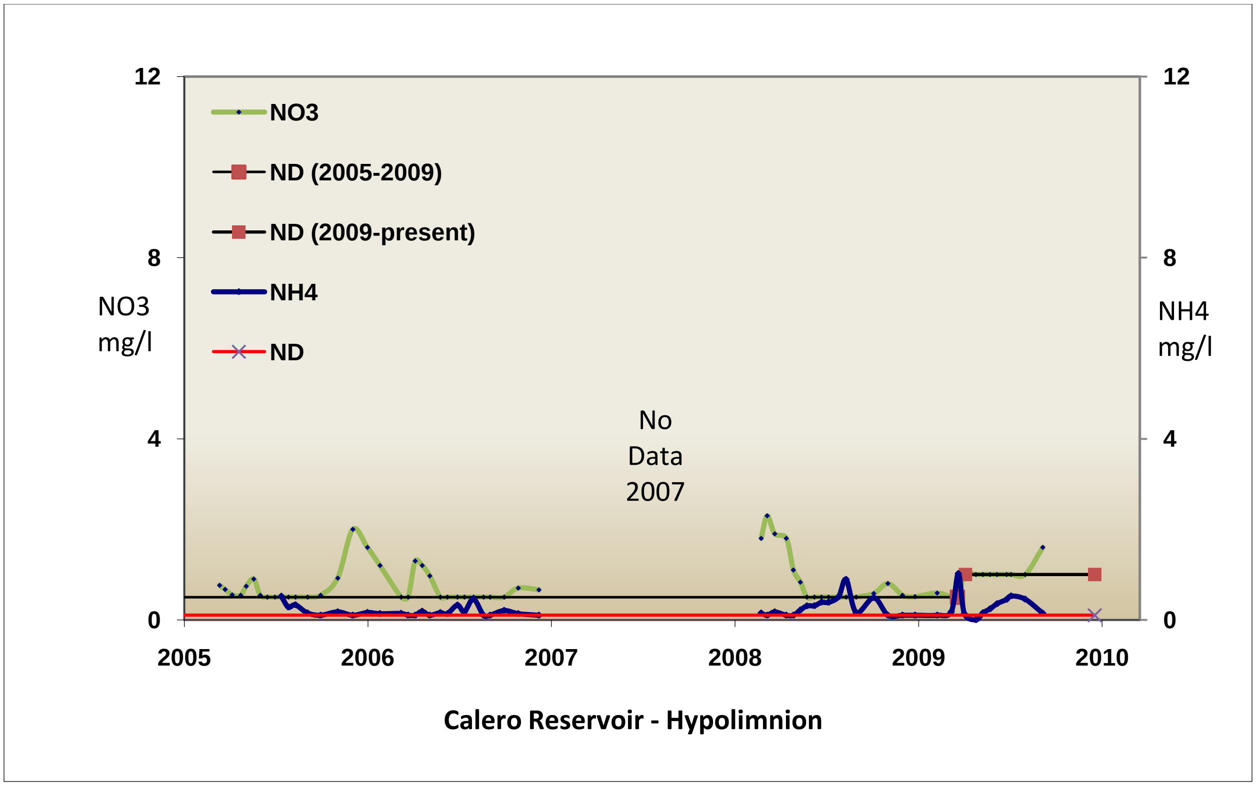


Figure 5: Seasonal Nitrate (NO3) and Ammonia (NH4) Concentrations in Guadalupe Reservoir



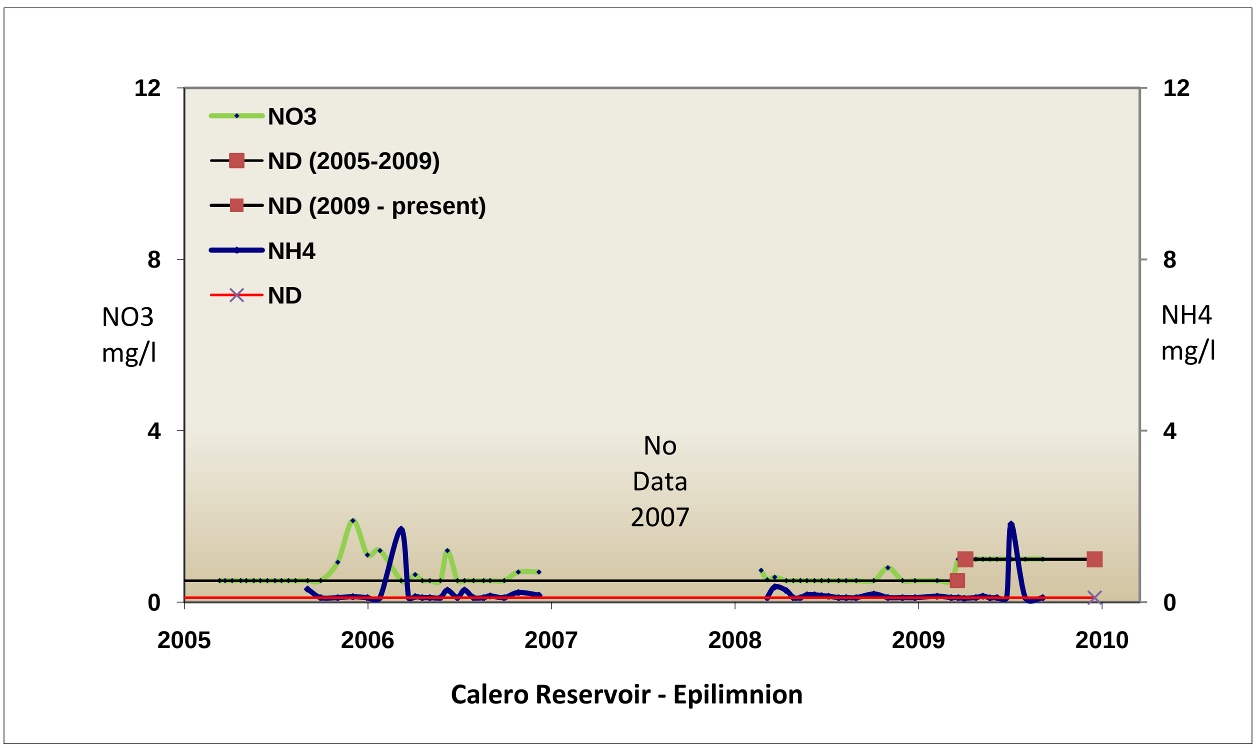
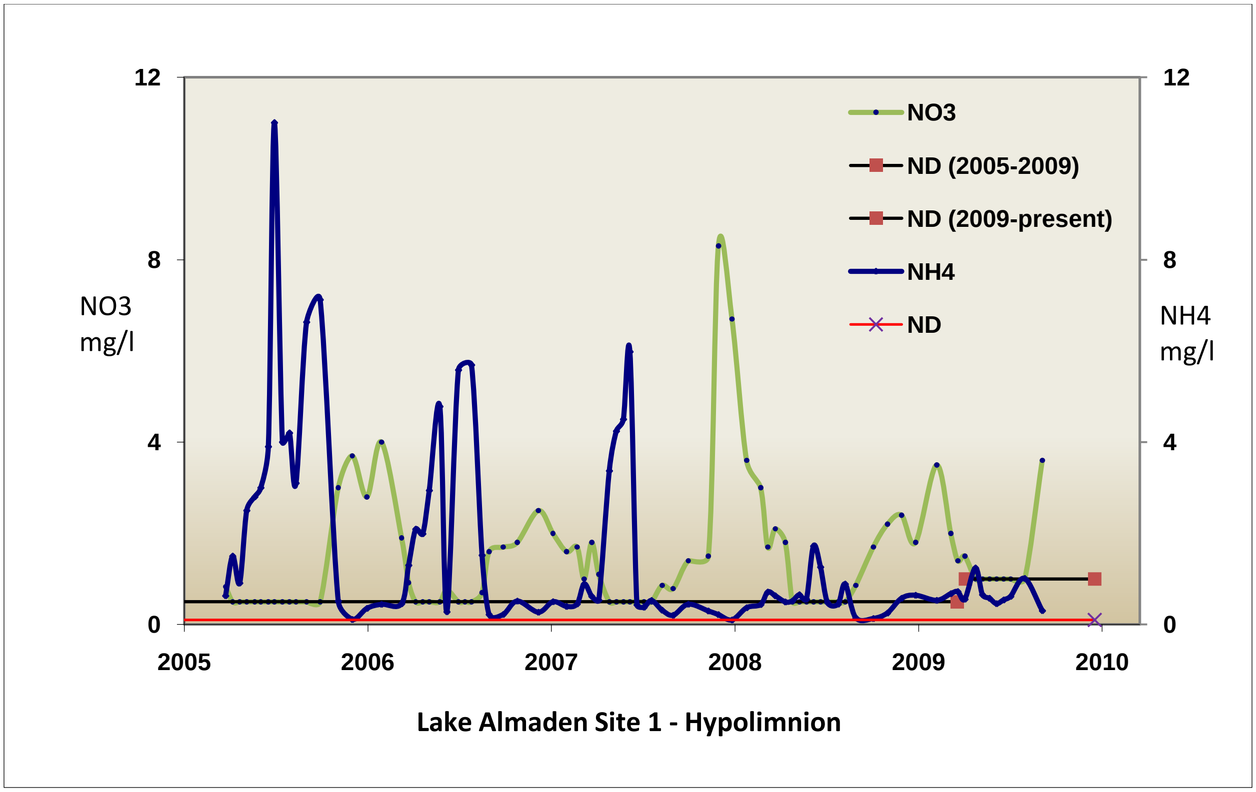


Figure 6: Seasonal Nitrate (NO3) and Ammonia (NH4) Concentrations in Calero Reservoir



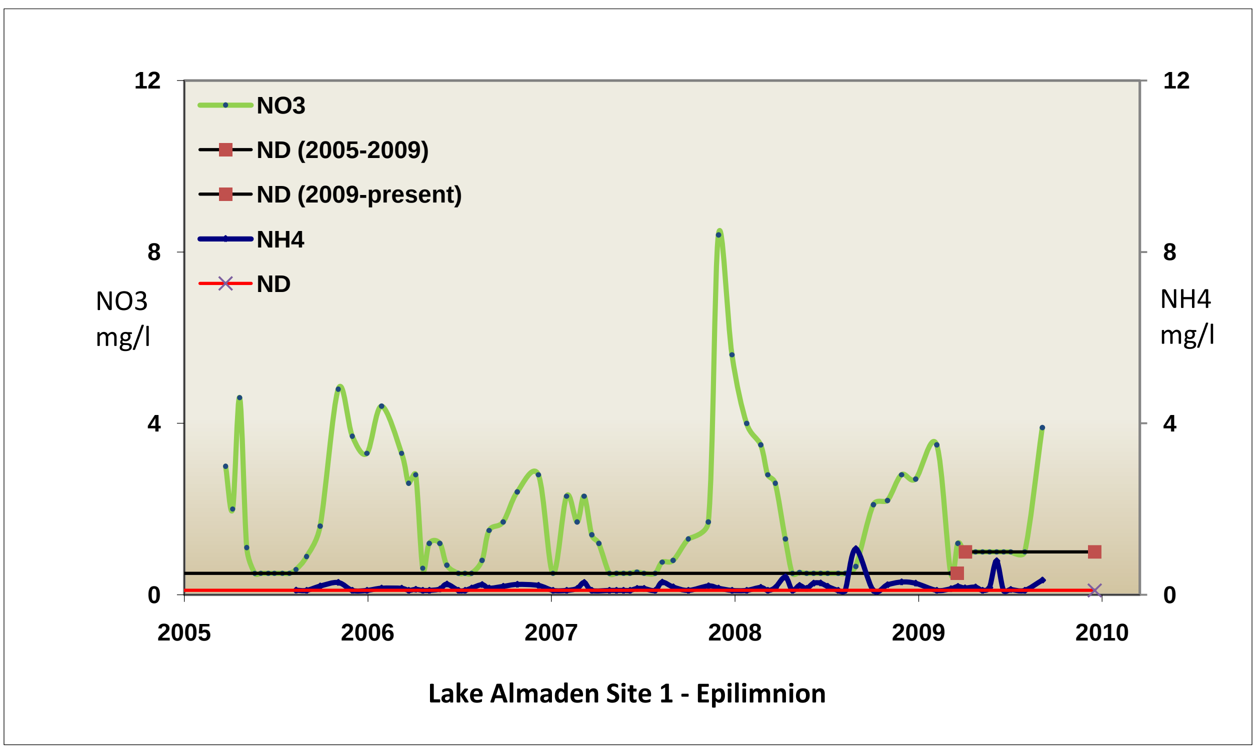
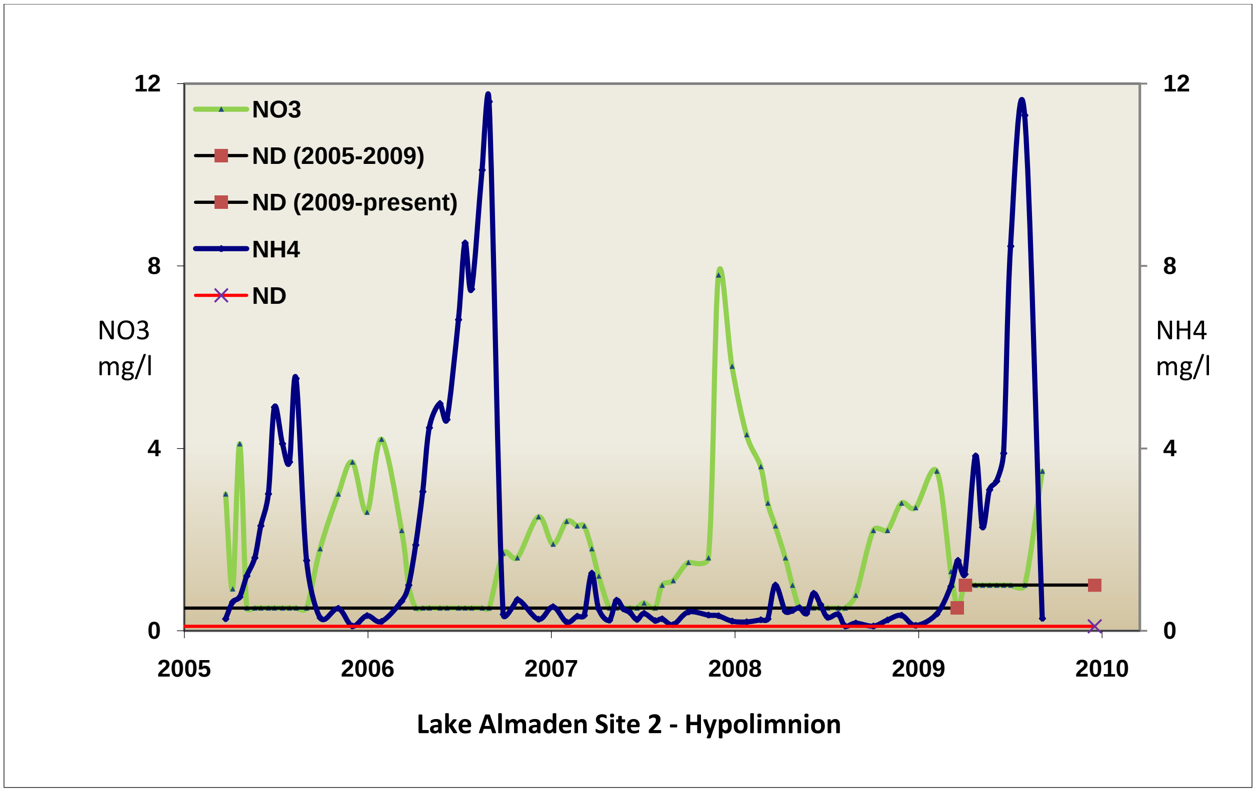


