Guadalupe River Watershed Mercury TMDL: 2020-2021 Progress Report on Methylmercury Control Measures in Reservoirs

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Watershed Stewardship and Planning Division

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1 Executive Summary

The Guadalupe River Watershed in Santa Clara County, California is contaminated by Hg from the former New Almaden Mining District: North America's oldest and most productive mercury (Hg) mine. In reservoirs and lakes that experience seasonal hypoxia, Hg can be microbially converted to bioavailable methylmercury (MeHg). MeHg is a potent neurotoxin that biomagnifies in the food chain and presents significant health risks to humans and piscivorous birds. The San Francisco Bay Regional Water Quality Control Board (Regional Board) adopted an amendment to the Water Quality Control Plan for the San Francisco Bay Basin (Basin Plan) to establish contaminant load allocations and implementation plans for mine and reservoir owners in the watershed with the creation of the Guadalupe River Watershed Hg Total Maximum Daily Load (TMDL).

In accordance with the implementation actions set forth by the TMDL, Valley Water operates remediation systems in Hg-impaired reservoirs affected by the TMDL and completes studies evaluating the effectiveness of these control measures. Valley Water has installed treatment systems in Almaden Reservoir, Calero Reservoir, Guadalupe Reservoir, and Almaden Lake, as well as Stevens Creek Reservoir, which is located outside of the Guadalupe River Watershed and serves as an additional reference site. The treatment systems aim to decrease fish Hg in the reservoirs by suppressing anoxic conditions that facilitate bacterial conversion of Hg to MeHg.

This report provides updates on Valley Water’s Hg control studies, including an evaluation of the effectiveness of the treatment systems in decreasing MeHg in water and fish, and estimates of Hg and MeHg loads released from reservoir outlets. Valley Water staff collected water quality profiles and grab samples of Hg and other analytes from treated water bodies throughout the reporting period as COVID-19 safety restrictions allowed. Water quality data were evaluated by comparing dry season measurements taken prior to and during treatment system operation. Measured Hg and MeHg concentrations were used to estimate downstream loads by integrating measured concentrations with reservoir outlet gauge data. Fish monitoring occurred in summer 2021, but due to exceptionally low water levels, Calero was the only reservoir where an electrofishing boat could be used. In all other reservoirs, fish were instead captured using hook-and-line methods. Fish samples were used to track trends in fish tissue Hg concentrations in years following treatment system installation.

The four solar circulators in Almaden Lake were ineffective at improving dissolved oxygen saturation in bottom water. Though the circulators caused exchange between surface and bottom waters, they did not destratify the water column in their immediate vicinity or the lake at large. In general, the hypolimnetic oxygenation systems (HOSs) in the reservoirs effectively oxygenated the sediment-water interface. In Almaden, Guadalupe, and Stevens Creek reservoirs, high dissolved oxygen concentrations propagated throughout the hypolimnion, maintaining oxic sediment-water interfaces throughout the reservoirs. Calero Reservoir’s hypolimnion, however, commonly remained hypoxic during oxygenation. This is likely due to the system at Calero Reservoir being undersized to meet the total oxygen demand.

The HOSs caused vertical advection that degraded water quality in the reservoirs. Despite increasing oxygen concentration, oxidation-reduction potential decreased significantly in the surface waters of all reservoirs during oxygenation. This is likely due to the rising bubble plumes transporting reduced profundal compounds to the reservoir surface. These compounds stimulated algal blooms upon transport to the photic zone as evidenced by significant increases in chlorophyll *α* and phycocyanin in surface waters of each reservoir during oxygenation. Mixing also degraded water quality by increasing bottom water temperatures, which increased the temperature of outlet releases. Though MeHg concentrations decreased significantly in bottom waters of all reservoirs during oxygenation, it is likely that the observed decreases were due to dilution throughout the water column caused by vertical transport as opposed to inhibition of MeHg production

With the inclusion of summer 2021 fish tissue data, there were significant trends in fish Hg in all reservoirs. Declining trends were meaningful in Almaden, Guadalupe, and Stevens Creek reservoirs. Average Hg concentrations in 100 mm length-standardized largemouth bass decreased by about 46% in Almaden Reservoir, 45% in Guadalupe Reservoir, and 68% in Stevens Creek Reservoir since the beginning of HOS operation. The fact that declining trends persisted in Guadalupe and Stevens Creek reservoirs despite nonoperation of the HOSs in 2021 suggests that fish Hg trends were dependent on other factors than HOS, such as source control or primary productivity. In Calero Reservoir, there was a statistically significant increasing trend in fish Hg that is too slight to be practically meaningful.

Loads of Hg and MeHg released from reservoir outlets were relatively low in the reporting period due to low reservoir outflow volumes. While mixing MeHg throughout the water column may increase MeHg available for biological uptake, mixing decreases the MeHg load discharged downstream. Without HOS operation, flow weighted mean MeHg concentrations in Guadalupe and Stevens Creek reservoirs were notably higher in 2021 than in recent years. Flow-weighted mean MeHg concentrations were highest during the dry season when MeHg production peaked.

The findings described above, along with significant operational and maintenance challenges, have highlighted the questionable effectiveness of line-diffuser HOSs as a Hg management strategy in bottom-release reservoirs. Valley Water recommends the following possible modifications for implementation of the Guadalupe River Watershed Hg TMDL during the 2022-2023 reporting period:

Adaptive Management of Treatment Systems

- Halt use of solar circulators in Almaden Lake
- Conduct engineering calculations to determine if HOS operation can be optimized to meet creek temperature targets.

- Halt HOS operation if unacceptable hypolimnetic water temperature increase cannot be avoided during HOS operation.

Decrease Sampling Frequency

- Decrease reservoir water sampling to monthly.
- Decrease Almaden Lake water sampling to quarterly.
- Decrease fish Hg sampling to once annually, unless water levels permit access by electrofishing boat.

Re-allocate Funding to Additional Studies

- Study local atmospheric deposition of Hg in the New Almaden Mining District.
- Study sorbent treatment methods as an alternative to HOS operation in Guadalupe Reservoir.

2 Introduction

The Guadalupe River Watershed in Santa Clara County, California is contaminated by Hg from the former New Almaden Mining District: North America's oldest and most productive mercury (Hg) mine. Though active mining ended by 1970, waste material and contaminated sediments persist as sources of Hg to the watershed, causing elevated Hg concentrations in fish to this day. Fish Hg concentrations that exceed the United States Environmental Protection Agency (EPA) criteria for protection of human health have been measured in numerous creeks and reservoirs in the Guadalupe River Watershed.

Figure 1: Guadalupe Watershed Location

The Santa Clara Valley Water District (Valley Water) manages four water bodies affected by historical mining operations in the Guadalupe River Watershed: Almaden, Calero, and Guadalupe reservoirs, and Almaden Lake. Almaden, Calero, and Guadalupe reservoirs were constructed in the 1930s for water conservation and are located within the upper Guadalupe River Watershed, which drains to the San Francisco Bay (Figure 1). Hg-laden sediments and waste material from the New Almaden Mining District affect Almaden and Guadalupe reservoirs directly, and Calero Reservoir receives Hg atmospherically and through water transfers from Almaden Reservoir via the Almaden-Calero Canal. Almaden Lake is the flooded remnant of an in- and off-stream gravel quarry that operated between 1950 and 1960. The lake is fed by Alamitos Creek, which receives discharge from Almaden and Calero reservoirs. The Almaden Lake outlet is located 100 meters upstream of Alamitos Creek's confluence with Guadalupe Creek, which receives discharge from Guadalupe Reservoir. The confluence of Alamitos and Guadalupe creeks forms the main stem of the Guadalupe River, which flows to the southern San Francisco Bay (Figure 2). Valley Water also manages Stevens Creek Reservoir, which does not have a mining Hg source, but is nonetheless listed as impaired due to elevated Hg in fish. Stevens Creek Reservoir serves as a reference site to account for variations in Hg source.

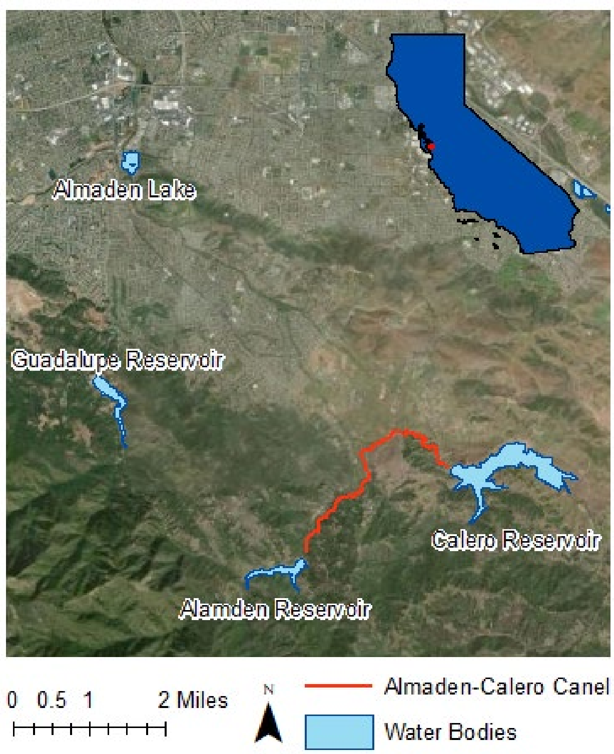

Figure 2: Guadalupe Watershed hydrologic connectivity

In 1999, Almaden, Calero, Guadalupe, and Stevens Creek reservoirs and Almaden Lake were included on the U.S. Environmental Protection Agency's Clean Water Act 303(d) list as impaired for Hg. In response, in 2008, the San Francisco Bay Regional Water Quality Control Board (Regional Board) adopted an amendment to the Water Quality Control Plan for the San Francisco Bay Basin, establishing contaminant allocations and implementation plans for mine and reservoir owners in the Guadalupe River watershed. In keeping with the Guadalupe River Watershed Hg Total Maximum Daily Load (TMDL), Valley Water conducts and reports on the technical studies included herein. This report addresses the following questions posed in Section 9.10 of the TMDL Staff Report:

"Is it possible to increase the assimilative capacity for methylmercury in reservoirs and lakes? Is it feasible to do so? If it is feasible, does it result in attaining fish tissue targets?"

A portion of this report evaluates the effectiveness of treatment systems in the reservoirs and Almaden Lake that intend to curtail the production of methylmercury (MeHg) by discouraging the establishment of seasonal hypoxia in the hypolimnion. Valley Water also documents fish populations in the study reservoirs to assess changes in fish assemblages over time that may affect Hg bioaccumulation. Select fish are analyzed for tissue Hg concentration to determine progress toward attaining fish tissue objectives. This progress report from Valley Water encompasses the 2020-2021 reporting period of October 1, 2019 through September 30, 2021. It includes a description of program implementation actions during the reporting period, treatment system evaluation, and reports Hg loading at discharge points.

3 Treatment Systems

3.1 Treatment System Descriptions

The Hg treatment systems described in this section are intended to curtail the production of MeHg by discouraging the establishment of seasonal hypoxia in the hypolimnion of reservoirs and lakes. These systems may increase the assimilative capacity by suppressing anoxic conditions (through forced mixing or direct injection of oxygen) that facilitate bacterial conversion of Hg to MeHg. Records of treatment system operation began in 2016. Prior to 2016, dates associated with treatment system operation were inferred from patterns of dissolved oxygen saturation levels in the bottom waters as well as narrative records (Figure 3).

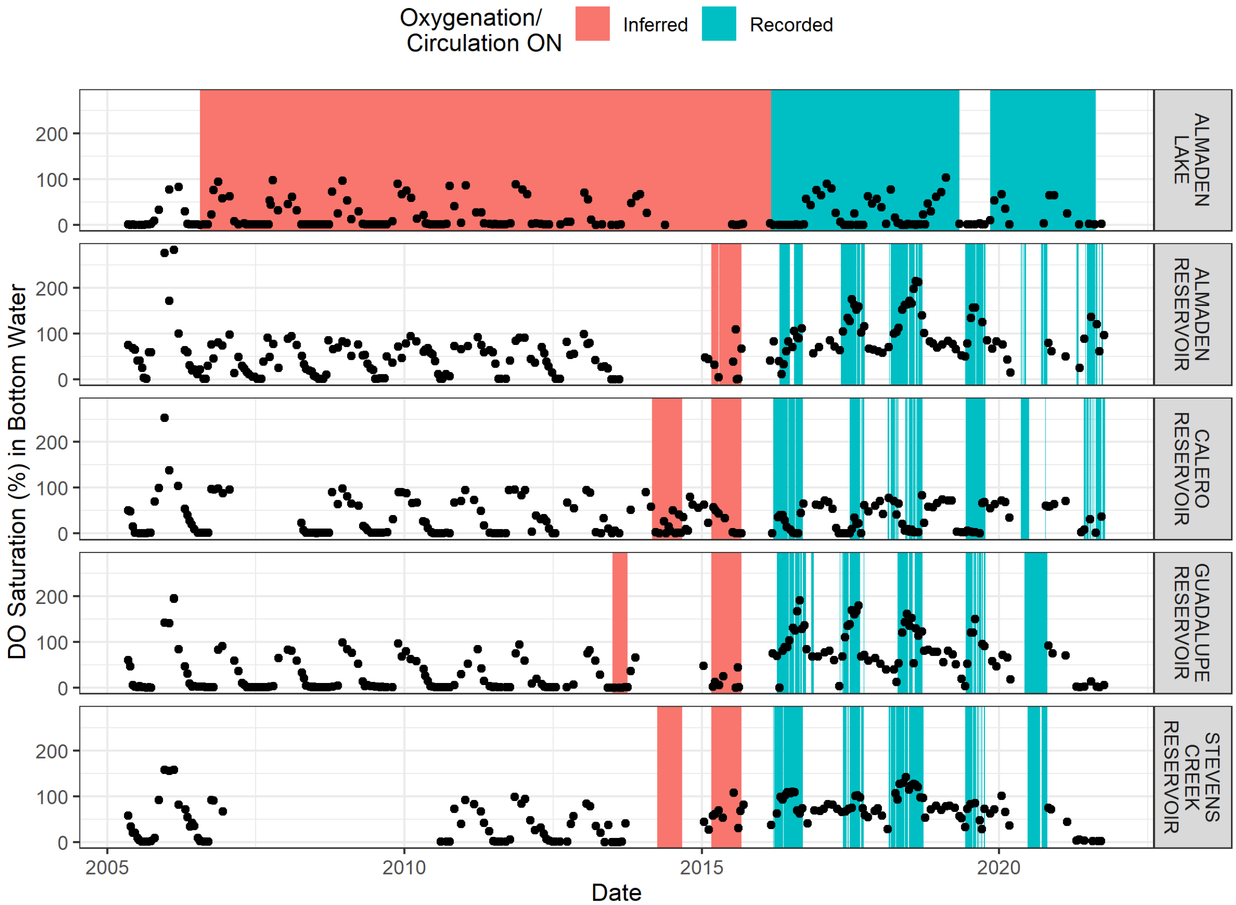

Figure 3: Hypolimnetic dissolved oxygen saturation in reservoirs and Almaden Lake.

Almaden Lake

Almaden Lake is equipped with four solar-powered hypolimnetic circulators. The first circulator was installed in 2006 at Site 1, a second circulator was installed in March 2007, and the remaining two circulators were installed in January 2009 (Figure A 1). These circulators are situated in the deepest portions of the lake, which were the main pits of the historic gravel quarry. The circulator intake at Site 1 was lowered deeper into the water column in 2007, after it was found to be ineffective as its position was too high above the lake bottom.

Almaden Reservoir

Three circulators were deployed in Almaden Reservoir in April of 2007. Two epilimnetic circulators intended to decrease phytoplankton abundance and reduce loading of organic matter to the bottom of the reservoir, while one hypolimnetic circulator aimed to increase dissolved oxygen and suppress hypoxic conditions that facilitate the methylation of Hg. These systems were found to be ineffective in reducing MeHg production and were subsequently removed. In April of 2014, Valley Water installed a line-diffuser HOS in Almaden Reservoir. Since 2016, it has operated nearly continuously during periods of thermal stratification apart from short-term system shutdowns caused by system malfunctions.

Calero Reservoir

A line-diffuser HOS was installed in Calero Reservoir in November of 2011 and began operation in April of 2013. The system is operated nearly continuously during periods of thermal stratification apart from short-term system shutdowns caused by system malfunctions.

Guadalupe Reservoir

Three epilimnetic circulators were deployed in Guadalupe Reservoir in 2007. These proved ineffective at decreasing algal biomass and were subsequently removed. A line-diffuser HOS installed June 2013 was operated nearly continuously between 2016 and 2020 during periods of thermal stratification. In 2021, Valley Water suspended operation to preserve cold water pools and avoid impacts to water quality during low-storage conditions (described in section 3.3.2).

Stevens Creek Reservoir (Reference Site)

A line-diffuser HOS was installed in Stevens Creek Reservoir in 2013 and has operated nearly continuously between 2016 and 2020 during periods of thermal stratification. In 2021, Valley Water suspended operation to preserve cold water pools and avoid impacts to water quality during low-storage conditions (described in section 3.3.2).

3.2 Maintenance Activities

3.2.1 Routine Maintenance

To keep the reservoir HOSs operational, the air compressors and oxygen generators must be maintained regularly. Biannual maintenance of the oxygen generators was performed by Vanguard Global Solutions, who subcontracted maintenance of the air compressors to their manufacturer, Atlas Copco USA, as needed. Regular maintenance included system inspections, leak checks, filter replacements, and repairs if necessary. Routine maintenance of the oxygen generators was completed in February 2020, May/June 2020, April 2021, and June/July 2021.

Even when proactive and preventive maintenance was completed regularly, shutdowns and equipment failures were common. Ambient air temperatures at the four reservoirs regularly exceed 90 °F during summertime operations. The metal oxygenation trailers are poorly ventilated, retaining heat from the environment and the air compressors inside. As a result, the air compressors overheated frequently, sometimes requiring repair. Fluctuations in voltage of the power supply were common due to the remote locations of the reservoir. This caused periodic shutdowns, particularly of the two variable speed drive compressors that require a stable power source. On multiple occasions, circuit breakers needed to be replaced due to machinery overdraw or power surges. Additional shutdowns in summer 2020 occurred as a result of PG&E preventive shutdowns due to fire danger.

Biweekly (twice per week) inspections of the reservoir HOSs were necessary during operation to ensure consistent operation and restart systems when necessary. Mechanical failures delayed operations by weeks to months depending on the availability of parts and contractor service.

3.2.2 Diffuser Line Replacement

Mobley Engineering, Incorporated manufactured and installed the HOSs in Almaden, Calero, Guadalupe, and Stevens Creek reservoirs between 2011 and 2014. Diffuser lines and anchors must be replaced periodically to maintain proper function. If sections of diffuser line become detached from the impermeable supply line (e.g., by a boat anchor), it will create a plume of bubbles with lower oxygen transfer efficiency, resulting in less oxygen dissolved in the water. If anchors that keep the supply and diffuser lines on the reservoir bottom become detached, the lines may float to the surface during system operation.

The HOS lines were maintained in 2021 for the first time since installation. Major repairs were needed in Guadalupe and Calero reservoirs to return them to design specifications. The Guadalupe Reservoir HOS was creating bubble plumes, indicating sections of line had become detached. The HOS at Calero Reservoir had bubble plumes and anchor failures that caused the supply and diffuser lines to float to the surface during operation. The Calero Reservoir system had an anchor failure on October 14, 2020, which was, fortunately at the end of the season of operation. This needed to be repaired before the system could be operated again. Routine maintenance was also needed in Almaden and Stevens Creek reservoirs to ensure continued function.

In 2021, Valley Water engaged Mobley Engineering, Incorporated for repair and maintenance of the oxygenation lines. Mobley had originally designed, fabricated, and installed the lines. The scope of work included pre-repair inspection, replacing porous hose, replacing broken anchors, re-positioning the systems on the bottom as designed, and performing inspections following repair. Low water levels in Guadalupe and Stevens Creek reservoirs made access and maintenance activities impossible, so maintenance was only completed in Almaden and Calero reservoirs. This maintenance is detailed below.

Almaden Reservoir

Connections were made at the mobile compressor and oxygen trailer onshore to operate the diffusers and send air to the buoyancy lines. The longer diffuser (Diffuser 2) was raised first and secured with ropes at either end. The old diffuser hose was stripped and bagged, then new hose was unreeled and installed. No missing anchors or bad cables were found. Diffuser 2 was positioned in Almaden Reservoir with three GPS equipped units MEI work boats and water was pumped into the buoyancy line to sink the diffuser in position. The short diffuser (Diffuser 1) was raised next and secured with ropes. All old sections of hose were stripped, bagged, and replaced with new hose. Down ropes were set up from the corners of Diffuser 1's zigzag shape to the dam and to boats to hold the diffuser in position and checked with GPS before being sunk to the bottom. The final bubble pattern of both Almaden diffusers can be seen in Figure 4.

Figure 4: Almaden Reservoir bubble pattern following diffuser maintenance.

Calero Reservoir

Connections were made at the mobile compressor and oxygen trailer onshore to operate and send air to the buoyancy lines. Air was put to the buoyancy line and the diffuser was raised to the surface and secured to shore with ropes. The old hose was stripped and bagged before new hose was installed. Missing anchors were abundant on the Calero diffuser. Some of the old, original anchor cable and crimp combination were inadequate and failed frequently causing many anchors to go missing. All the anchor cables were inspected and replaced with the new stainless on stainless cables and crimps. All missing anchors were replaced with 65 lb. concrete block weights with eyebolts. The original diffuser position interferes with the buoy line that was positioned after the original diffuser deployment. The diffuser was repositioned closer to the dam to stay well inside the buoy line and prevent any entanglement issues. Depth finders and GPS were used to ensure the new diffuser position maintained design depth. Water was pumped into the buoyancy line and the diffuser sunk into its new position. Figure 5 shows the bubble pattern for the Calero diffuser.

Figure 5: Calero Reservoir bubble pattern following diffuser maintenance.

3.3 Logistical Challenges

3.3.1 COVID-19

The COVID-19 pandemic presented various logistical and operational challenges that interfered with planned operations and maintenance of the reservoir HOSs. On March 16, 2020, Santa Clara County issued a “shelter in place” order that directed government agencies to cease all non-essential operations at physical locations in the county. Government agencies were tasked with identifying essential functions and employees. Routine maintenance of the HOSs, which usually occurs prior to deployment in March/April, was delayed due to the order, but this work was permitted in May and June of 2020 as the contractor was able to perform the work alone. Delays in routine maintenance, however, caused delays in HOS deployment. The Almaden and Calero reservoir HOSs were deployed in May 2020, but the Guadalupe and Stevens Creek reservoir systems were not deployed until June 2020, when reservoir bottoms were likely already anoxic.