Figure 7: Seasonal Nitrate (NO3) and Ammonia (NH4) Concentrations in Lake Almaden (Site 1)



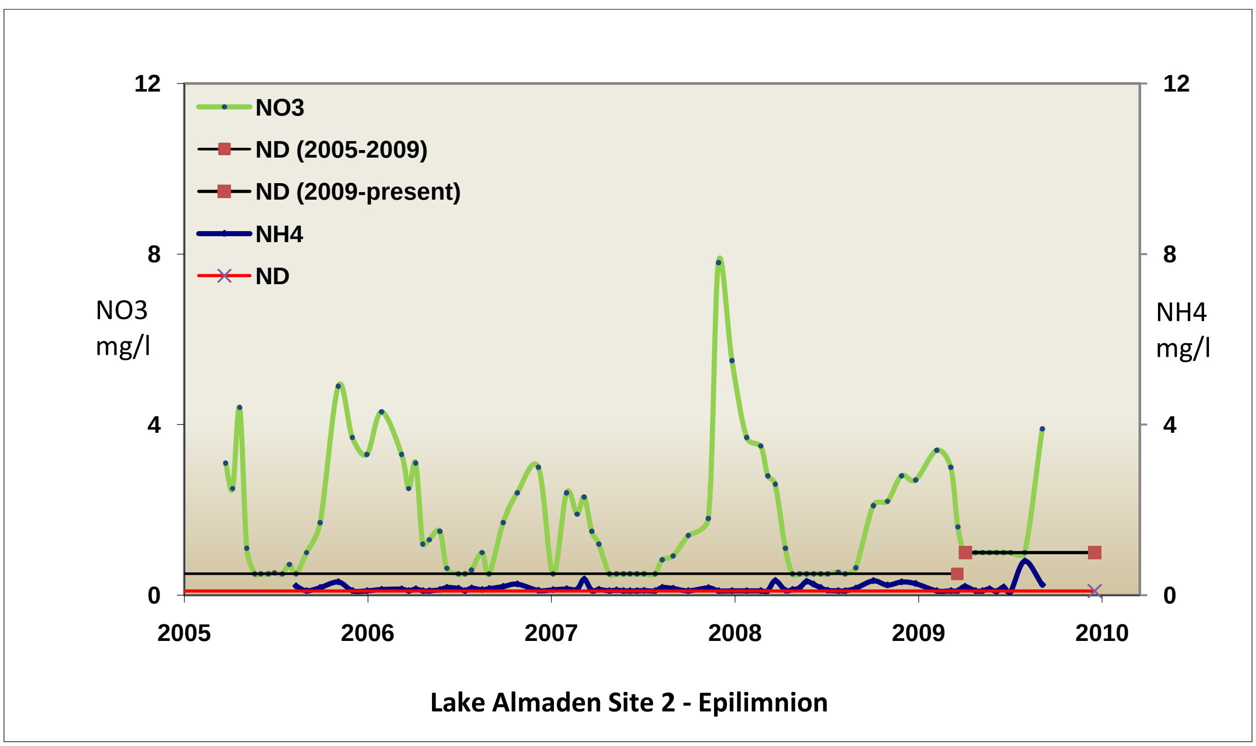
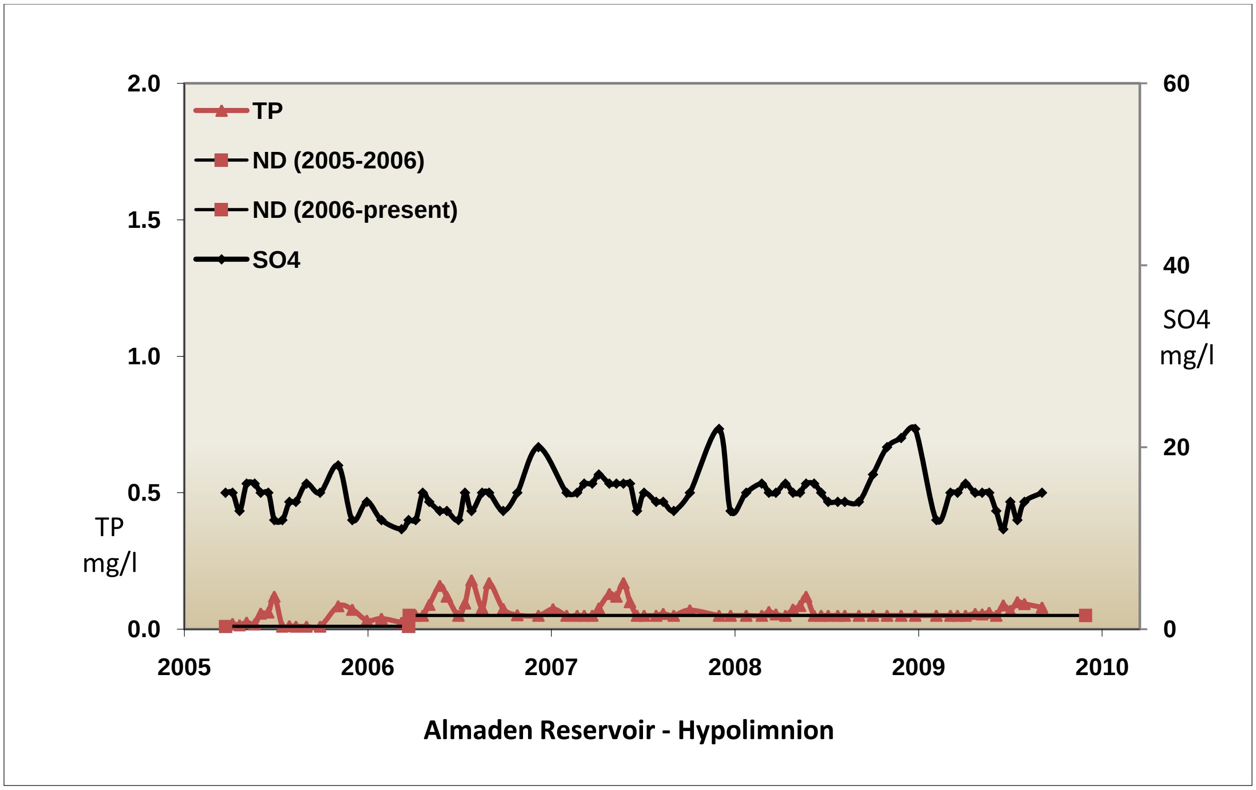


Figure 8: Seasonal Nitrate (NO3) and Ammonia (NH4) Concentrations in Lake Almaden (Site 2)



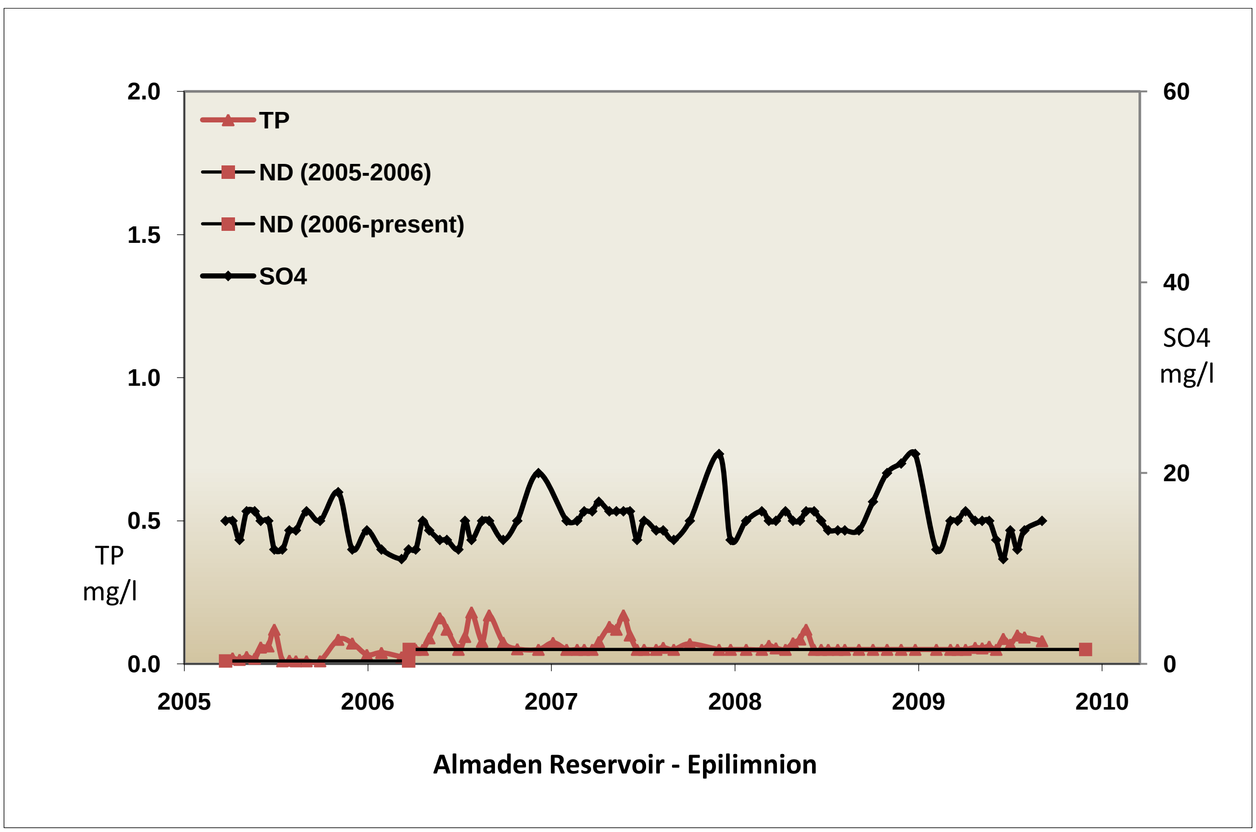
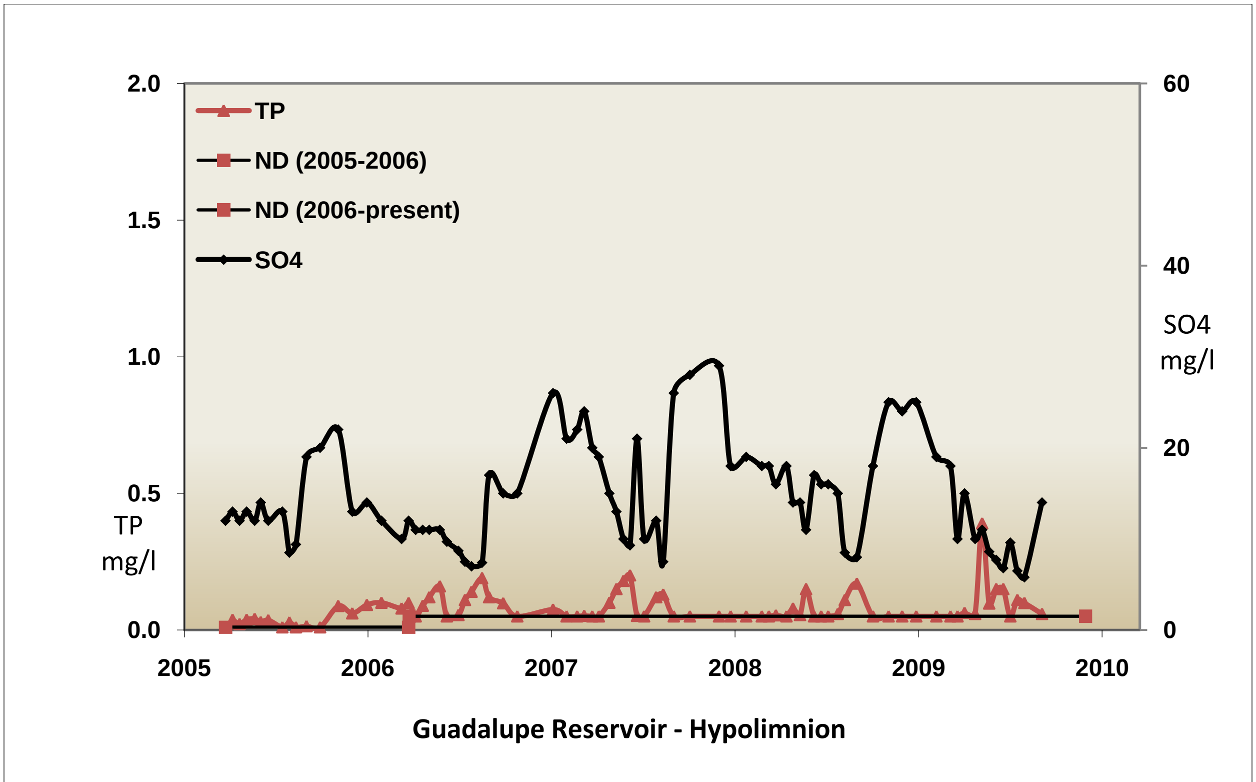


Figure 9: Seasonal Total Phosphorus (TP) and Sulfate (SO4) Concentrations in Almaden Reservoir