A Santa Clara County Health Office order released on July 2, 2020 permitted most government activities to resume, but were subject to specified restrictions, limitations, and conditions, including the use of face coverings, social distancing, and mandatory COVID case reporting. Nevertheless, maintenance activities were delayed in 2021 due to staffing and supply chain shortages caused by the ongoing pandemic. Routine maintenance of the HOSs occurred in April 2021. The Almaden Reservoir system was deployed immediately following maintenance but experienced a major mechanical failure in early May 2021. The oxygenation trailer was returned to Valley Water's corporation yard for repair and was redeployed on June 15, 2021. The Calero Reservoir system was deployed on June 3, 2021 following completion of line diffuser maintenance. The maintenance consultant identified various issues that needed to be fixed prior to deployment of the other two HOSs. This work was completed in June and July 2021.

3.3.2 Drought

The California drought has had profound effects on water supply, water quality, and reservoir operations. Water Year 2021 was one of the driest on record in California, with precipitation at about 50% of average statewide (DWR). Low water levels caused by drought affected the operation and maintenance of the reservoir HOSs and the required monitoring (Figure 6).

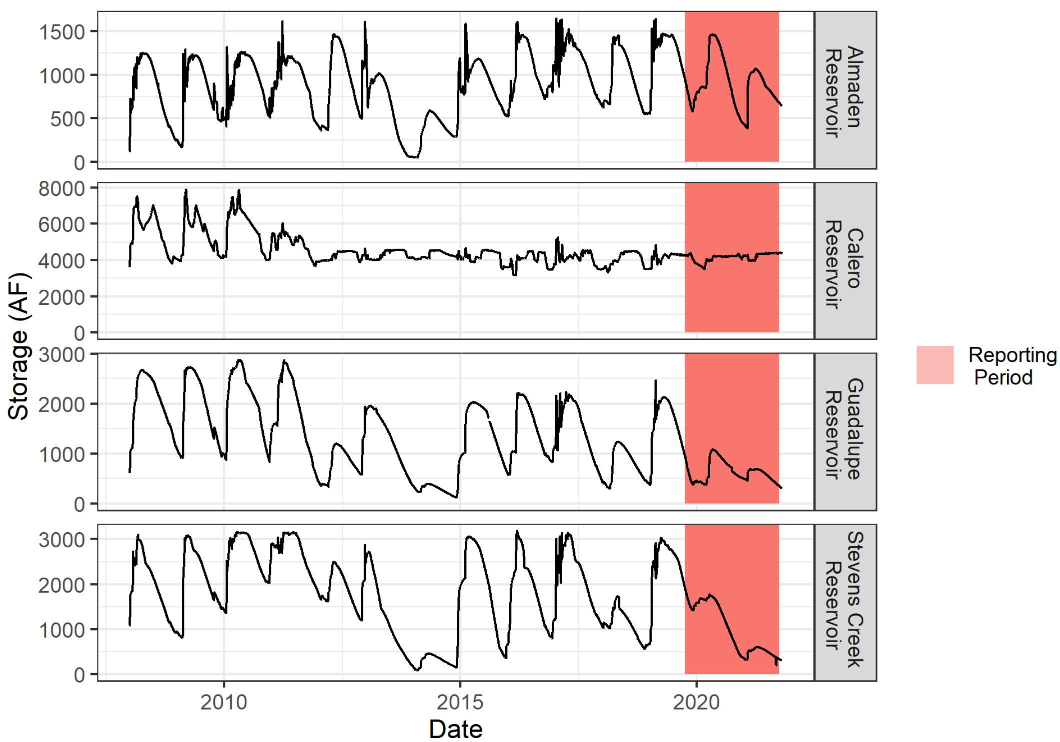

Figure 6: Reservoir storage (AF) over time.

Line diffuser maintenance was identified as high priority in Calero and Guadalupe reservoirs, but only occurred in Calero and Almaden reservoirs because low water levels prevented boat access to Guadalupe Reservoir. Low water levels also encumbered access to all reservoirs except Calero for water quality monitoring and fish sampling in 2021. Almaden, Guadalupe, and Stevens Creek reservoirs were not accessible by electrofisher boat, preventing fish assemblage monitoring, and water quality sampling required access by canoe. Canoe access increased the overall effort of monitoring and limited the number of reservoirs that could be sampled in one day.

Guadalupe and Stevens Creek Reservoirs were not oxygenated in 2021 due to low water levels and concerns about temperature and turbidity increases during system operation. Reservoir oxygenation and aeration are known to cause hypolimnetic mixing and increase water temperature (Gantzer et al., 2009; Niemistö et al., 2020; Toffolon & Serafini, 2013). In our study reservoirs, we noted temperature increases in bottom water during oxygenation of 2.5 to 5.5 °C above pre-oxygenation values (Seelos et al., 2021). We also noted a 40% average increase in turbidity in Stevens Creek Reservoir outflow during oxygenation (Seelos et al., 2021).Thus, reservoir oxygenation has the potential to degrade the quality of reservoir outflow with respect to the needs of downstream fish. These effects are expected to be exacerbated during low water levels, as hypolimnetic mixing could cause even greater temperature increases and sediment mobilization.

Valley Water seeks to improve aquatic spawning and rearing habitat and fish passage for migration to and from the watersheds of the Coyote and Stevens Creeks and Guadalupe River. In accordance with its Fisheries and Aquatic Habitat Settlement Agreement (FAHCE), Valley Water maintains cold water management zones (CWMZs) downstream of Guadalupe and Stevens Creek reservoirs to provide over-summer refugia for steelhead trout. Rule curves dictating reservoir releases are designed to maximize the extent of the CWMZs from April 30 through October 31. Instream temperature targets are set at 14 °C for Guadalupe Reservoir and 15 °C for Stevens Creek Reservoir.

In Water Year 2021, significant cold-water pools (hypolimnion temperature < temperature targets) existed in Stevens Creek Reservoir until June, and in Guadalupe Reservoir until August. To maximize water quality and fish habitat in the CWMZs, Valley Water decided to forgo reservoir oxygenation in Guadalupe and Stevens Creek reservoirs in summer 2021. Valley Water may make similar decisions in the future to provide acceptable conditions for downstream fish. The reservoir HOSs have notable effects on downstream water quality that are worthy of consideration.

3.3.3 Cost and Energy Consumption

From 2016 to 2019, when the operation of the HOSs was most consistent, the four systems consumed an average of about 540,000 kW h per year, totaling nearly $86,000 annually (Table 1). This annual energy consumption is equal to approximately 50 single family homes (United States Energy Information Administration). Not only could these high energy costs be prohibitive for some reservoir owners, but excessive energy usage from non-renewable sources exacerbates anthropogenic climate change. Industrial production of liquid oxygen is also an energy intensive process. Cost-benefit analyses are needed to weigh the carbon emissions incurred by the operation of reservoir HOSs against potential reductions in greenhouse gas efflux from reservoirs due to the systems.

Table 1: Annual energy consumption and cost of HOS operation

	Almaden		**Calero**		**Guadalupe**		**Stevens Creek**	
	USD ($)	kW h	USD ($)	kW h	USD ($)	kW h	USD ($)	kW h
2016	$12,227	76,417	$22,726	142,036	$31,683	198,017	$29,180	182,374
2017	$25,309	158,182	$17,378	108,614	$18,907	118,166	$21,476	134,227
2018	$31,474	196,713	$24,893	155,579	$27,318	170,735	$29,802	186,261
2019	$20,843	130,271	$11,777	73,608	$11,165	69,781	$7,762	48,514
Total	$89,853	561,583	$76,774	479,836	$89,072	556,699	$88,220	551,376

4 Water Quality and Fish Monitoring

4.1 Methods

4.1.1 Water Quality

Water quality profiles and samples were collected above the deepest portions of Almaden, Calero, Guadalupe, and Stevens Creek reservoirs (Appendices A 2 - A 5). At all reservoirs besides Guadalupe, the bottom water sampled above the deepest portion of the reservoir is representative of water released downstream and can be used to calculate Hg loads. At Guadalupe Reservoir, additional samples and water quality data were taken at the outlet structure to calculate Hg loads to downstream waters. Water quality profiles and samples were also collected at Almaden Lake Site 1 and at the lake's inlet and outlet (Appendix Figure A 1).

Water quality depth profiles at all reservoirs and Almaden Lake were collected using Hydrolab DS5 multiparameter sondes. Parameters included pH, temperature, oxidation-reduction potential, specific conductivity, dissolved oxygen, chlorophyll *a*, and phycocyanin. Profile data were logged at 0.25-1 meter intervals throughout the water column. At reservoir inlets and outlets, a multiparameter handheld YSI sonde or a Hydrolab DS5 multiparameter sonde was used to collect pH, specific conductivity, turbidity, dissolved oxygen, and temperature data.

Water samples were collected using a Wildco alpha-type Van Dorn sampling device at discrete depths. Epilimnion samples were collected two meters from the surface and hypolimnion samples were collected one meter above the bottom. During mixed conditions, mid-depth samples were taken at three equal intervals between the epilimnion and hypolimnion samples. In stratified conditions, mid-depth samples were taken at the top, middle, and bottom of the thermocline as indicated by the temperature depth profile. Samples were dispensed using EPA Method 1669 “Clean Hands-Dirty Hands” procedures into the containers described in Table 2.

Table 2: Sample Collection Bottles and Preservatives

Analyte	Container Material	Volume	Preservative
Ammonia (as N)	HDPE	500mL	Sulfuric Acid
Chloride, Sulfate	HDPE	500mL	Unpreserved
Total Hg	Fluorinated Polyethylene	250mL, double bagged	Unpreserved
Total MeHg	Fluorinated Polyethylene	250mL, double bagged	Hydrochloric Acid

Table 3 describes the laboratory methods used by the contracted laboratory for chemical analysis. The reporting limits describe the concentration below which measured values were considered “non-detects”. Note that these reporting limits have changed over time, requiring the use of statistical methods for censored data when analyzing parameters with a significant percentage of non-detect values.

Table 3: Laboratory Analysis Methods

Analyte	Method	Reporting Limit
Ammonia (as N)	EPA 350.1	0.1 mg/L
Chloride, Sulfate	EPA 300	1 mg/L
Total Hg	EPA 1631 E	0.5 ng/L
Total MeHg	EPA 1630	0.05 ng/L

Water quality data were evaluated by comparing dry season (May 1 -September 30) measurements taken prior to (OFF) and during (ON) years of seasonal treatment system operation. Due to periodic shutdowns during ON years, the treatment systems were only considered ON if hypolimnetic dissolved oxygen concentration remained above 2mg/L. Welch’s t-test was used to compare ON/OFF groups where data were normally distributed or could be transformed to fit a normal distribution. The nonparametric Mann-Whitney test was used to compare ON/OFF groups where data could not be normalized. For parameters with more than 10% non-detect values, the CENDIFF function of the Non-Detects and Data Analysis (NADA) package for R was used.

4.1.2 Fish Monitoring

Valley Water collected fish from Almaden, Calero, Guadalupe, and Stevens Creek reservoirs twice annually from 2015 to 2019 to document changes in fish assemblages and Hg body burden. Due to Covid-19 restrictions, sampling could not be completed in 2020 or spring of 2021. Fish monitoring resumed in summer 2021, but due to exceptionally low water levels, Calero was the only reservoir where an electrofishing boat could be used. In all other reservoirs, fish were instead captured using hook-and-line methods.

When boat electrofishing was used, fish were captured using a Smith-Root Model H electrofishing boat. This method can capture fish up to 4.5 meters deep depending on conductivity and settings. Turbidity, aquatic vegetation, and water level limit the area that can be sampled by electrofishing boat. Boat electrofishing also introduces bias associated with species catchability and netting efficiency. The pelagic tendency of forage fish, for example, makes them more susceptible to capture using boat electrofishing so results may overestimate prey populations relative to predatory fish.

Hook-and-line sampling was conducted from a 14-foot aluminum Jon Boat. Methods included open water trolling along transects and stationary angling along shore margins. Hook-and-line sampling may present a bias toward larger fish, as gape size can limit catchability of smaller fish. Additionally, the sampling location and ability of the angler may confound the collection results. The primary goal of this sampling effort was, however, to collect fish for the body burden analysis, so more emphasis was placed on collecting target fish than providing an estimate of fish assemblage or size distribution.

The body burden Hg analysis targets trophic level 3 and 4 fish, including largemouth bass, bluegill, and black crappie from 50-150 mm and 150-350 mm because consuming these fish poses reproductive and developmental risk to piscivorous birds. Target Fish are collected to measure progress toward attaining fish tissue objectives of 0.05 mg Hg/kg (wet weight) for 50-150 mm fish (TL3A) and 0.1 mg/Hg/kg (wet weight) for 150-350 mm fish (TL3B). A subset of these fish also serve as “remediation effectiveness indicators” (REIs) and are required to be monitored as short-term measurements of the effectiveness of management actions. The samples are designed to be sensitive measures of Hg exposure variability in space and time. In the Guadalupe River Watershed, based on recommendations from the Regional Board, “age-1” largemouth bass (55-102mm) in length have been chosen as the primary REIs. Fish Hg was analyzed by EPA method 1631E.

4.2 Summary of Monitoring Completed in Reporting Period

Water Quality Monitoring

Water quality monitoring was scheduled to occur twice monthly at each station during periods of thermal stratification and monthly during mixed conditions. Monthly sampling occurred during mixed conditions between October 2019 and March 2020. However, due to the COVID-19 pandemic, sampling events throughout the rest of the reporting period were altered to comply with Santa Clara County COVID-19 safety mandates as outlined in the Blueprint for a Safer Economy framework. Sampling did not occur between April and August 2020. In September 2020, grab samples were taken at each reservoir’s outlet and at the inlet and outlet of Almaden Lake because this sampling could be accomplished while maintaining workplace social distancing requirements. Water quality monitoring resumed in October 2020 on a limited basis and was completed when possible in accordance with the dynamic COVID-19 recommendations set forth by federal, state, and local agencies (Table 4, Table 5).

Table 4: Number of sampling events occurring each season of Water Year 2020 and 2021.

	Water Year 2020				**Water Year 2021**			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Almaden Lake Inlet	3	1	0	4	2	1	2	2
Almaden Lake Outlet	3	1	0	4	2	1	2	2
Almaden Lake Site 1	3	1	0	3	2	1	2	2
Almaden Reservoir	3	1	0	3	1	1	3	2
Calero Reservoir	3	1	0	3	2	1	3	2
Guadalupe Reservoir	3	1	0	3	1	2	3	2
Guadalupe Reservoir Outlet	3	1	0	4	1	2	3	2
Stevens Creek Reservoir	3	1	0	3	1	2	3	2

Table 5: Total number of samples taken at each location per reservoir in Water Year 2020 and 2021.

	Almaden Reservoir				Calero Reservoir				Guadalupe Reservoir				Stevens Creek Reservoir				Almaden Lake			
	Hg	MeHg	Ammonia	Cl^-/SO_4^{2-}	Hg	MeHg	Ammonia	Cl^-/SO_4^{2-}	Hg	MeHg	Ammonia	Cl^-/SO_4^{2-}	Hg	MeHg	Ammonia	Cl^-/SO_4^{2-}	Hg	MeHg	Ammonia	Cl^-/SO_4^{2-}
EPI	14	15	14	14	15	16	15	15	14	18	14	15	15	15	15	15	13	17	13	13
EPIM		11				15				8				7						
MID		14				15				14				15				13		
MIDH		11				15				8				7						
HYP	14	15	14	13	15	16	15	15	14	18	14	15	15	15	15	15	13	17	13	13
Inlet																	13	13		
Outlet	1	1	1	1	1	1	1	1	12	12	1	1	1	1	1	1	14	14	2	2

Fish Monitoring

Fish sampling events were scheduled to occur in spring and summer of 2020 and 2021. However, due to the COVID-19 pandemic and Santa Clara County social distancing recommendations, fish sampling was only completed during the summer of 2021 (Table 6).

Table 6: Fish sampling date at each reservoir during the reporting period.

Reservoir	Sampling Date	Samples Collected
Almaden Reservoir	8/19/2021	25
Calero Reservoir	8/12/2021	42
Guadalupe Reservoir	8/23/2021	31
Stevens Creek Reservoir	8/26/2021	24

4.3 Water Quality Results and Discussion

This section discusses the effects of the treatment systems on water quality. Dissolved oxygen saturation, oxidation reduction potential, total MeHg concentrations, sulfate concentrations, and water temperature were compared in years before (2005-2016) and during (2016-2021) seasonal treatment system operation. Treatment systems are operated during the dry season (May-September) during which water bodies exhibit seasonal stratification and hypolimnetic oxygen depletion.

4.3.1 Dissolved Oxygen Saturation

The line diffuser HOSs in Almaden, Guadalupe, and Stevens Creek reservoirs were effective in oxygenating the sediment-water interface. Dissolved oxygen in bottom water increased significantly during oxygenation of these reservoirs, typically maintaining >100% saturation during consistent operation (Figure 3, Figure 7). Although the oxygen diffuser lines are limited to the deepest portions of the reservoirs near the outlet intakes, high dissolved oxygen concentrations propagated throughout the hypolimnia and maintained oxic conditions throughout Almaden, Guadalupe, and Stevens Creek Reservoirs (Figure 8).

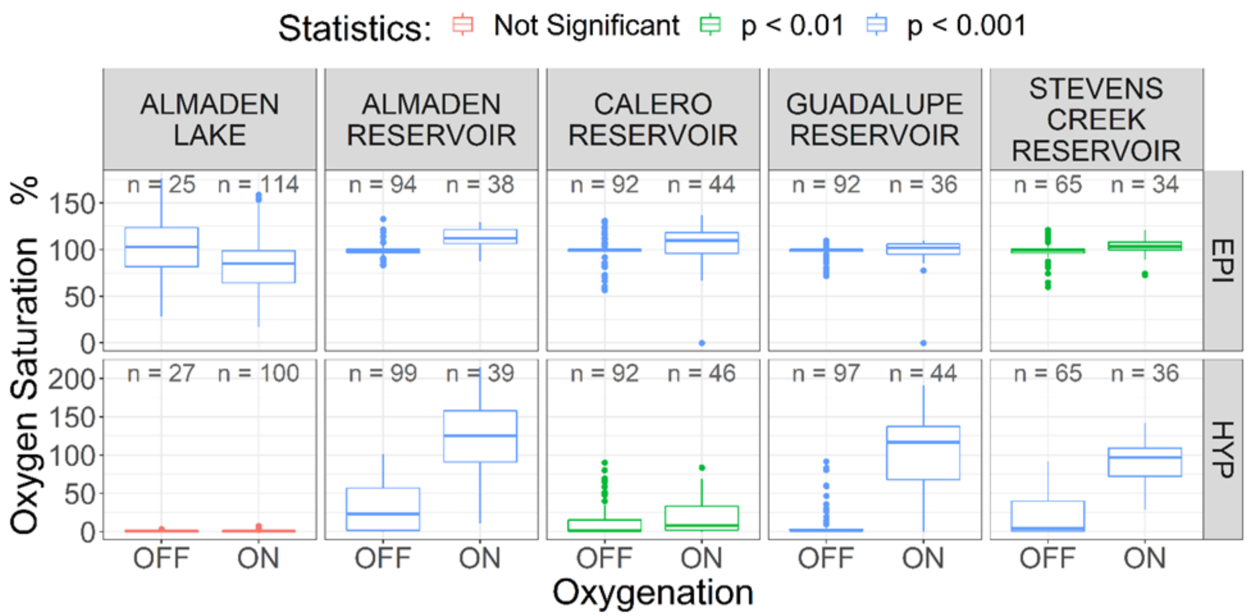

Figure 7: Epilimnetic and hypolimnetic dissolved oxygen saturation before (OFF) and during (ON) seasonal operation of the treatment systems.

The HOS at Calero Reservoir was ineffective at increasing dissolved oxygen concentrations above hypoxic (DO < 3 mg/L) levels despite roughly continuous operation (Figure 7). A longitudinal profile collected in Calero Reservoir during oxygenation on September 3, 2021 shows slightly increased dissolved oxygen concentrations in the middle of the hypolimnion directly above the diffuser line (Figure 9). However, the sediment-water interface remained anoxic throughout the hypolimnion. As discussed in Seelos et al., 2021, the HOS at Calero Reservoir failed to meet biochemical oxygen demand, leading to unimproved DO levels. This is likely because the system was undersized to meet additional oxygen demand induced by the system itself (Beutel, 2003; Gantzer et al., 2009). Additionally, the high surface area to volume ratio of Calero Reservoir and its relatively small hypolimnion thickness may have led to decreased oxygen transfer and retention (Moore et al., 2015).

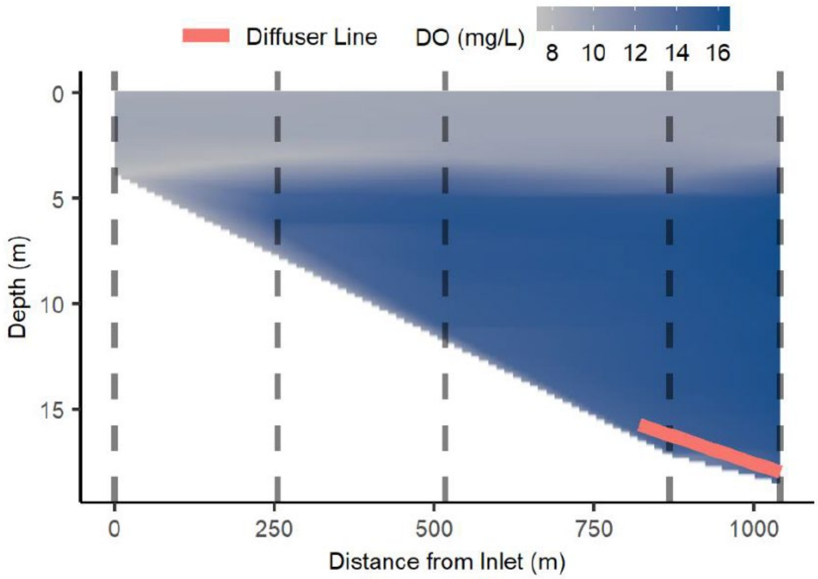

Figure 8: Lateral extent of hypolimnetic oxygenation in Almaden Reservoir (June 14, 2018). The extent of the diffuser line is shown in red.