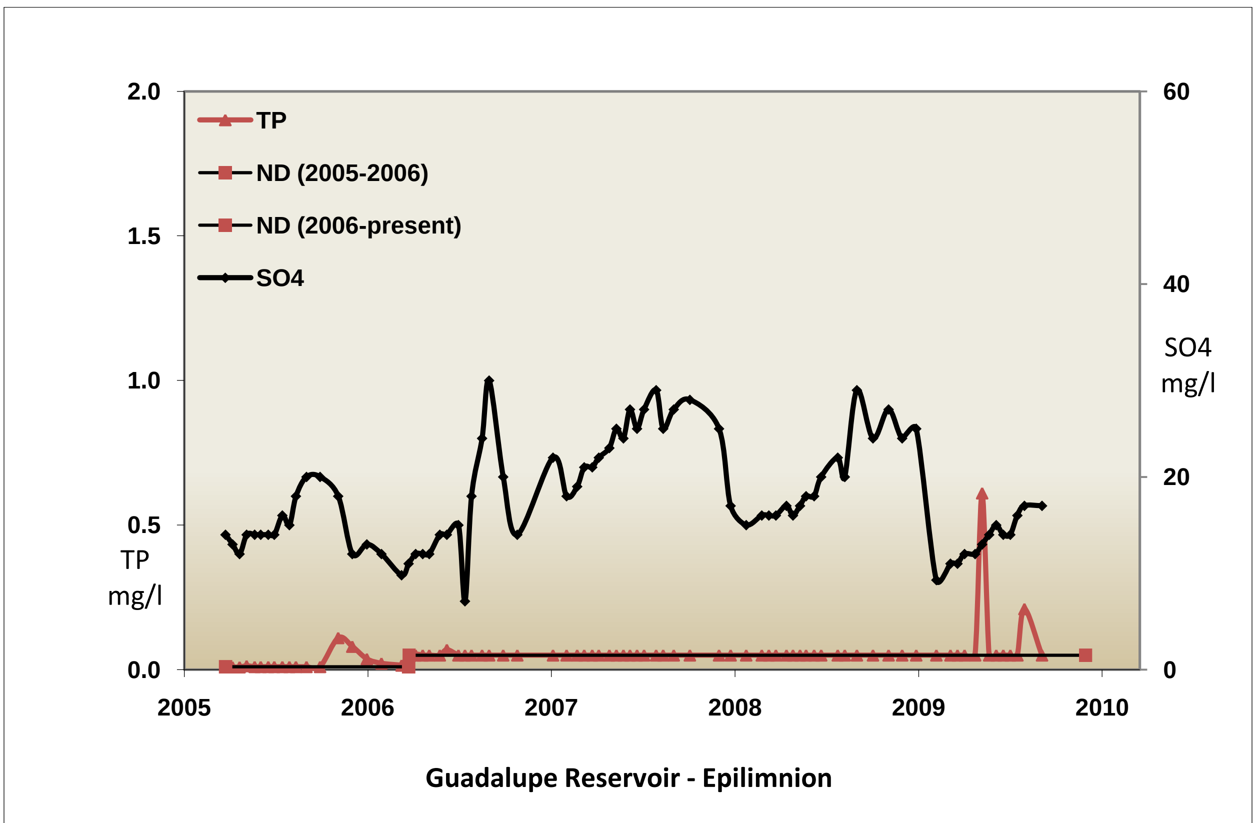
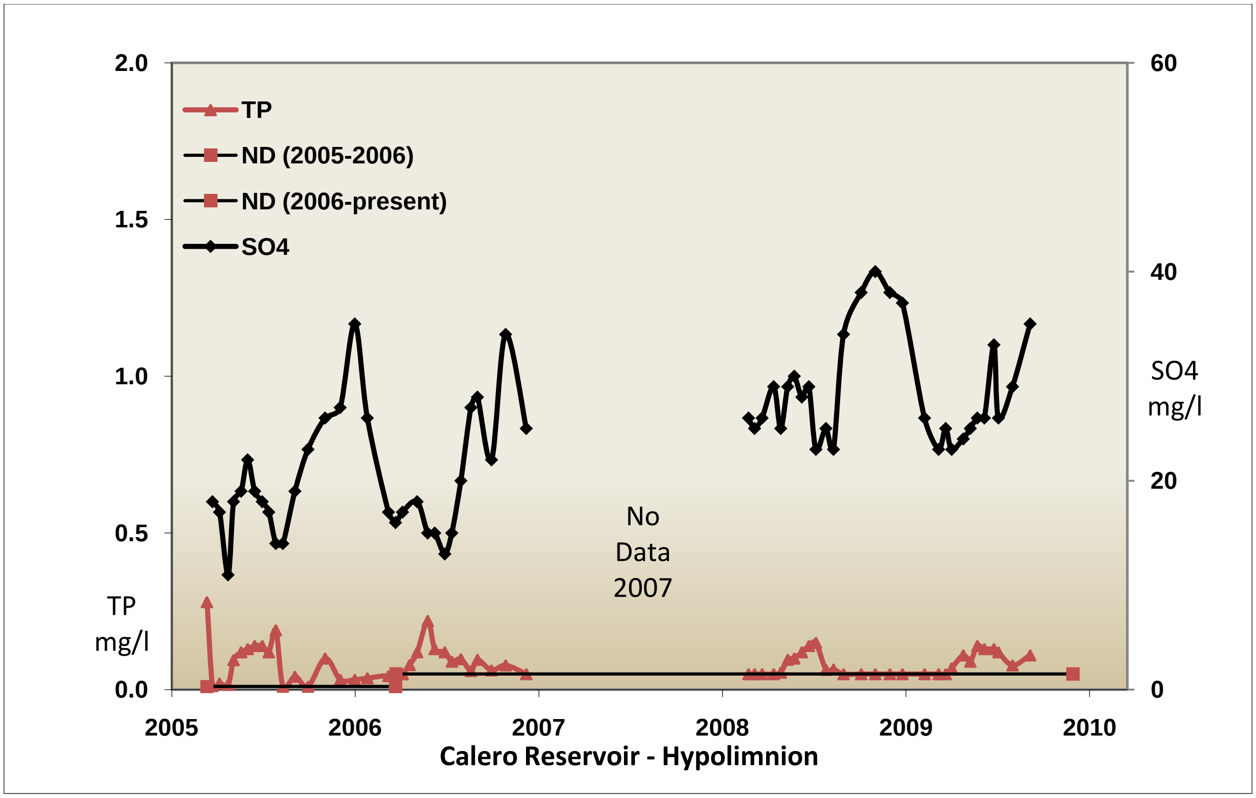


Figure 10: Seasonal Total Phosphorus (TP) and Sulfate (SO4) Concentrations in Guadalupe Reservoir



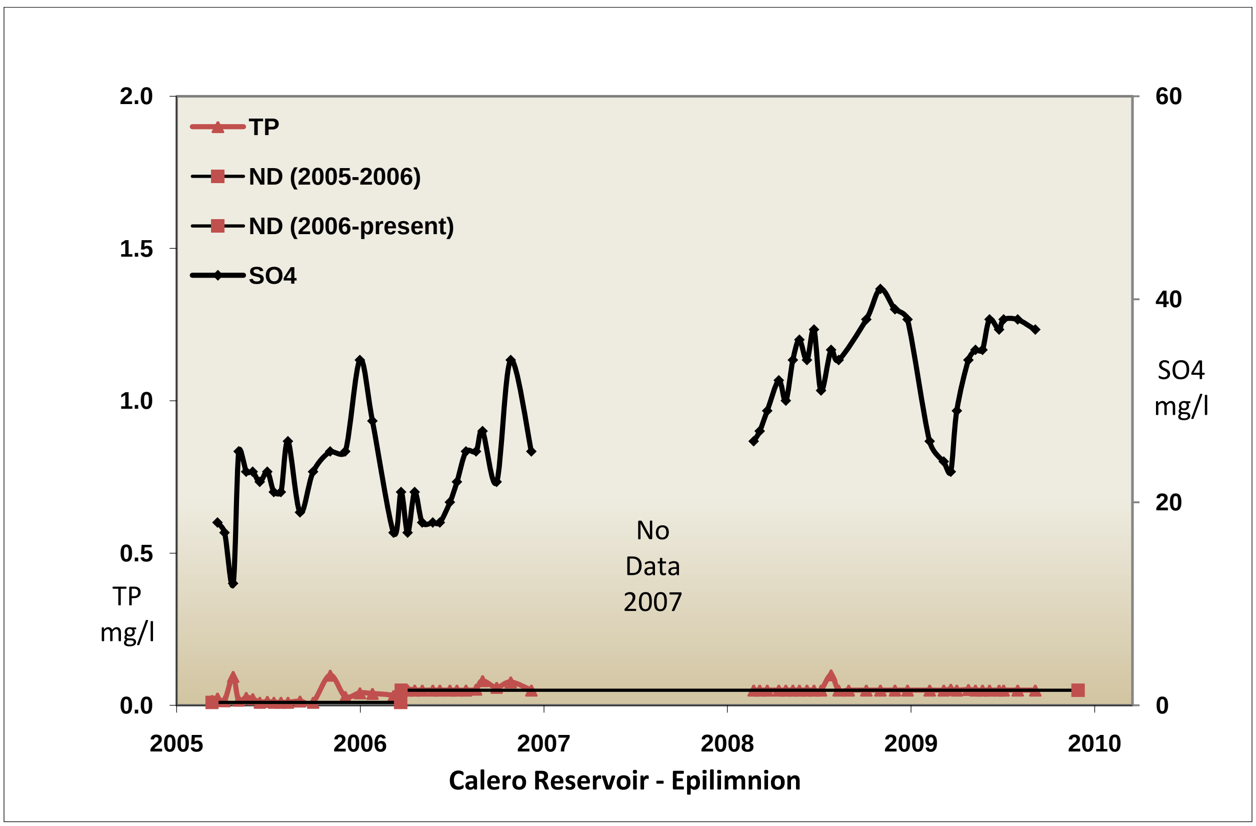
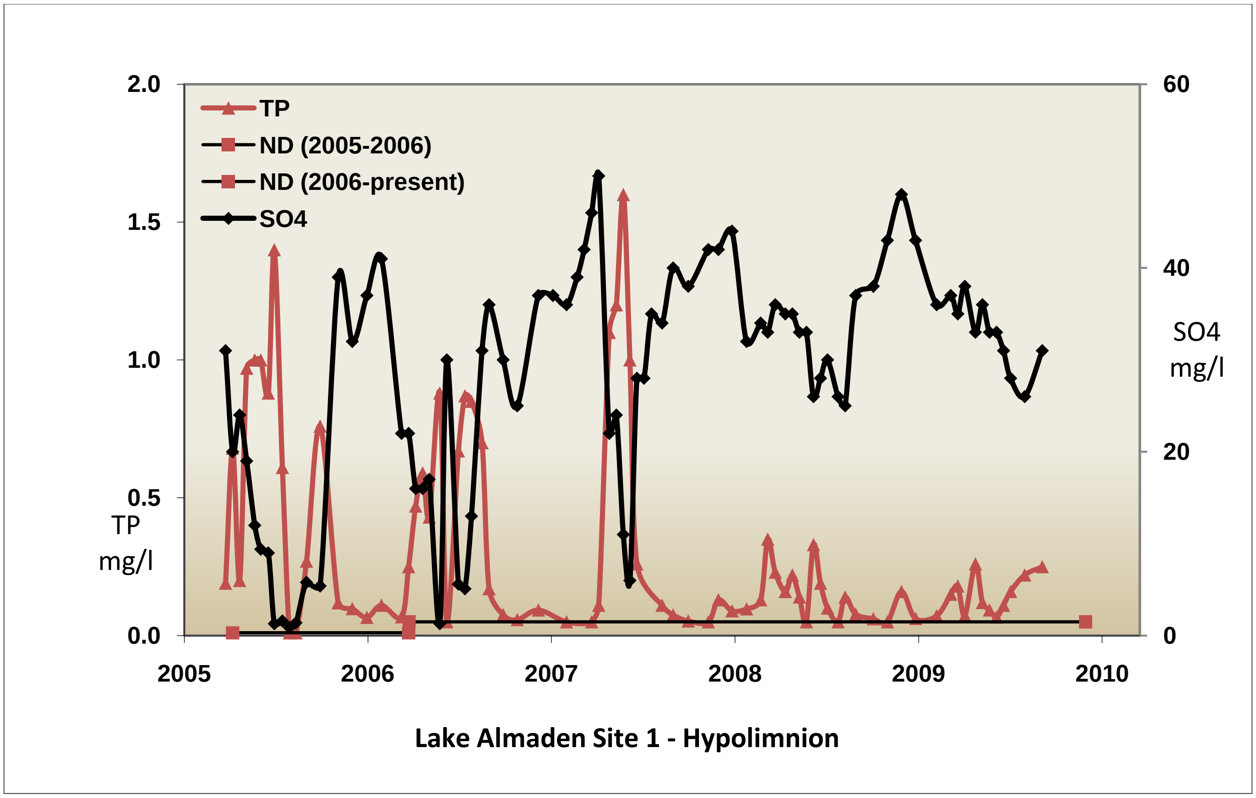


Figure 11: Seasonal Total Phosphorus (TP) and Sulfate (SO4) Concentrations in Calero Reservoir



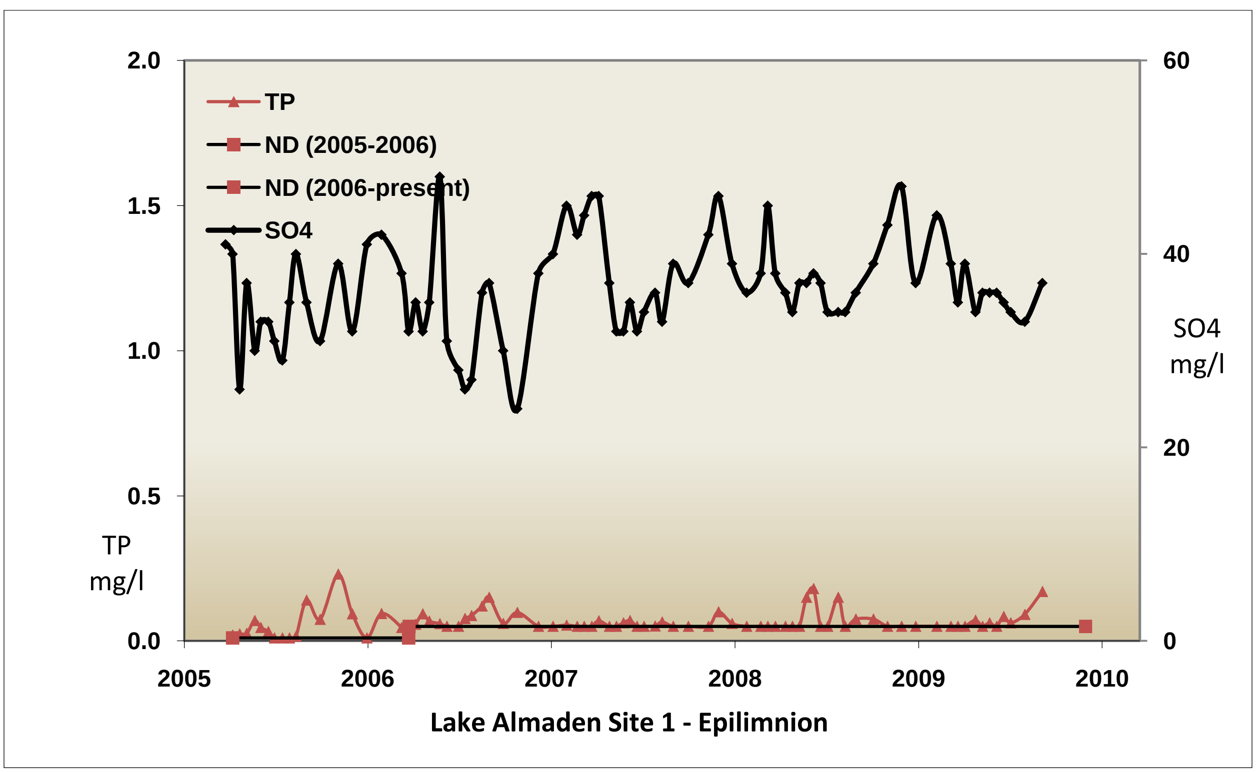
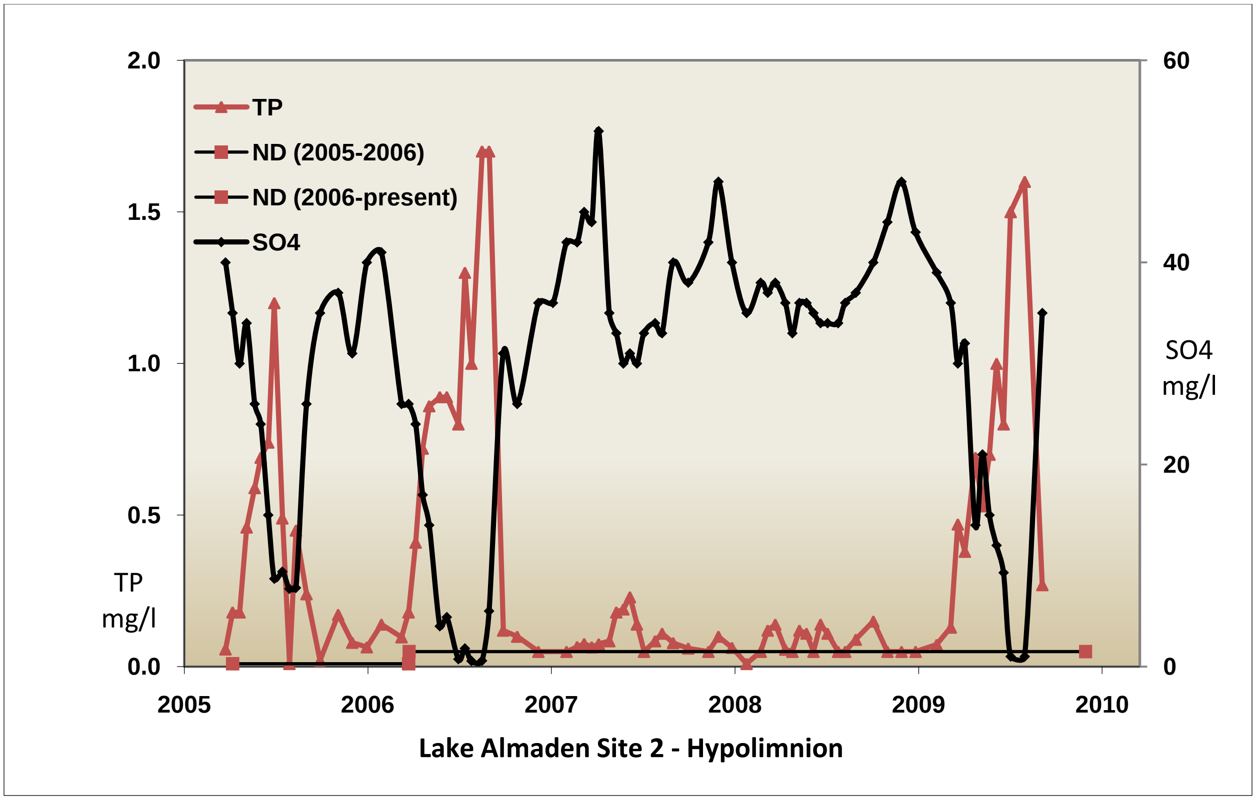