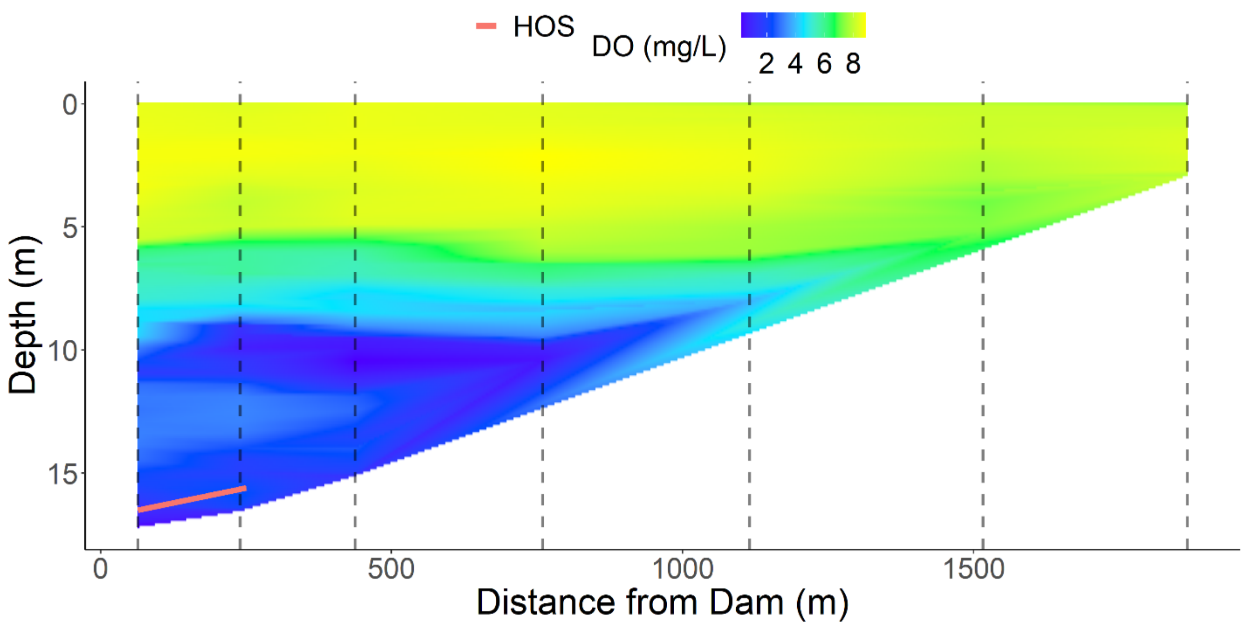

Figure 9: Lateral extent of hypolimnetic oxygenation in Calero Reservoir (September 3, 2021). The extent of the diffuser line is shown in red.

In Almaden Lake, the solar circulator had no significant effect on dissolved oxygen saturation in the hypolimnion (Figure 7). Average dissolved oxygen saturation in the Almaden Lake hypolimnion remained under 2%. In the Almaden Lake epilimnion, average dissolved oxygen saturation was significantly lower following the installation of the solar circulator due to vertical transport of anoxic bottom water into the surface.

4.3.2 Oxidation Reduction Potential

Surprisingly, oxidation-reduction potential decreased in the hypolimnia of Almaden and Calero Reservoir and in surface waters of all water bodies during treatment system operation (Figure 10; Table A 1, lines 67-112). This is counterintuitive because oxidation-reduction potential is expected to increase with the establishment of oxidizing conditions. We believe that the treatment systems disturbed the sediment-water interface and mixed reduced chemical species into surface waters, causing lower ORP readings. Lower ORP readings during oxygenation is evidence for HOS-induced vertical transport.

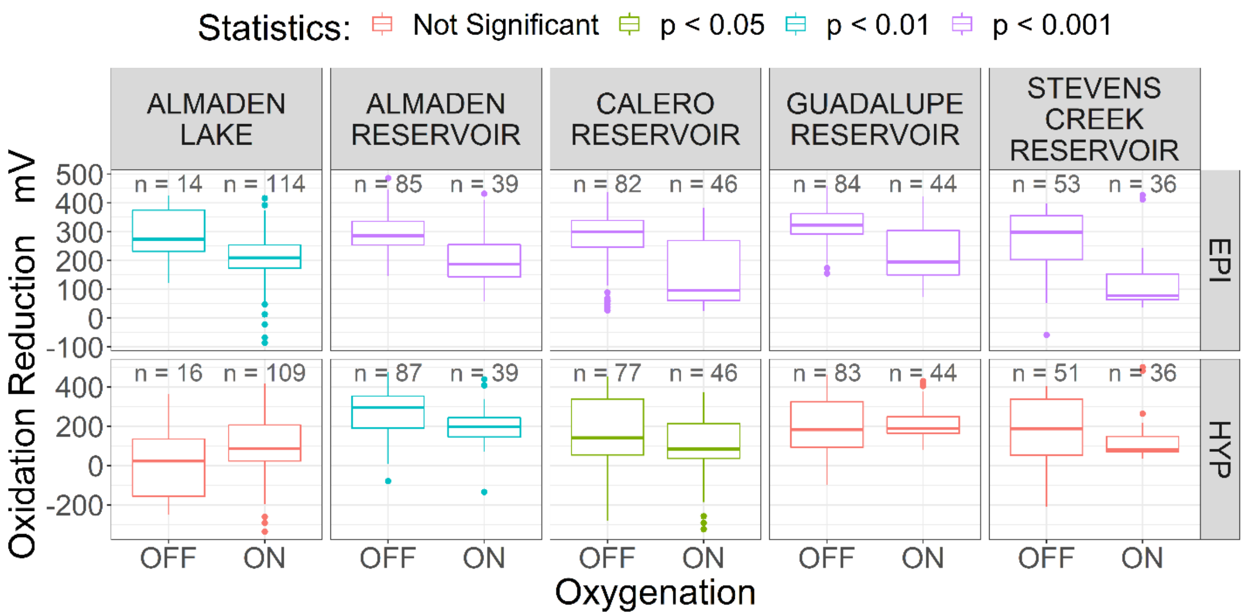

Figure 10: Epilimnetic and hypolimnetic oxidation reduction potential before (OFF) and during (ON) seasonal operation of the treatment systems.

4.3.3 Total MeHg

Total MeHg concentrations decreased in the hypolimnia of all water bodies during treatment system operation but were unchanged in surface waters (Figure 11; Table A 1, lines 363-408). For example, in Almaden Lake's hypolimnion, average total MeHg concentrations decreased from 32.3 ng/L prior to installation of the circulators to 10.0 ng/L during treatment system operation. Average MeHg concentrations in Guadalupe Reservoir decreased from 11.6 ng/L prior to HOS operation to 1.8 ng/L during treatment system operation. In all other reservoirs, average total MeHg concentrations dropped from around 2 ng/L prior to treatment system operation to around 0.9 ng/L during treatment system operation. Decreases in MeHg in lake and reservoir bottom waters are notable, but likely reflect dilution effects as whole lake MeHg concentrations were unchanged (Seelos et al., 2021).

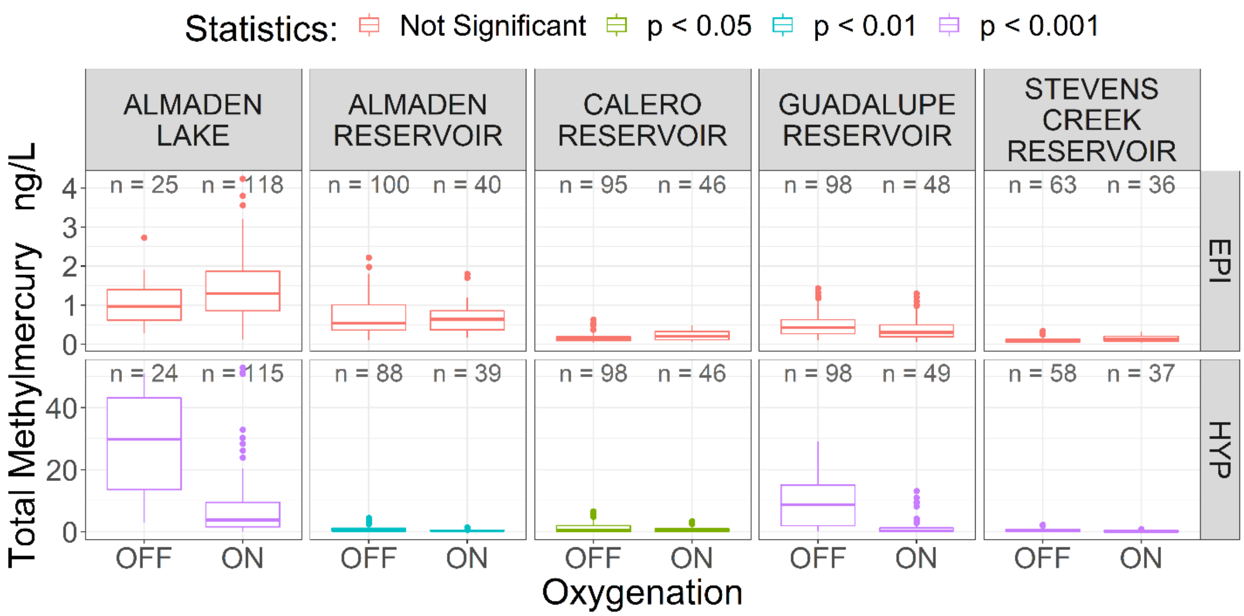

Figure 11: Epilimnetic and hypolimnetic total MeHg concentrations measured before (OFF) and during (ON) operation of the treatment systems.

4.3.4 Sulfate

Sulfate concentrations were significantly higher in the hypolimnia of all water bodies during treatment system operation (Figure 12; Table A 1, lines 353-362). Hypolimnetic sulfate concentrations increased by around 8% in Almaden Reservoir and Stevens Creek Reservoir and around 28% in Calero Reservoir and Guadalupe. The most notable increases were observed in Almaden Lake as sulfate concentrations increased by an average of 164%. Hypolimnetic sulfate increase was likely due to the combined effects of sulfide oxidation to sulfate, and decreased activity by sulfate reducing bacteria (Compeau & Bartha, 1985).

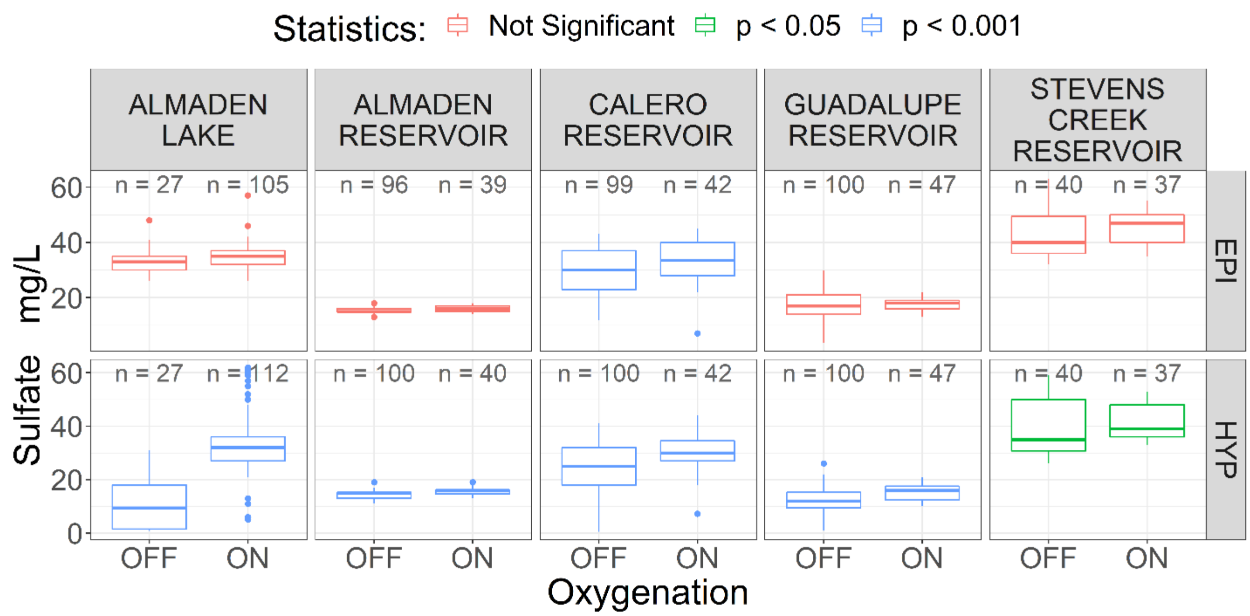

Figure 12: Epilimnetic and hypolimnetic sulfate concentration before (OFF) and during (ON) seasonal operation of the treatment systems.