Figure 12: Seasonal Total Phosphorus (TP) and Sulfate (SO4) Concentrations in Lake Almaden (Site 1)



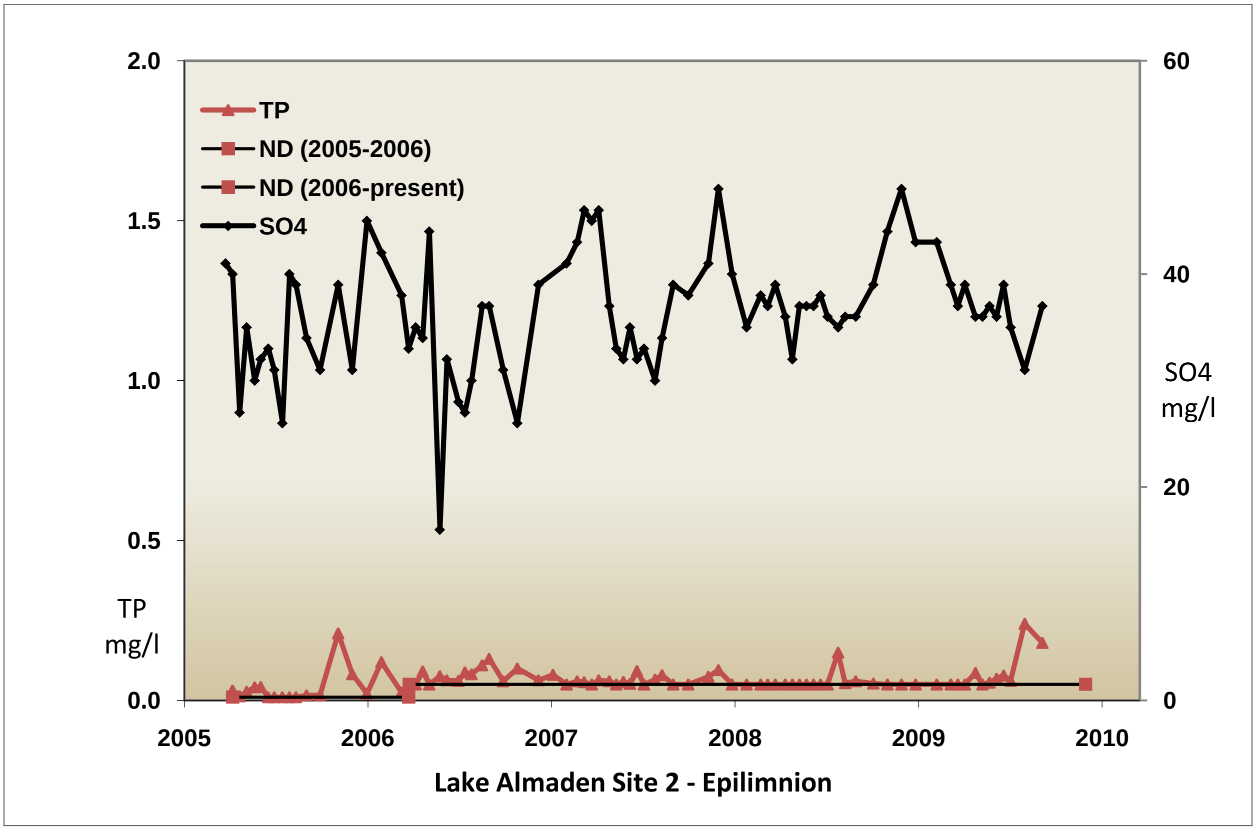


Figure 13: Seasonal Total Phosphorus (TP) and Sulfate (SO4) Concentrations in Lake Almaden (Site 2)

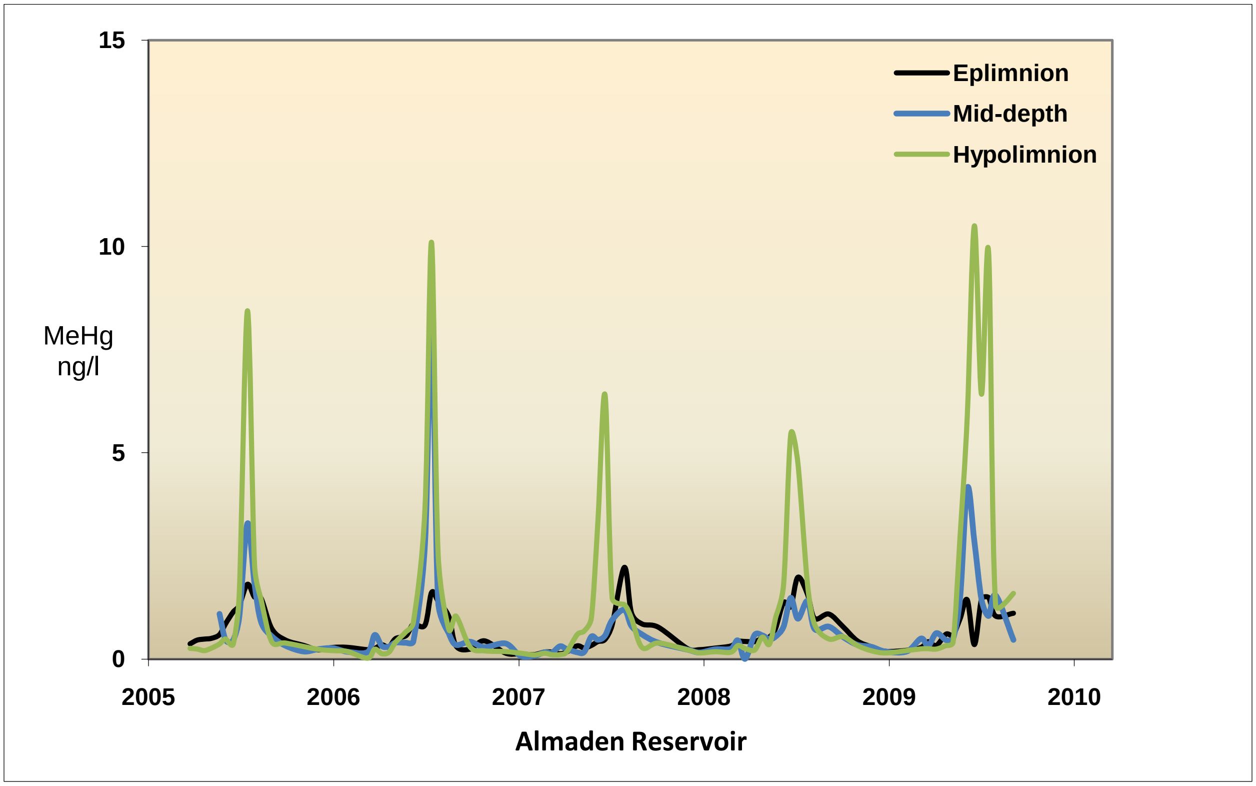


Figure 14: Seasonal Unfiltered Methyl Mercury (MeHg) Concentrations in Almaden Reservoir

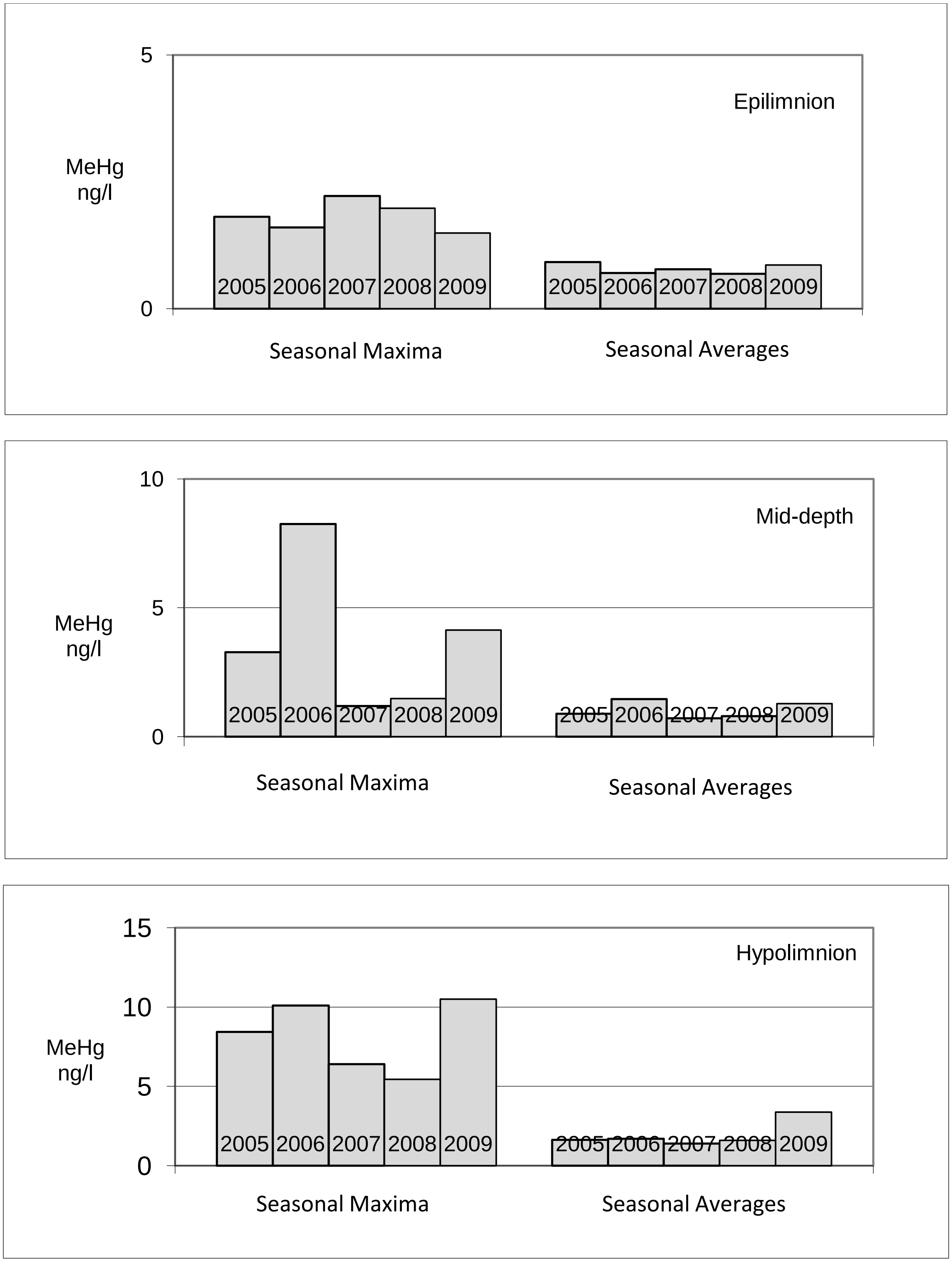


Figure 15: Seasonal Maxima and Average Unfiltered Methyl Mercury (MeHg) Concentrations in Almaden Reservoir

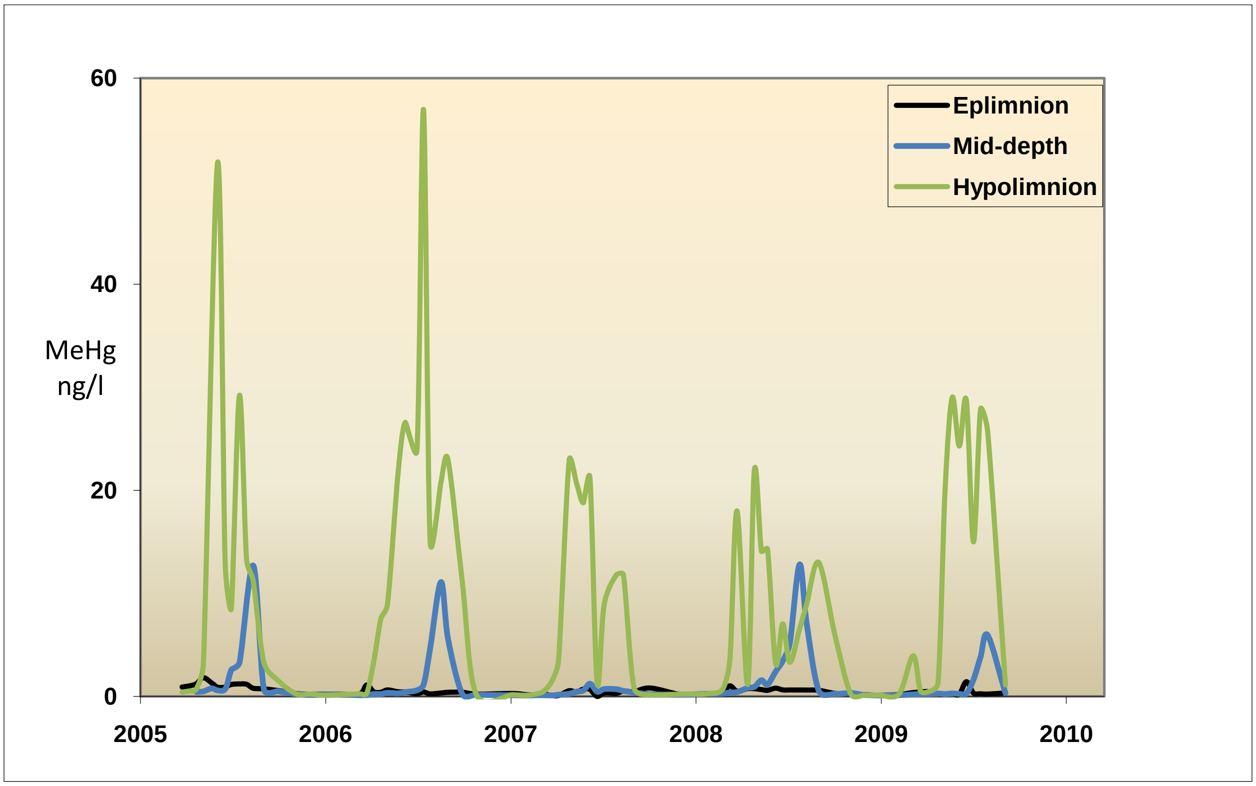


Figure 16: Seasonal Unfiltered Methyl Mercury (MeHg) Concentrations in Guadalupe Reservoir