4.3.5 Temperature

The HOSs and circulators significantly increased bottom water temperatures in all water bodies (Figure 13; Table A 1, lines 445-454). Bottom water temperatures in Almaden, Calero, and Stevens Creek reservoirs increased by an average of 2°C, Almaden Lake increased by an average of 3.8°C, and Guadalupe Reservoir increased by an average of 5.5°C during treatment system operation. During the dry season of 2021, when the treatment system was turned off in Guadalupe Reservoir, hypolimnetic water temperatures were 3.8°C below the mean hypolimnetic water temperature measured during HOS operation between 2016 and 2020. Temperature increases in the hypolimnia during treatment system operation may be due to mixing induced by rising bubble plumes.

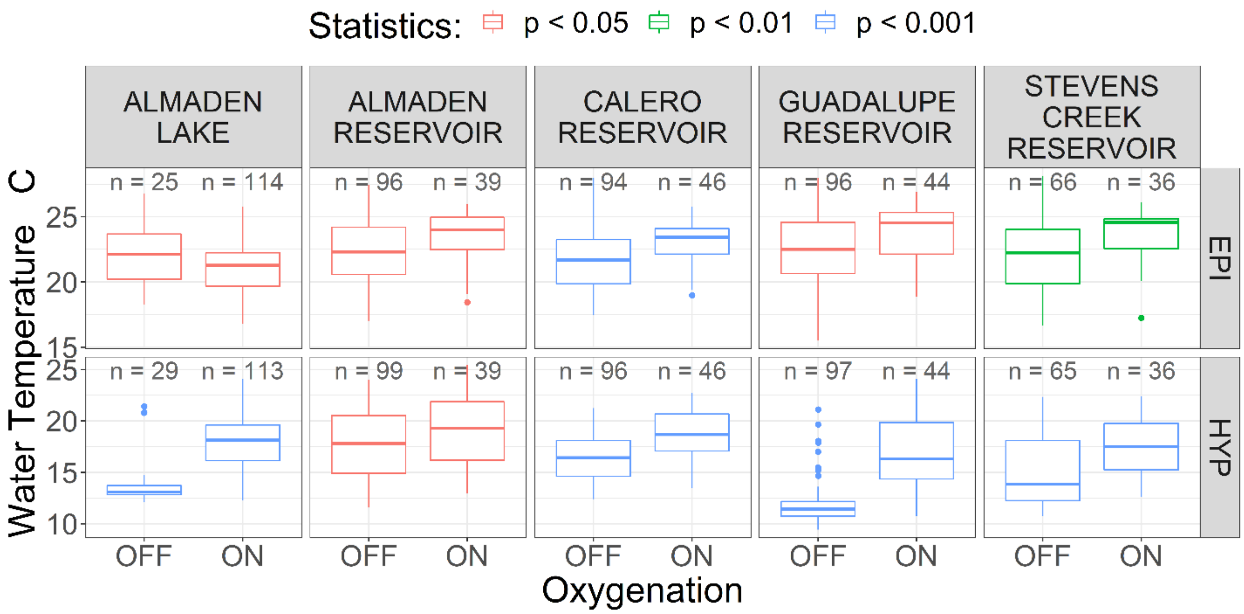

Figure 13: Epilimnetic and hypolimnetic water temperature recorded during the dry season before (OFF) and during (ON) seasonal operation of the treatment systems.

4.3.6 Internal Nutrient Loading and Primary Productivity

Ammonia

Hypolimnetic ammonia concentrations were significantly lower during treatment system operation in all water bodies except Calero Reservoir (Figure 14; Table A 1, lines 11-20). This was most notable in Almaden Lake, where mean ammonia concentrations decreased from 2.8 mg/L to 0.1 mg/L. These effects extended to surface waters in Guadalupe Reservoir and Stevens Creek Reservoir (Figure 14; Table A 1, lines 7-10). Decreases in hypolimnetic ammonia concentrations were likely due to enhanced nitrification under aerobic conditions, and dilution of profundal ammonia through the water column.

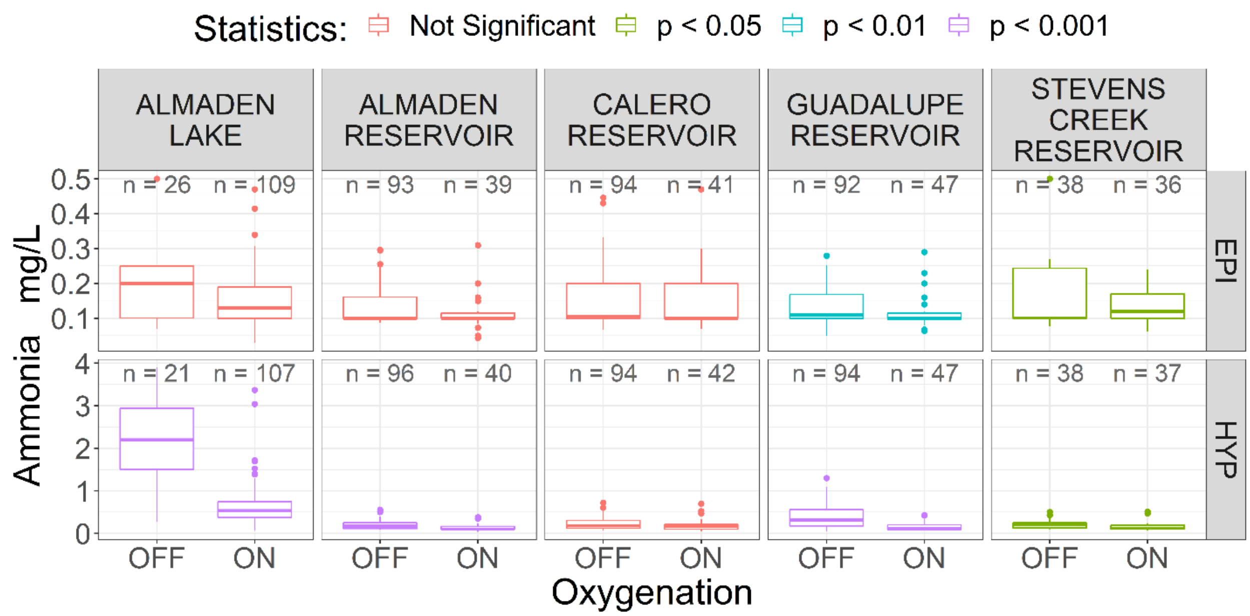

Figure 14: Epilimnetic and hypolimnetic ammonia concentrations before (OFF) and during (ON) seasonal operation of the treatment systems.

Chlorophyll *a* and Phycocyanin

Oxygenation and circulation are commonly used for algae management in lakes and reservoirs. However, in some water bodies the treatment systems seemed to exacerbate eutrophication. The solar circulators were ineffective at controlling primary productivity in Almaden Lake. There was no significant difference in phycocyanin or chlorophyll concentrations in the epilimnion of Almaden Lake before and after installation of the circultors (Figure 15, Figure 16). Surprisingly, hypolimnetic oxygenation generally increased primary productivity in the reservoirs (Figure 15, Figure 16). Phycocyanin concentrations were significantly higher in epilimnia of all during HOS operation (Table A 1, lines 251-260). Chlorophyll *a* concentrations were also significantly higher in the epilimnia of Almaden, Calero, and Stevens Creek reservoirs (Table A 1, lines 21-30). Increases in primary productivity were likely due to warming effects and transport of nutrient-rich profundal water into the photic zone (Seelos et al., 2021). This highlights the importance of proper treatment system design in shallow reservoirs.

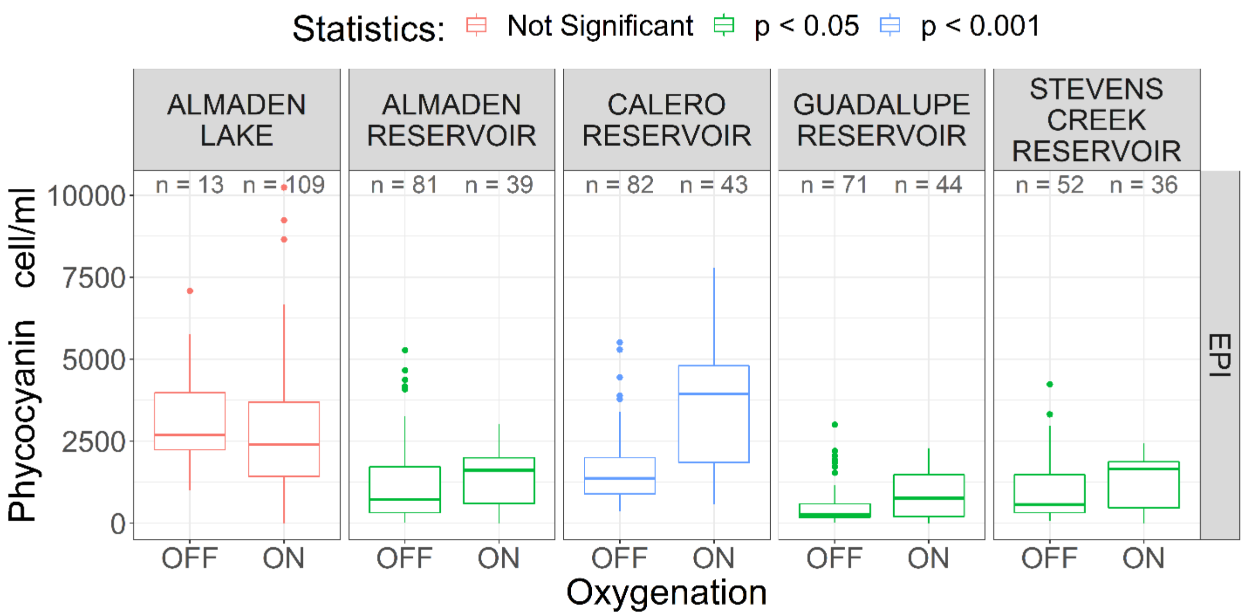

Figure 15: Epilimnetic phycocyanin concentrations before (OFF) and during (ON) seasonal operation of the treatment systems.

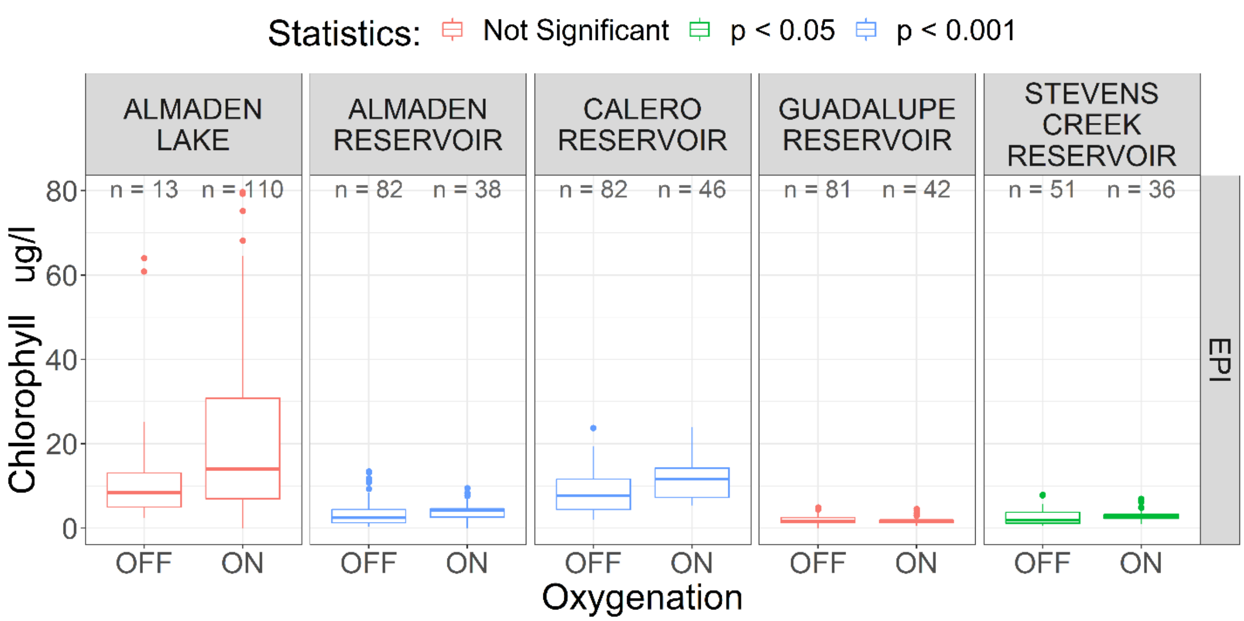

Figure 16: Epilimnetic chlorophyll concentrations before (OFF) and during (ON) seasonal operation of the treatment systems.

4.4 Results of Fish Monitoring

This section discusses results of fish assemblage and fish tissue Hg monitoring. Data collected from fish sampling efforts are intended to document changes in fish assemblages since treatment began and measure progress toward attaining fish tissue objectives for Hg.

4.4.1 Assemblage Monitoring

In 2020 and spring 2021, no fish monitoring occurred due to shelter in place and social distancing recommendations resulting from the COVID-19 pandemic as described in Section 4.1.2. While assemblage data are reported, the primary focus of this sampling effort was to collect fish for body burden analysis. The results and limitations of the assemblage monitoring are discussed.

Almaden Reservoir

Sampling occurred in Almaden Reservoir on August 19, 2021. Three species were observed: largemouth bass (n=57), bluegill (n=3), and black crappie (n=1). While variations in methods used over time make historical comparison difficult, assemblage data from summers prior that were collected using hook and line sampling also show largemouth bass and bluegill among the most abundant species (Figure 17).

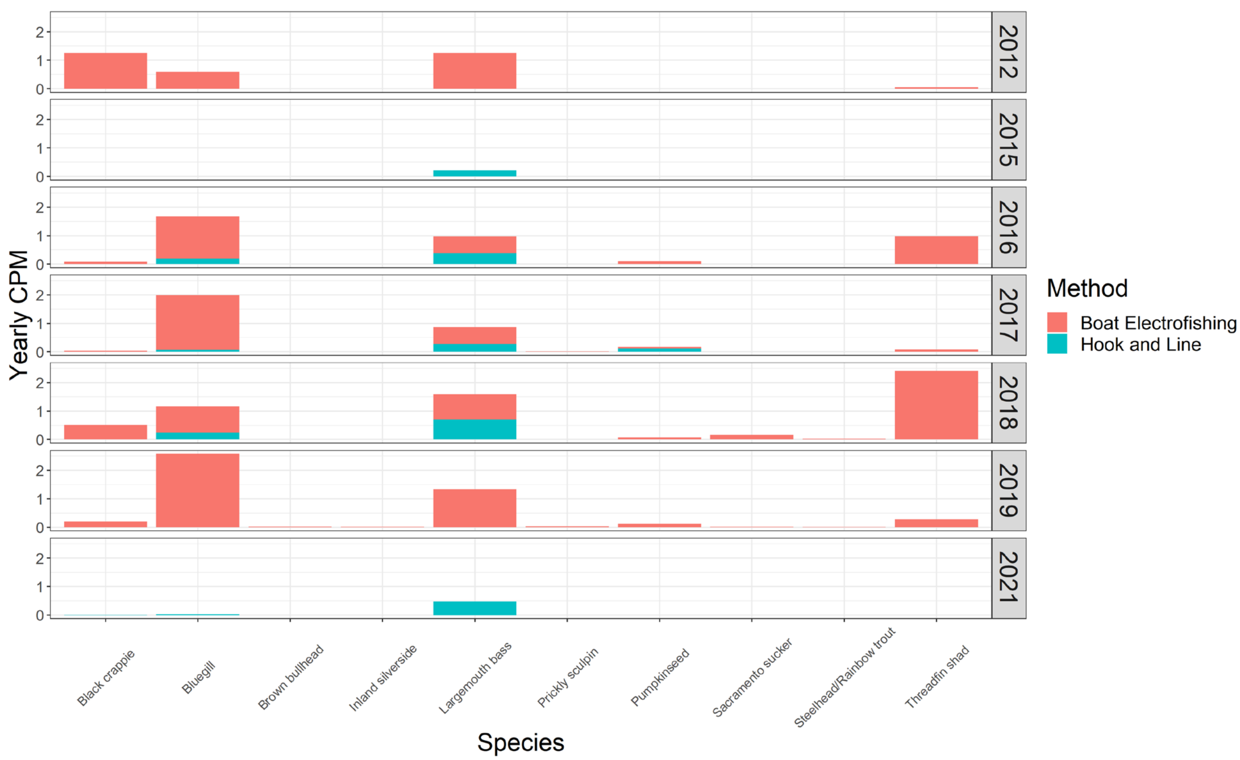

Figure 17: Fish species distribution in Almaden Reservoir.

Different age classes of largemouth bass are apparent, but due to bias associated with the hook and line sampling method, size distribution is likely not accurately represented (Figure 18). The distribution of largemouth bass does indicate, however, that successful spawning occurred in the reservoir. The gape size of bluegill in the young of the year size range, and potentially one-year old fish, limits detection by hook and line sampling.

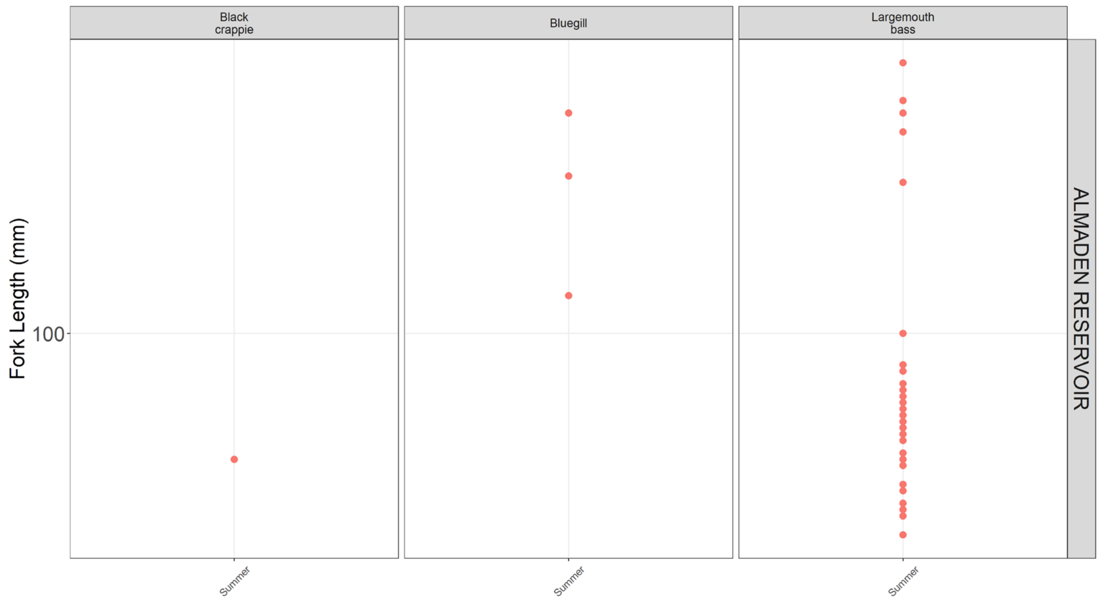

Figure 18: Size distribution of fish species in Almaden Reservoir summer 2021. All fish sampled by hook and line.

Calero Reservoir

Sampling occurred in Calero Reservoir on August 12, 2021. Calero Reservoir was the only water body in which conditions allowed for boat electrofishing. Twelve species were collected: bigscale logperch (n=2), black crappie (n=29), bluegill (n=28), brown bullhead (n=3), golden shiner (n=1), inland silverside (n=55), largemouth bass (n=85), prickly sculpin (n=1), pumpkinseed (n=1), Sacramento sucker (n=2), threadfin shad (n=58), and tule perch (n=1). The total species assemblage was similar to prior years, but fish abundance was notably lower (Figure 19). As in summer 2018 and 2019, tule perch, Sacramento sucker, and prickly sculpin were the only California native species collected. In the summer 2018 sampling event, threadfin shad (n=334) was the most frequently captured species followed by tule perch (n=242) and inland silverside (n= 220). In summer 2019, 27 tule perch were collected, representing only 5% of captured fish that summer, and only 1 tule perch was collected in summer 2021. The sharp decline in captured tule perch paired with the relative increases in both captured black crappie (increasing from 1% of captured fish in 2018 to 12% of captured fish in 2021) and bluegill (increasing from 2% of captured fish in 2018 to 10% of captured fish in 2021) that occupy a similar niche suggest that the black crappie and bluegill may be outcompeting the native tule perch.

It is important to note that boat electrofishing only samples the water column between the surface and the approximately 4.5 meters deep, depending on conductivity and settings. This limits the area that can be sampled, thus targeting fish nearshore or near the top of the water column. Low occurrence of captured prickly sculpin, brown bullhead, and Sacramento sucker in all years is likely affected by sampling method bias against benthic species and is not necessarily an indicator of population level.

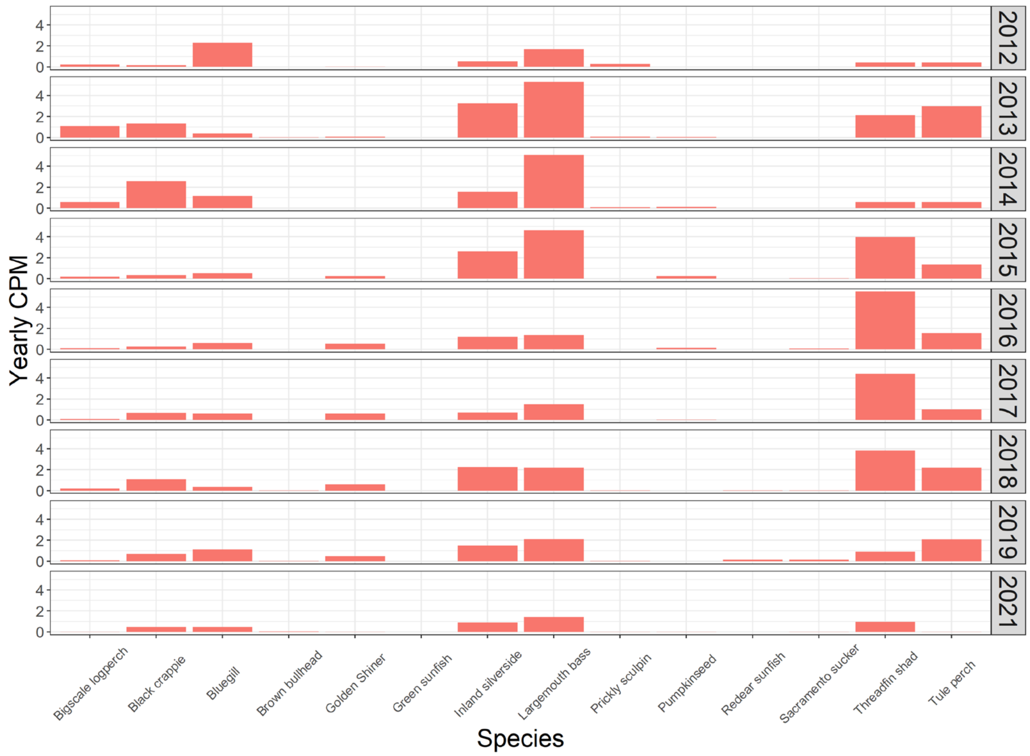

Figure 19: Fish species distribution in Calero Reservoir. All fish were sampled by boat electrofishing

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Size distributions indicate that black crappie age 0-3 were present in the reservoir and successful spawning of largemouth bass occurred over multiple years (Figure 20).