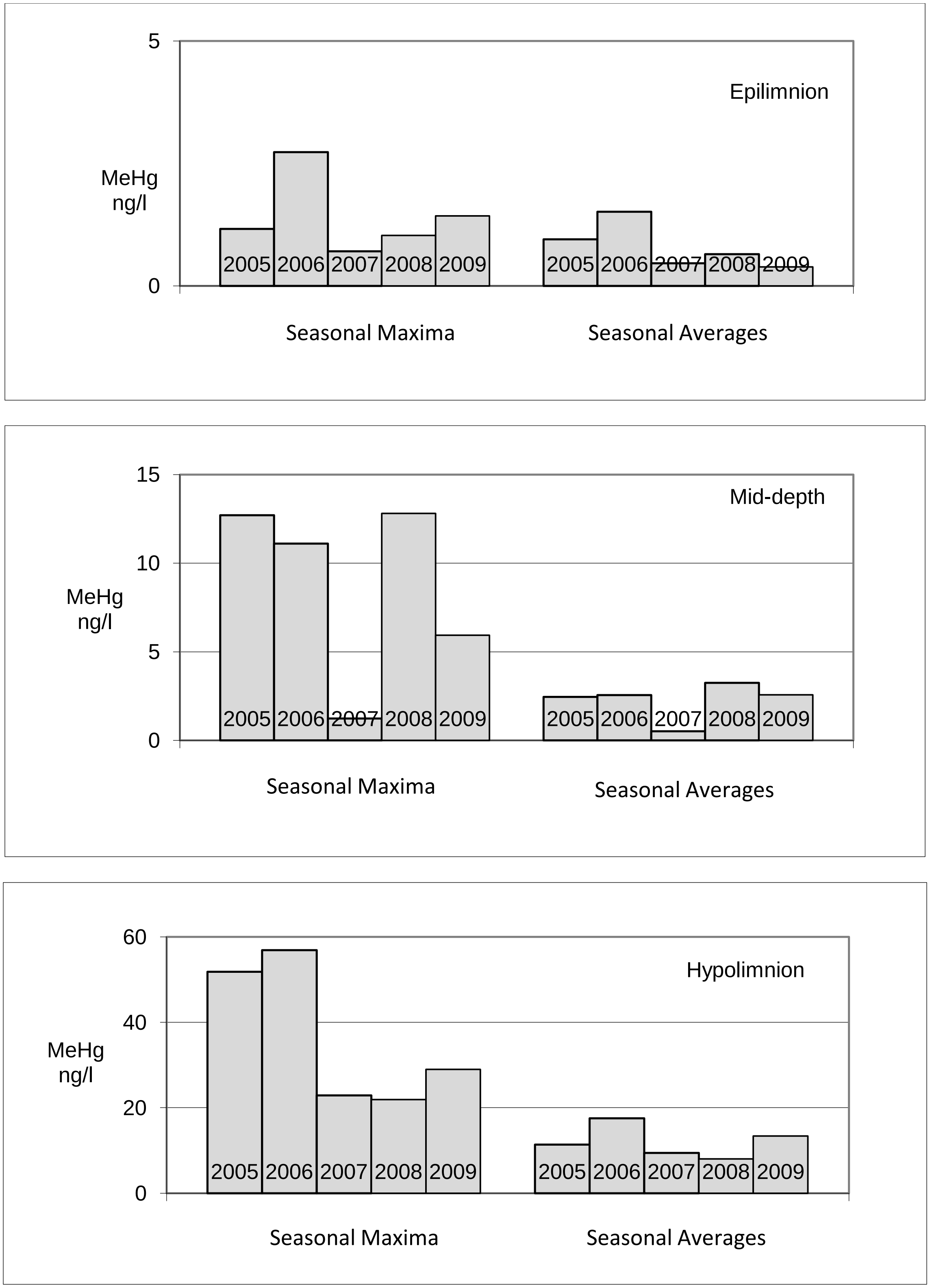


Figure 17: Seasonal Maxima and Average Unfiltered Methyl Mercury (MeHg) Concentrations in Guadalupe Reservoir

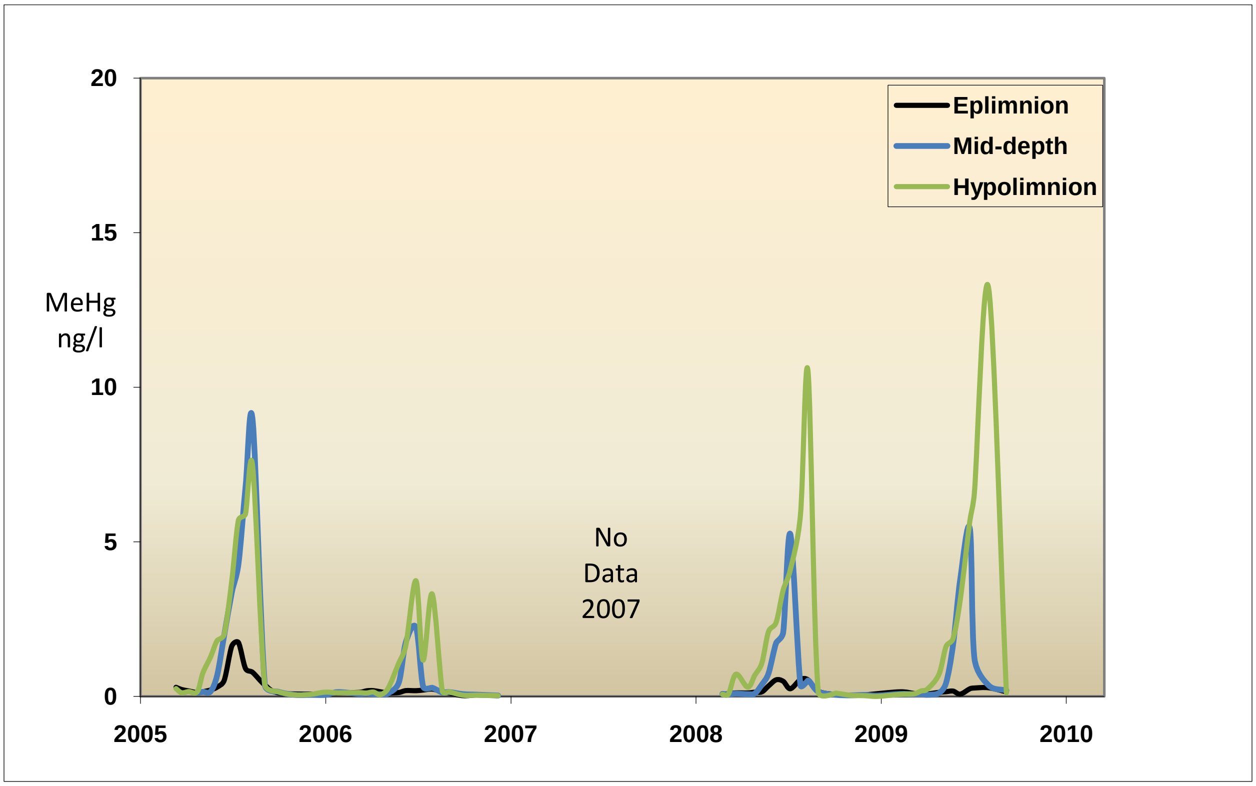


Figure 18: Seasonal Unfiltered Methyl Mercury (MeHg) Concentrations in Calero Reservoir

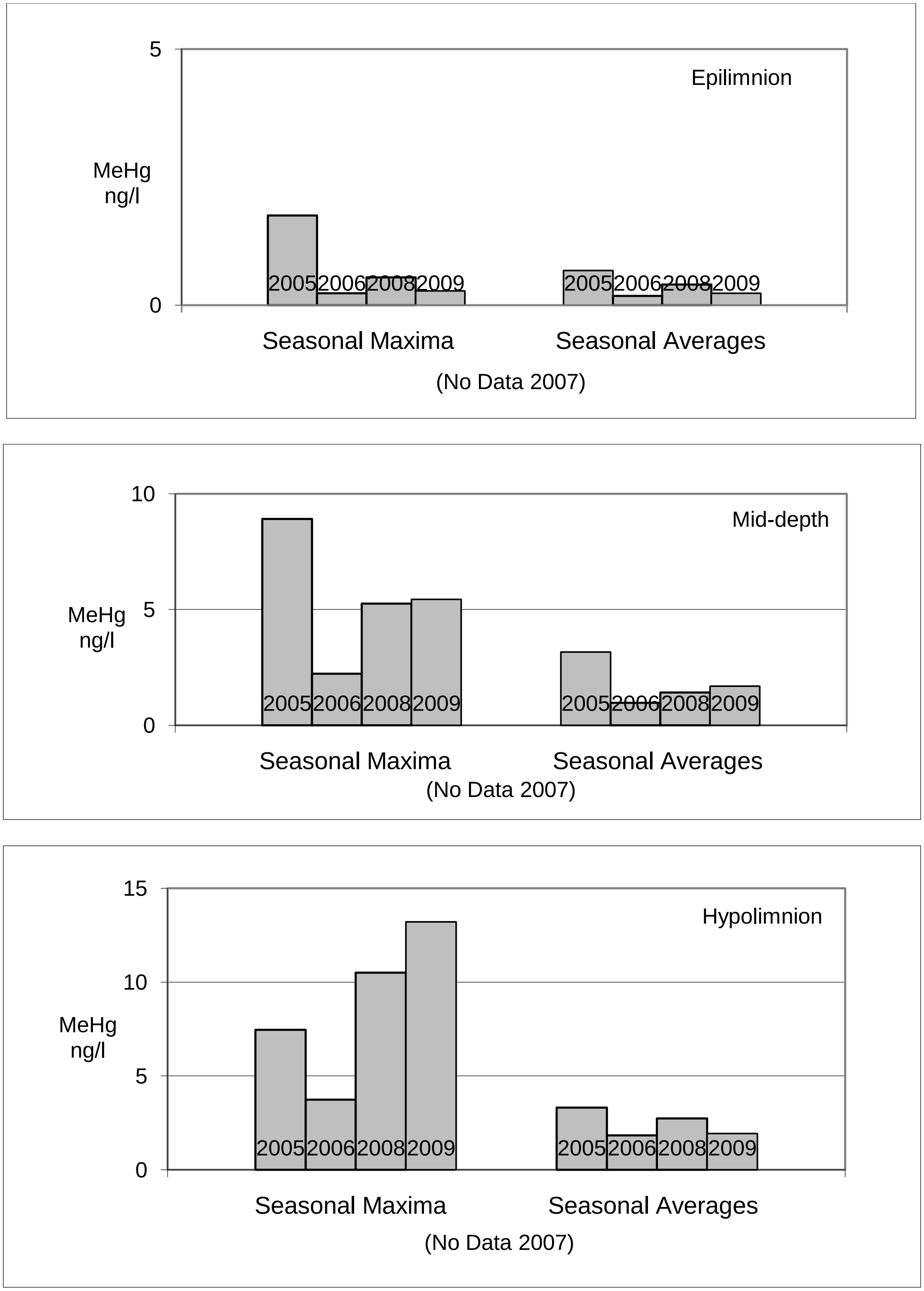


Figure 19: Seasonal Maxima and Average Unfiltered Methyl Mercury (MeHg) Concentrations in Calero Reservoir

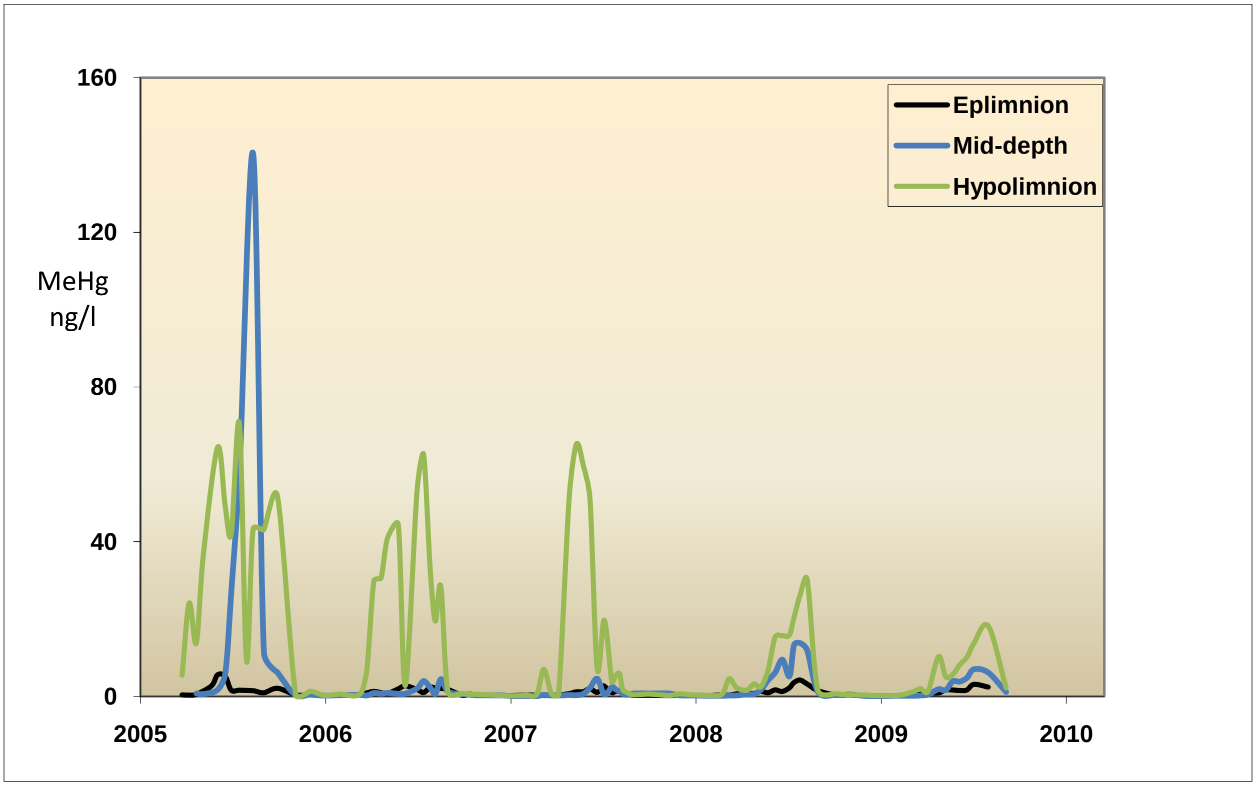


Figure 20: Seasonal Unfiltered Methyl Mercury (MeHg) Concentrations in Lake Almaden (Site 1)

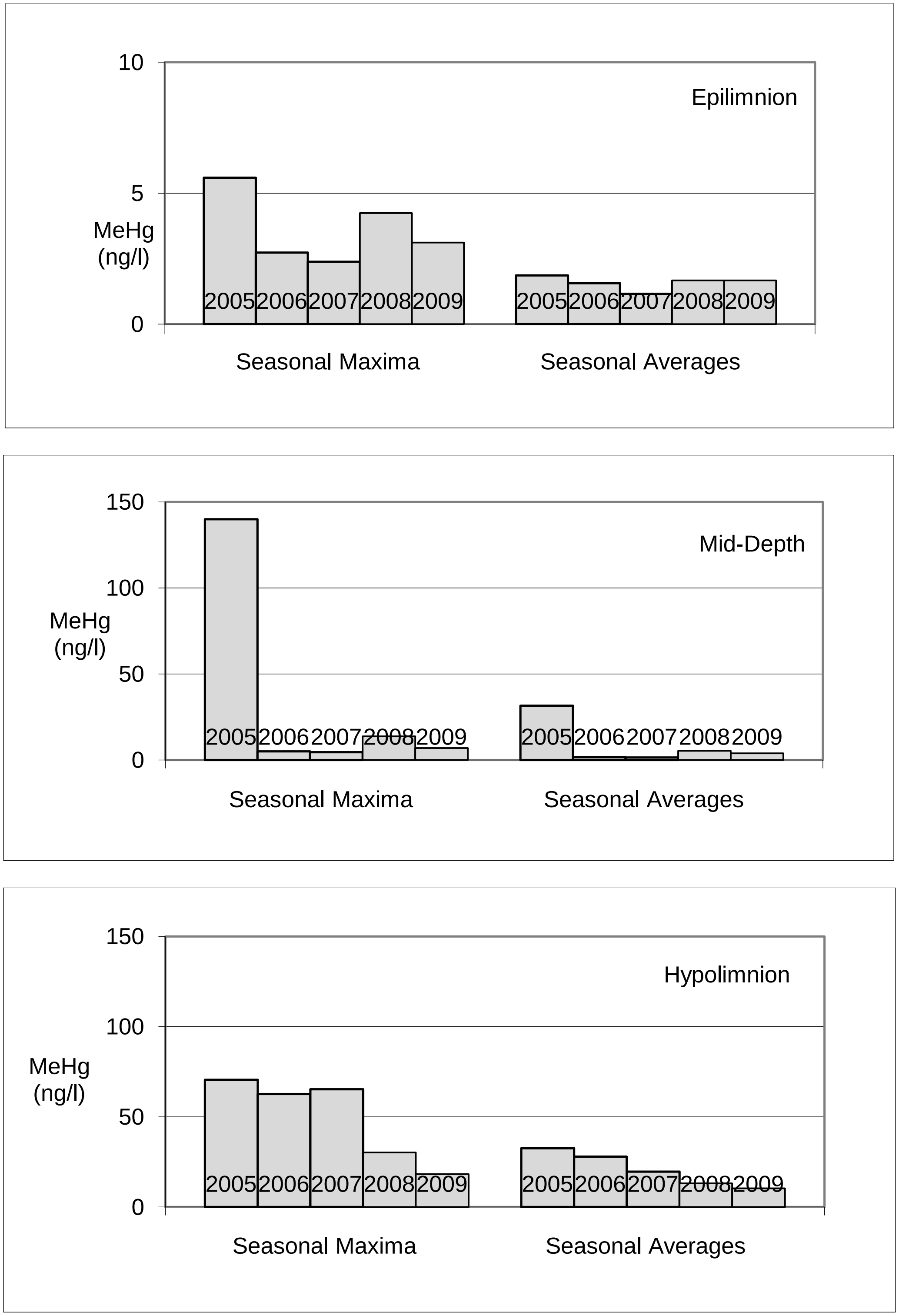


Figure 21: Seasonal Maxima and Average Unfiltered Methyl Mercury (MeHg) Concentrations in Lake Almaden (Site 1)

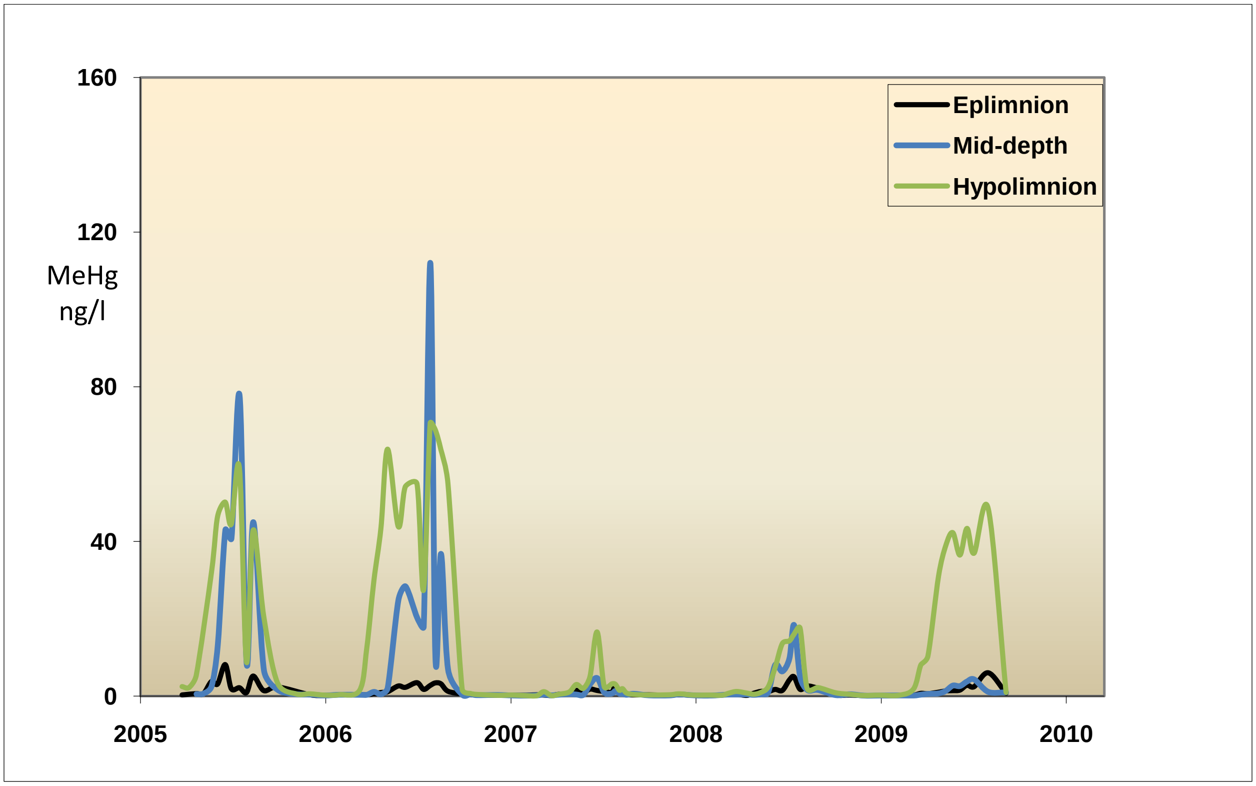
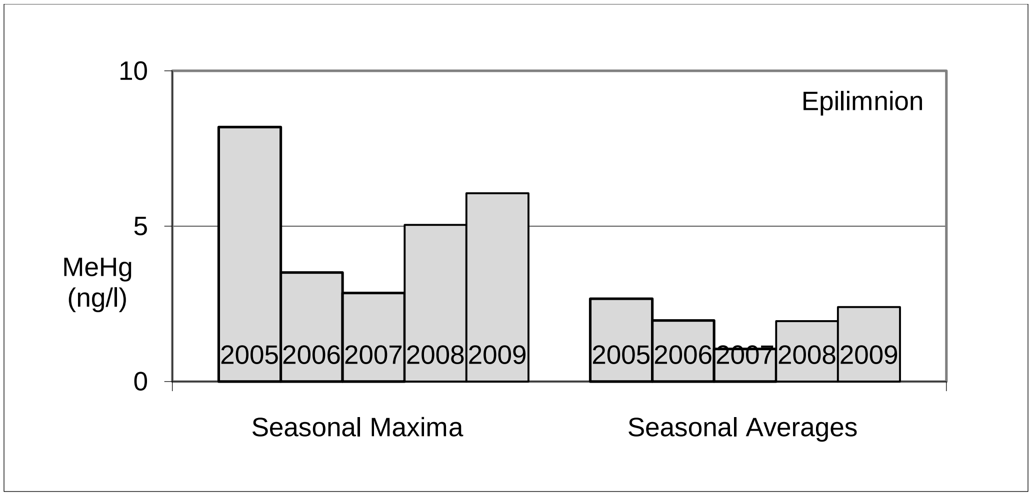
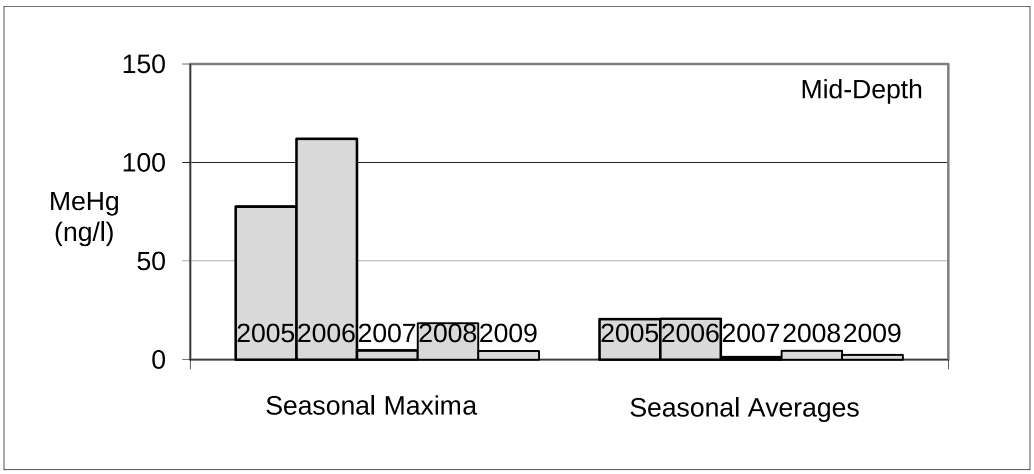


Figure 22: Seasonal Unfiltered Methyl Mercury (MeHg) Concentrations in Lake Almaden (Site 2)





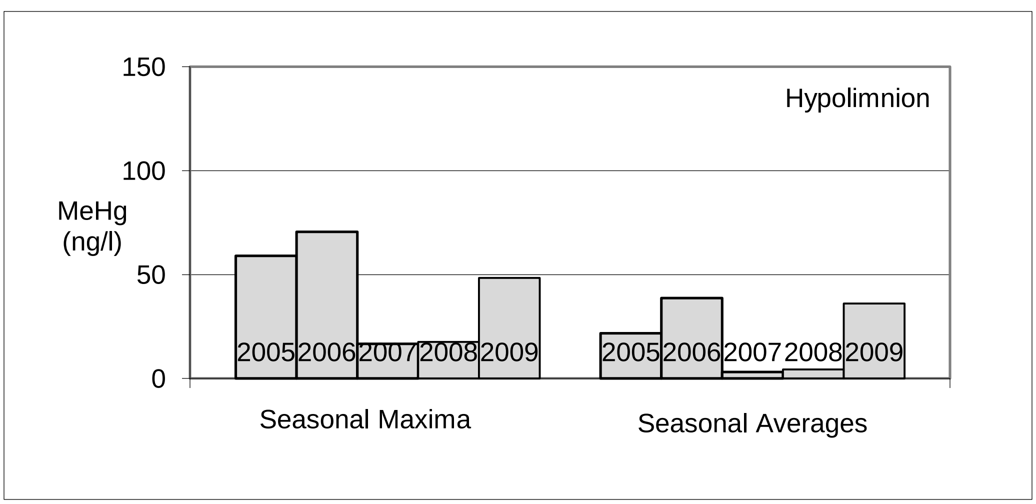


Figure 23: Seasonal Maxima and Average Unfiltered Methyl Mercury (MeHg) Concentrations in Lake Almaden (Site 2)

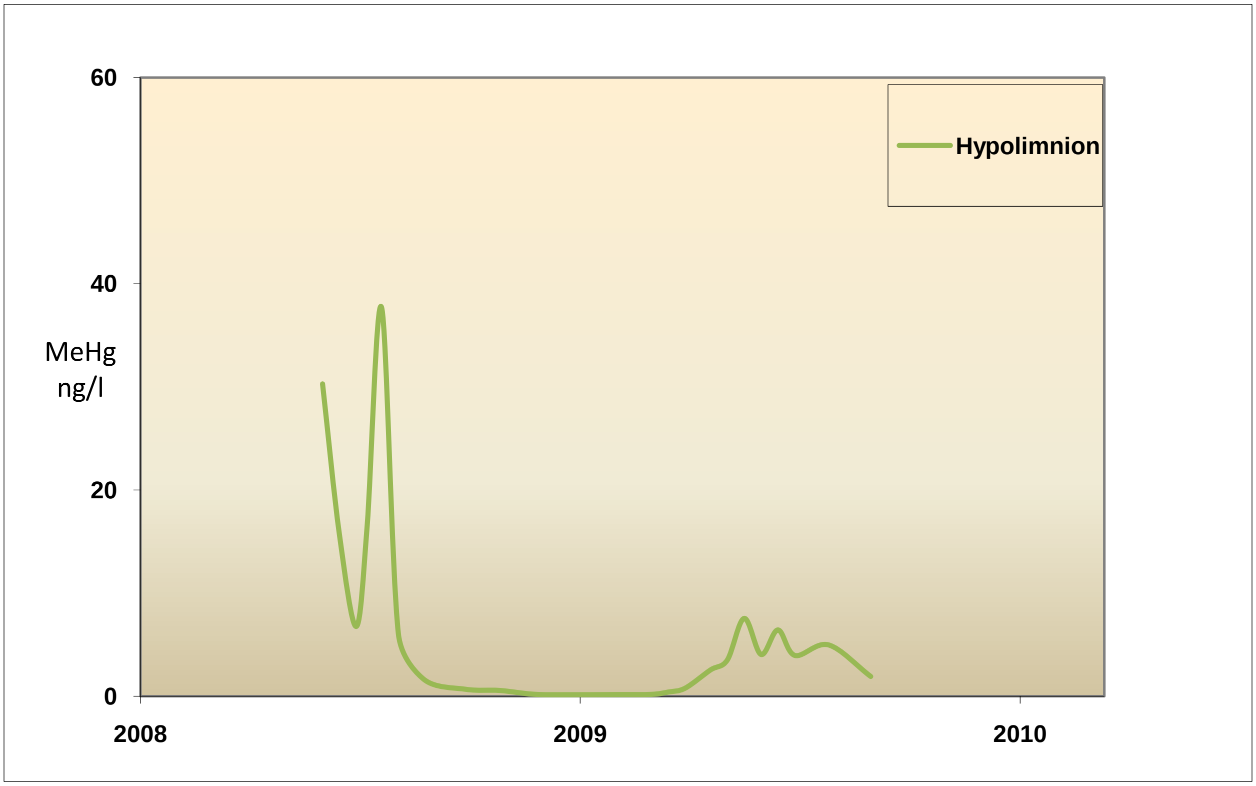


Figure 24: Seasonal Unfiltered Methyl Mercury (MeHg) Concentrations in Lake Almaden (Site 5)

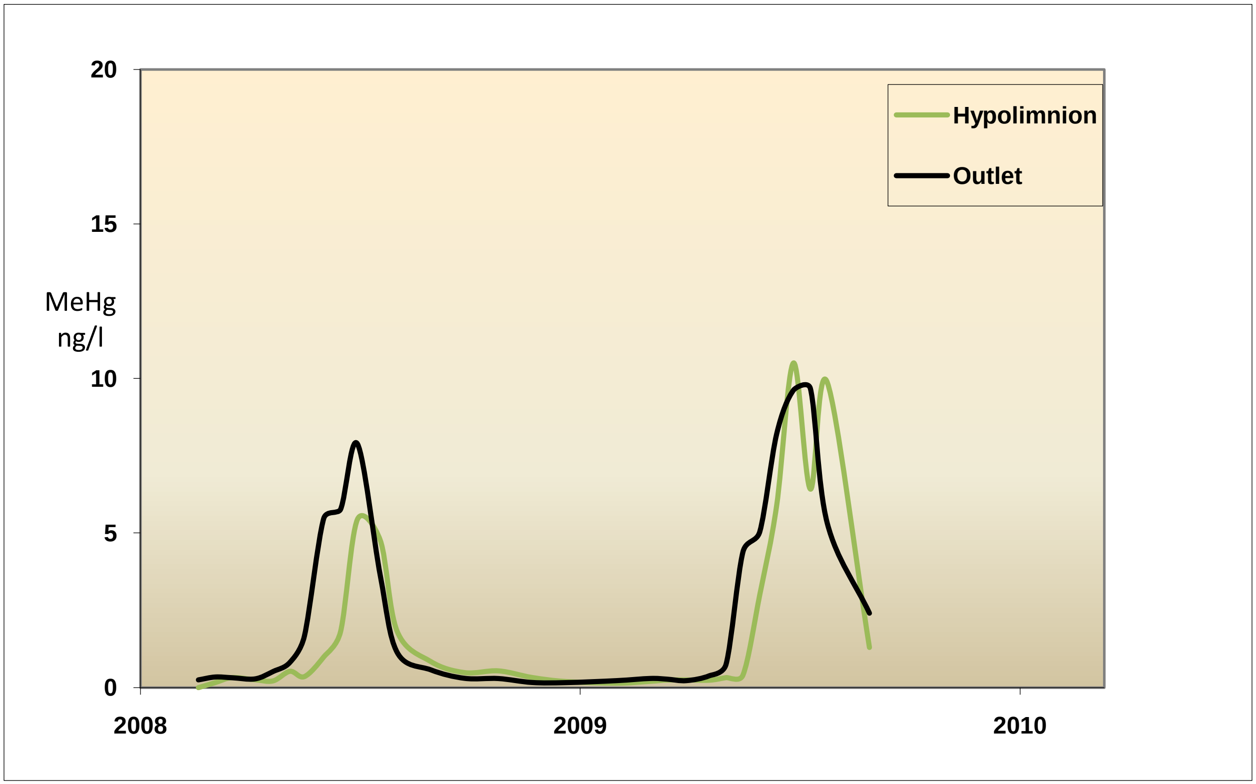


Figure 25: Comparison of Hypolimnion and Outlet Unfiltered Methyl Mercury (MeHg) Concentrations in Almaden Reservoir

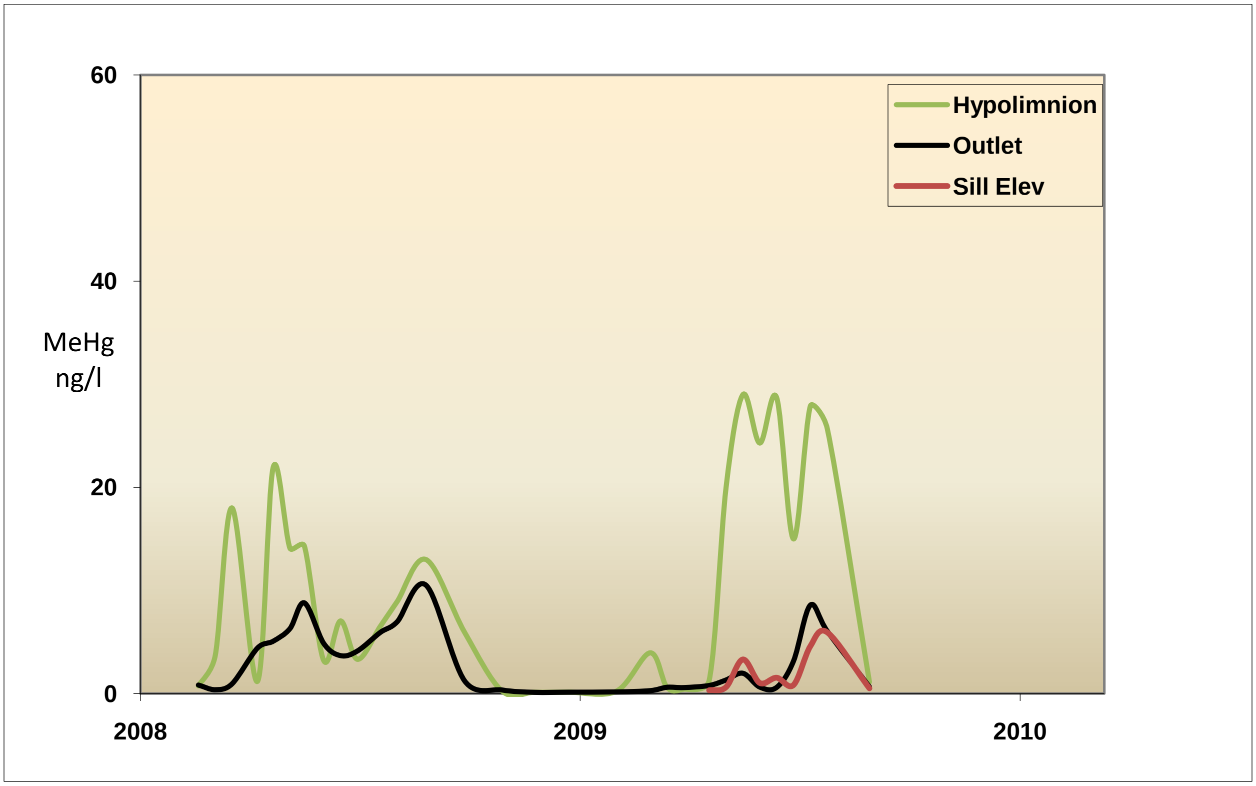


Figure 26: Comparison of Hypolimnion, Sill Elevation, and Outlet Unfiltered Methyl Mercury (MeHg) Concentrations in Guadalupe Reservoir

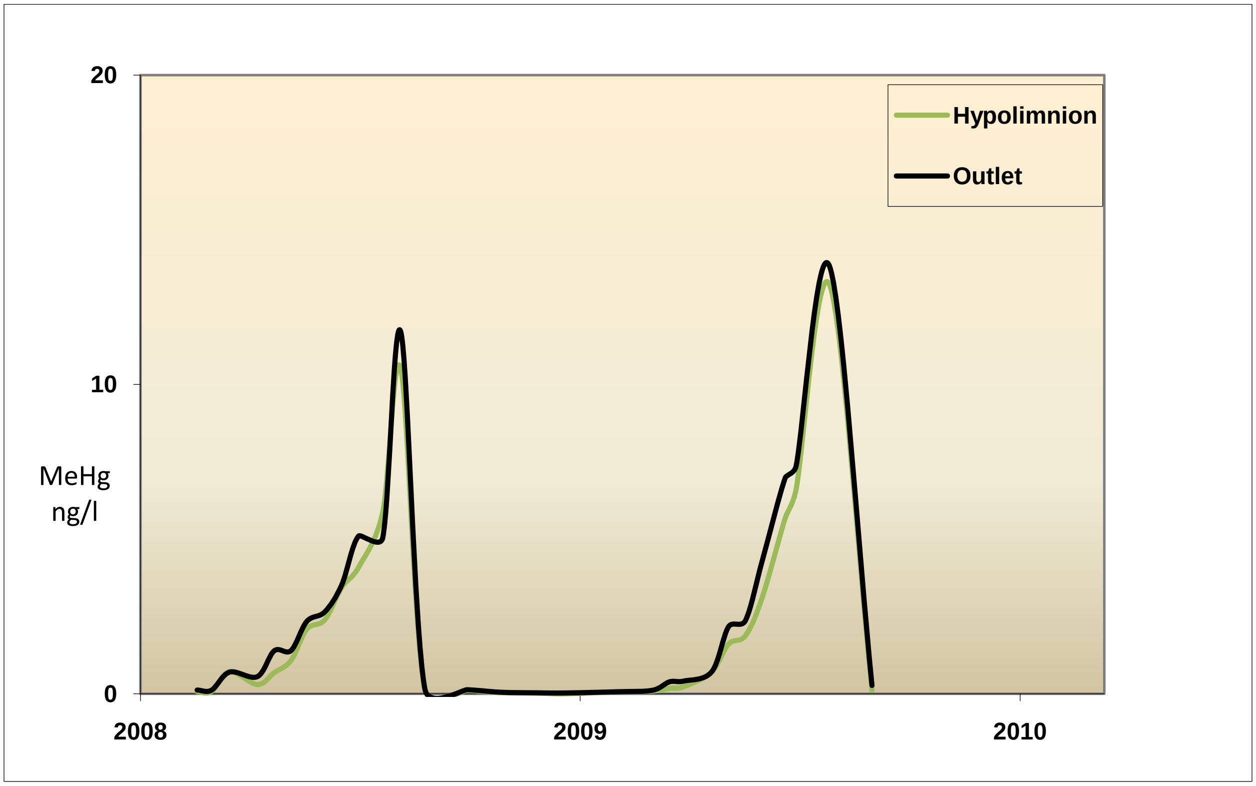


Figure 27: Comparison of Hypolimnion and Outlet Unfiltered Methyl Mercury (MeHg) Concentrations in Calero Reservoir

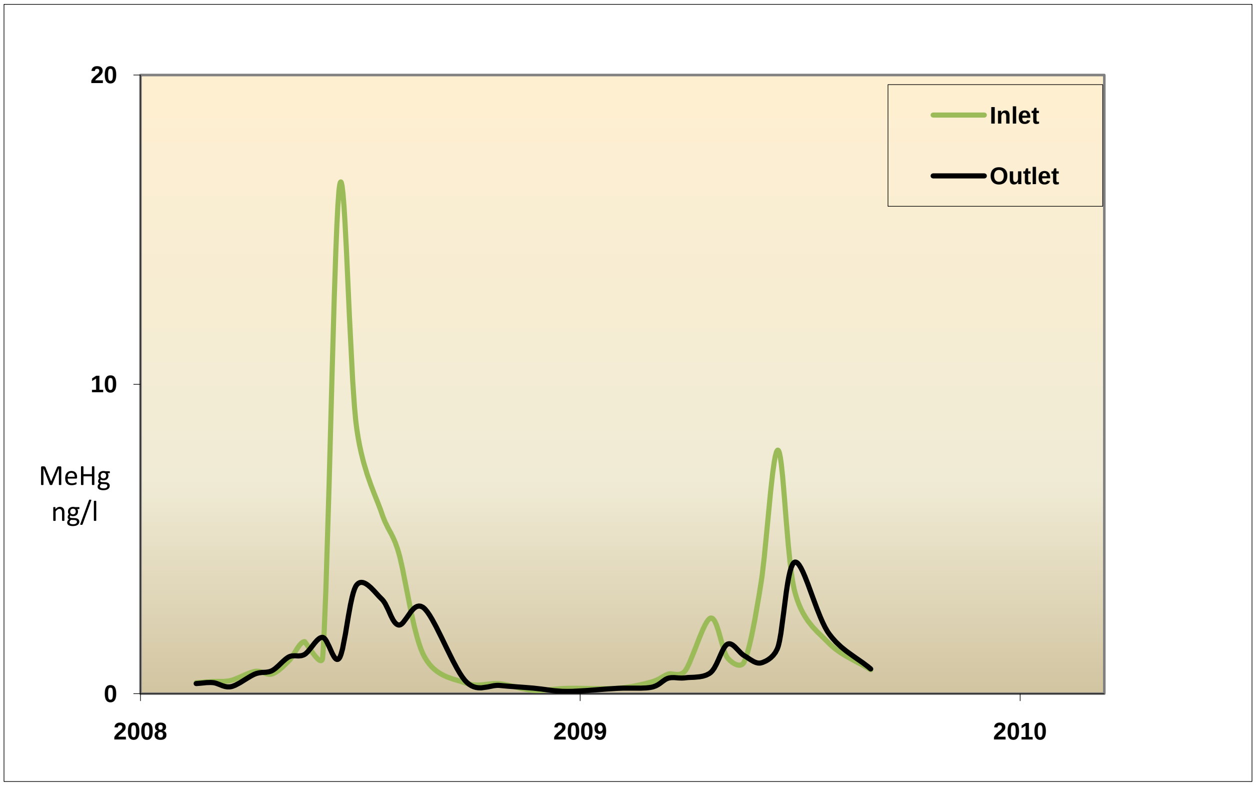


Figure 28: Comparison of Inlet and Outlet Unfiltered Methyl Mercury (MeHg) Concentrations in Lake Almaden

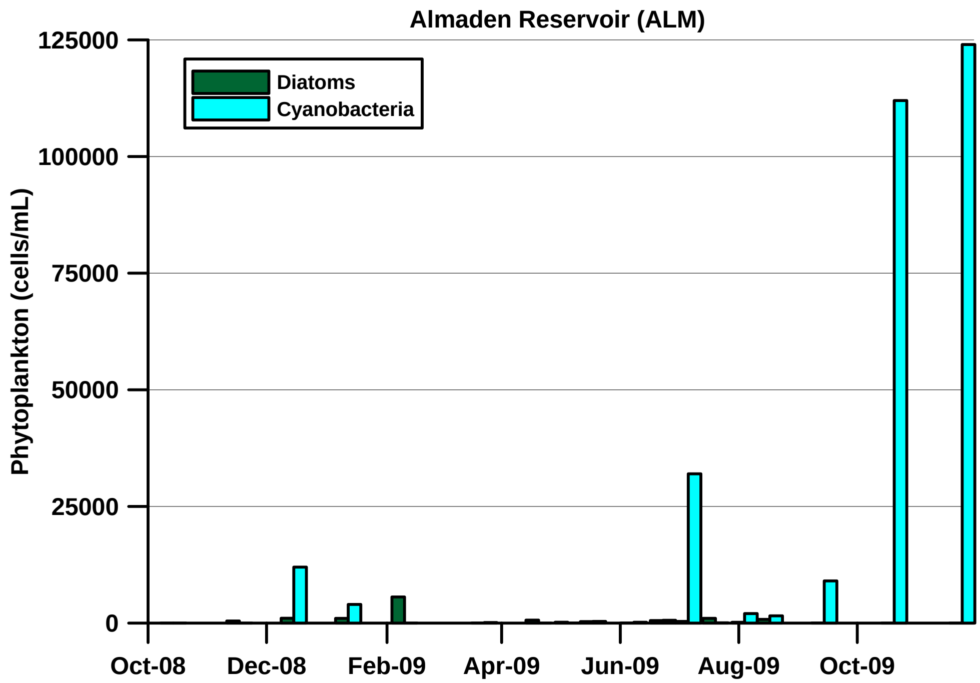


Figure 29. Density of Diatoms and Cyanobacteria in Almaden Reservoir.

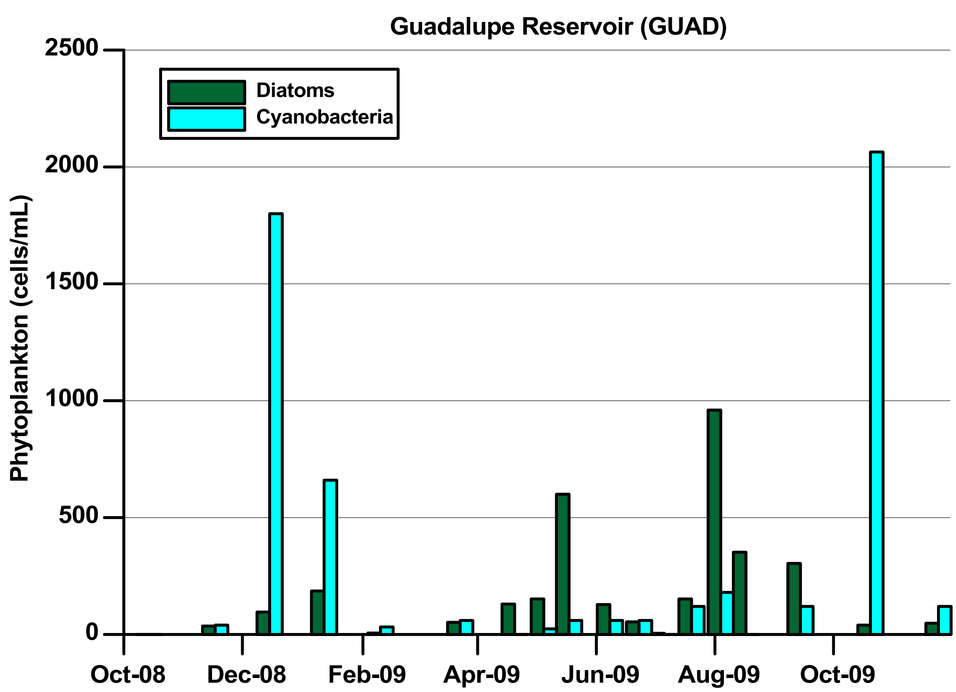


Figure 30. Density of Diatoms and Cyanobacteria in Guadalupe Reservoir.

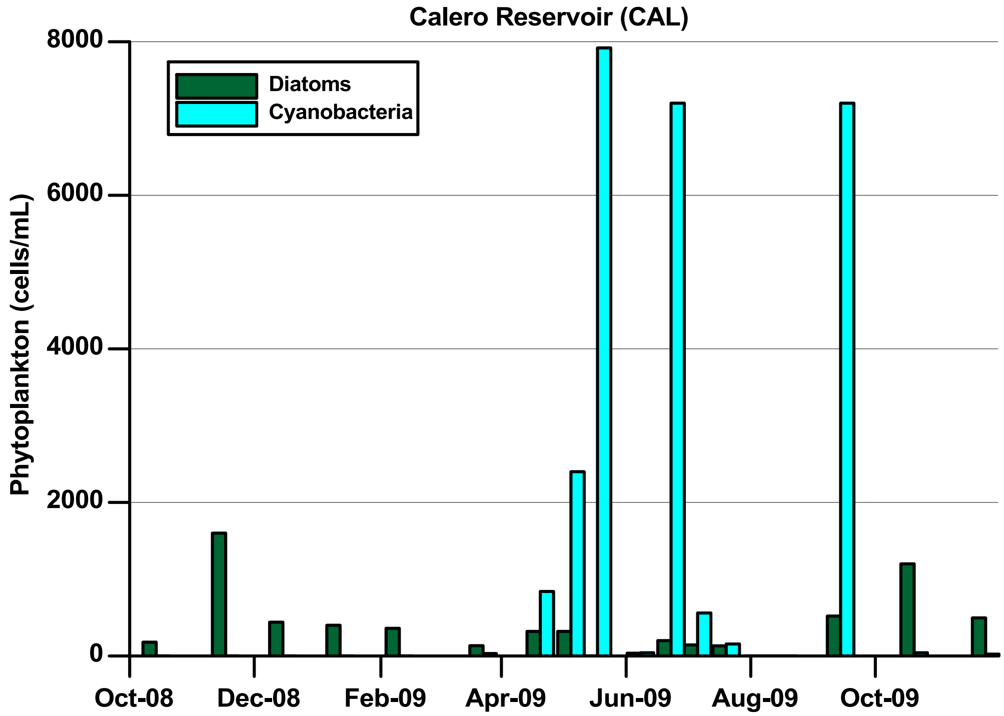


Figure 31. Density of Diatoms and Cyanobacteria in Calero Reservoir.

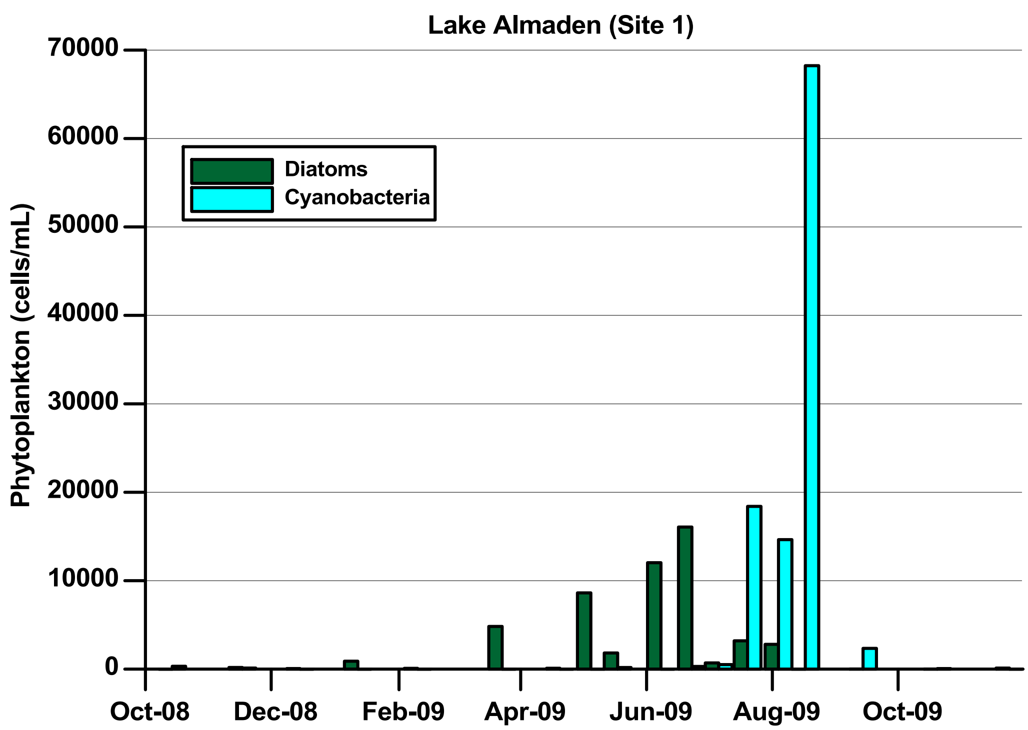


Figure 32. Density of Diatoms and Cyanobacteria in Lake Almaden (Site 1).

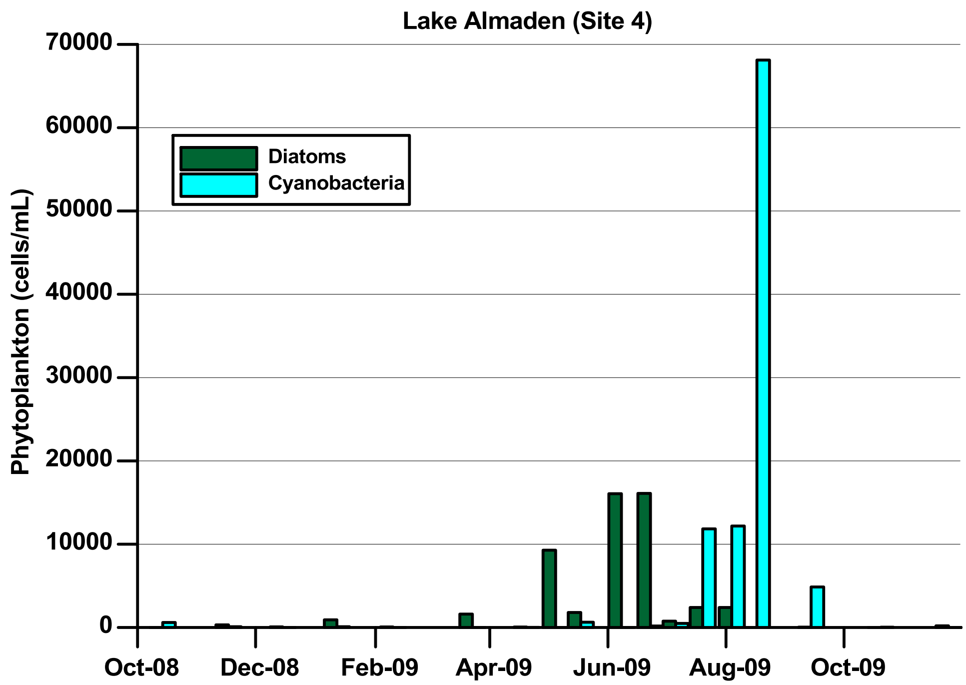


Figure 33. Density of Diatoms and Cyanobacteria in Lake Almaden (4).

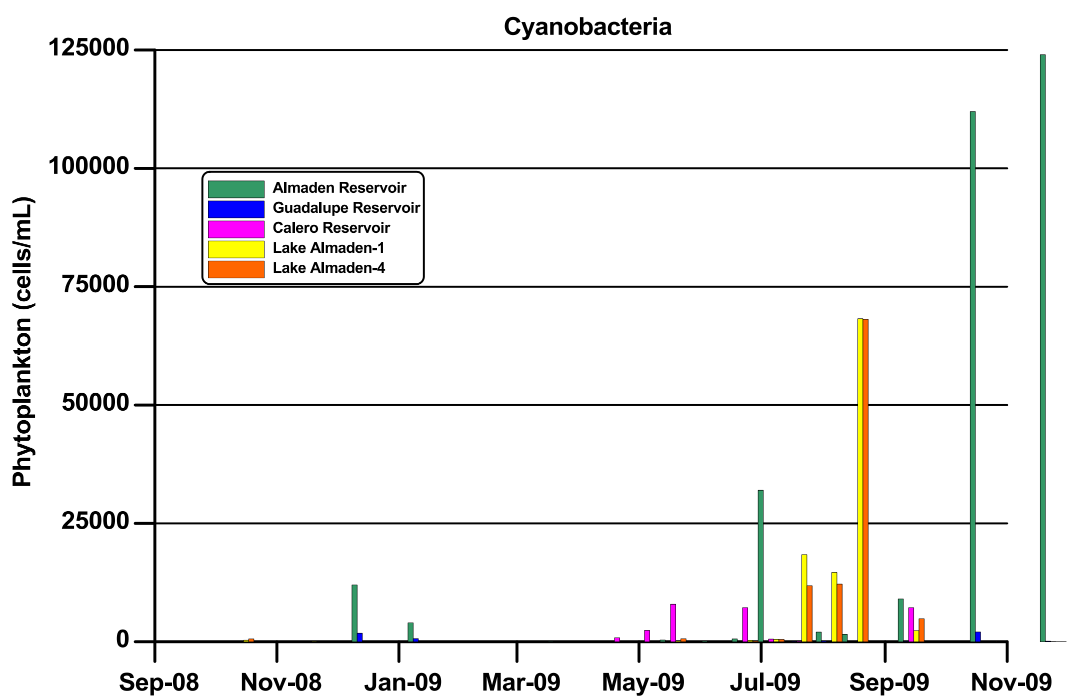


Figure 34. Density of Cyanobacteria in the four District water bodies.

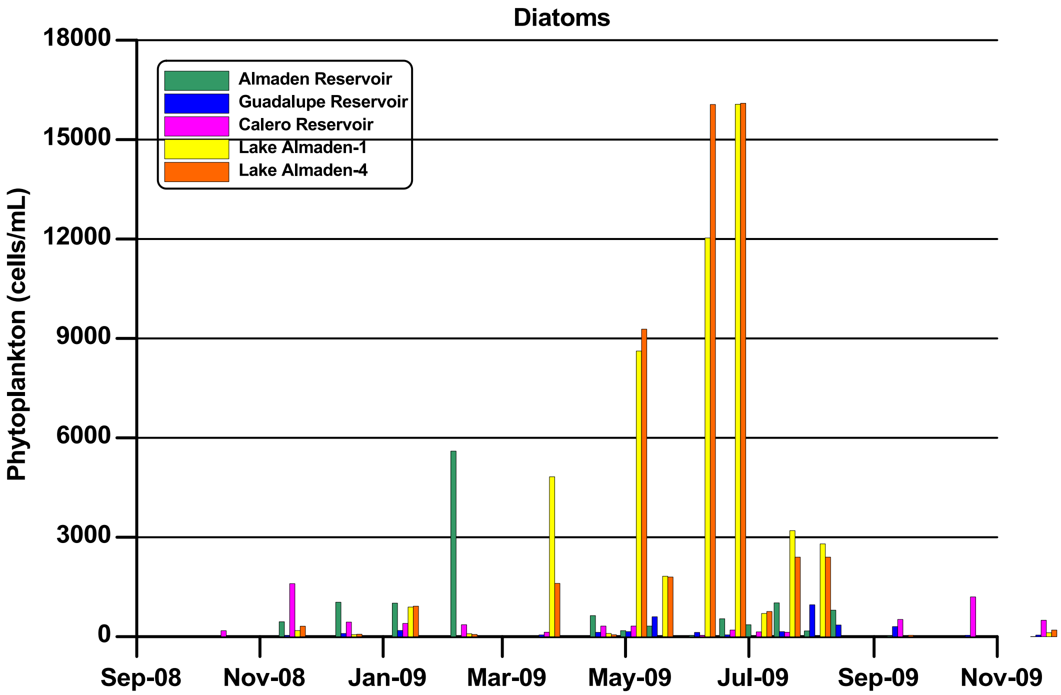


Figure 35. Density of Diatoms in the four District water bodies.

APPENDIX B

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