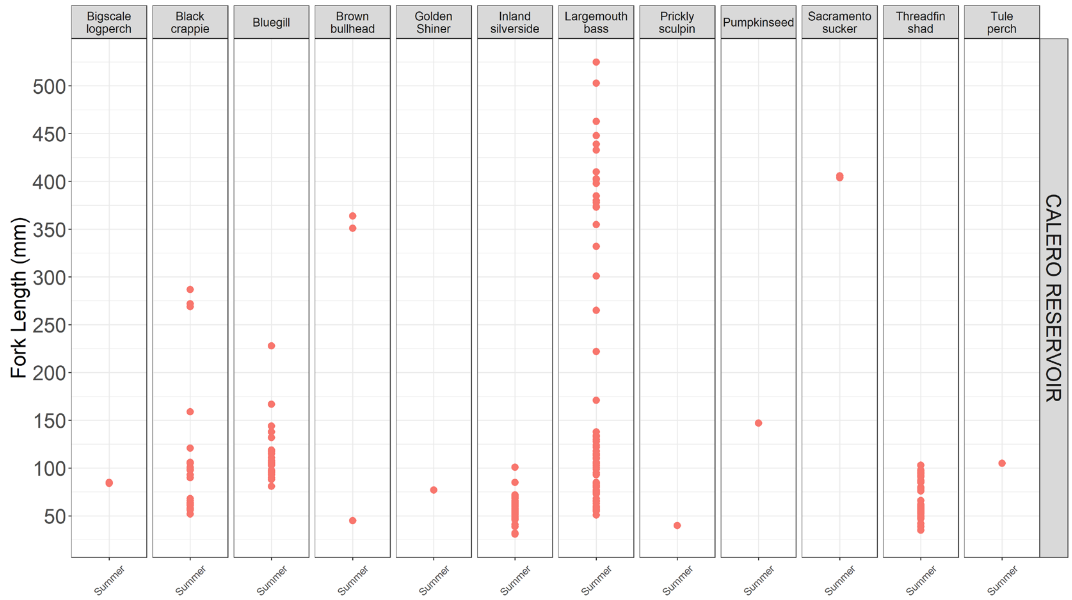

Figure 20: Size distribution of fish species caught in Calero Reservoir summer 2021. All fish were sampled using boat electrofishing.

Guadalupe Reservoir

Sampling occurred on Guadalupe Reservoir via hook and line on August 23, 2021. Two species were collected: Largemouth bass and bluegill. Variations in fish capture methods among years make year to year comparison difficult, but assemblage data collected in summers prior also show largemouth bass and bluegill as being some of the most abundant species (Figure 21). Based on the assemblage data collected since 2012, it appears that the trophic distribution within Guadalupe Reservoir is limited. No forage fish (inland silverside, threadfin shad, etc.) have been observed that effectively bridge the gap of phytoplankton and zooplankton to primary predators.

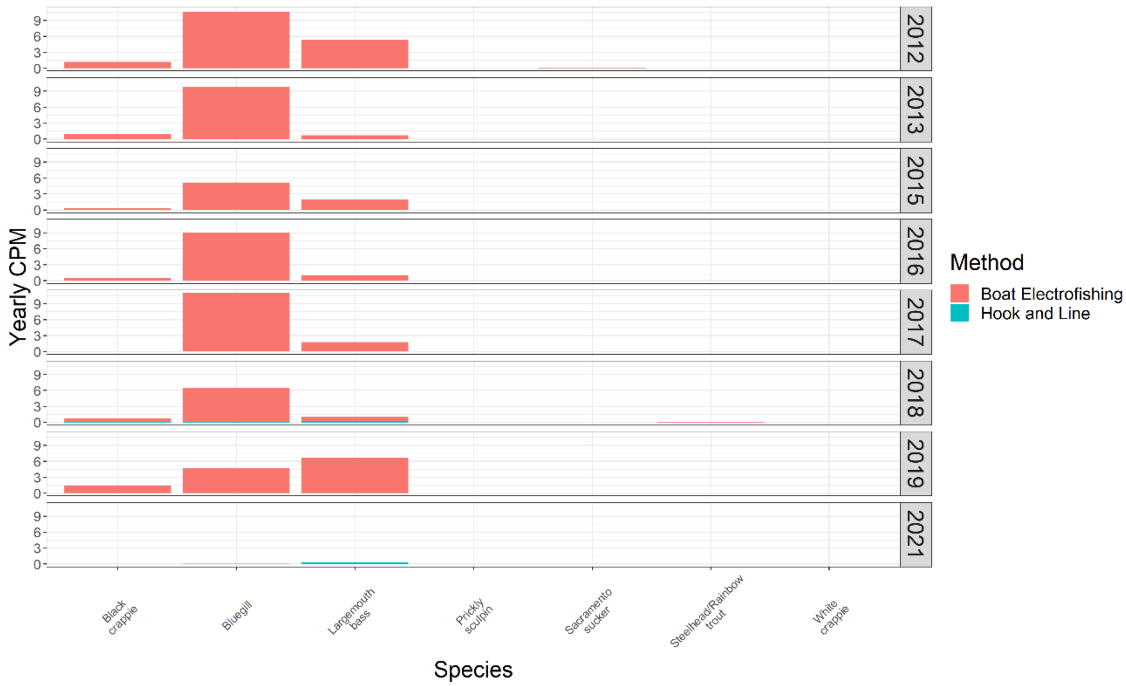

Figure 21: Fish species distribution in Guadalupe Reservoir.

Different age classes of largemouth bass are apparent, but due to bias associated with hook and line sampling, size distribution is likely not representative (Figure 22). The distribution of largemouth bass does indicate, however, that successful spawning occurred in the reservoir.

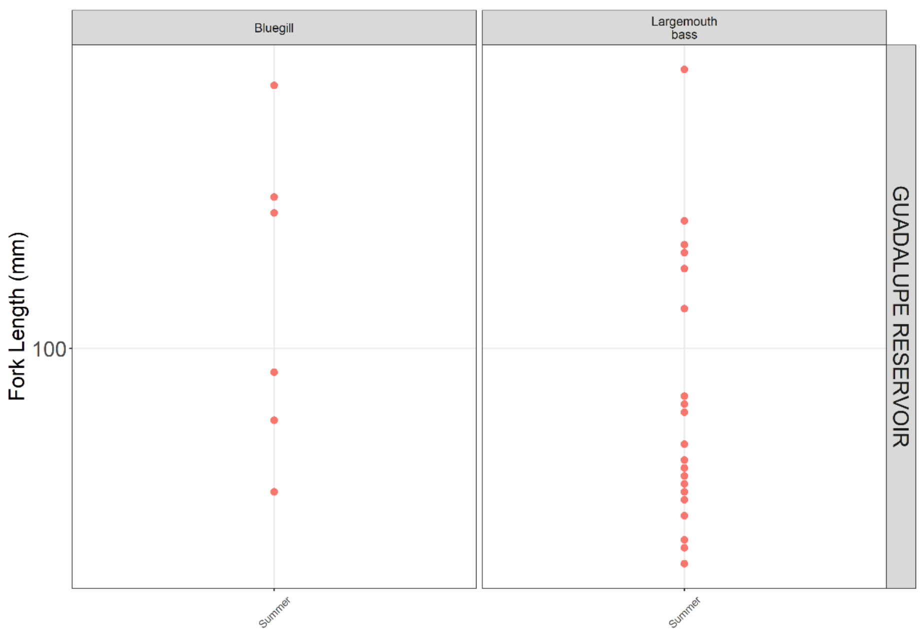

Figure 22: Size distribution of fish species caught in Guadalupe Reservoir summer 2021.

Stevens Creek Reservoir

Stevens Creek Reservoir was sampled on August 23, 2021 via hook and line. Three species were collected: Largemouth bass (n=13), black crappie (n=10), and bluegill (n=1). While variations in methods among years make year to year comparison difficult, species distributions are similar, with largemouth bass, black crappie, and bluegill most abundant (Figure 23). As with Guadalupe Reservoir, it appears that the trophic distribution within Stevens Creek Reservoir is limited. No pelagic forage fish (inland silverside, threadfin shad, etc.) that effectively bridge the gap of phytoplankton and zooplankton to primary predators have been observed since sampling began in 2012.

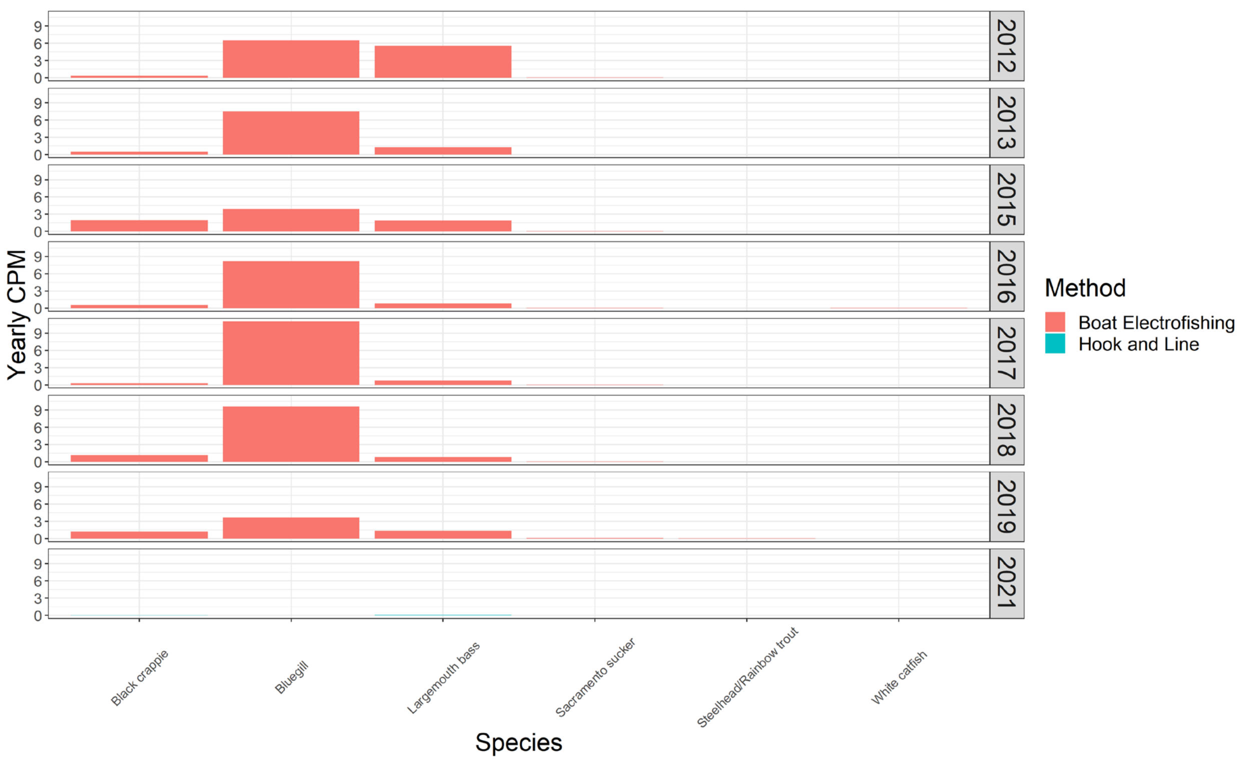

Figure 23: Fish species distribution in Stevens Creek Reservoir

Due to bias associated with hook and line sampling, size distribution is likely not representative. Low capture rates during this sampling event make determining age distribution difficult (Figure 24).

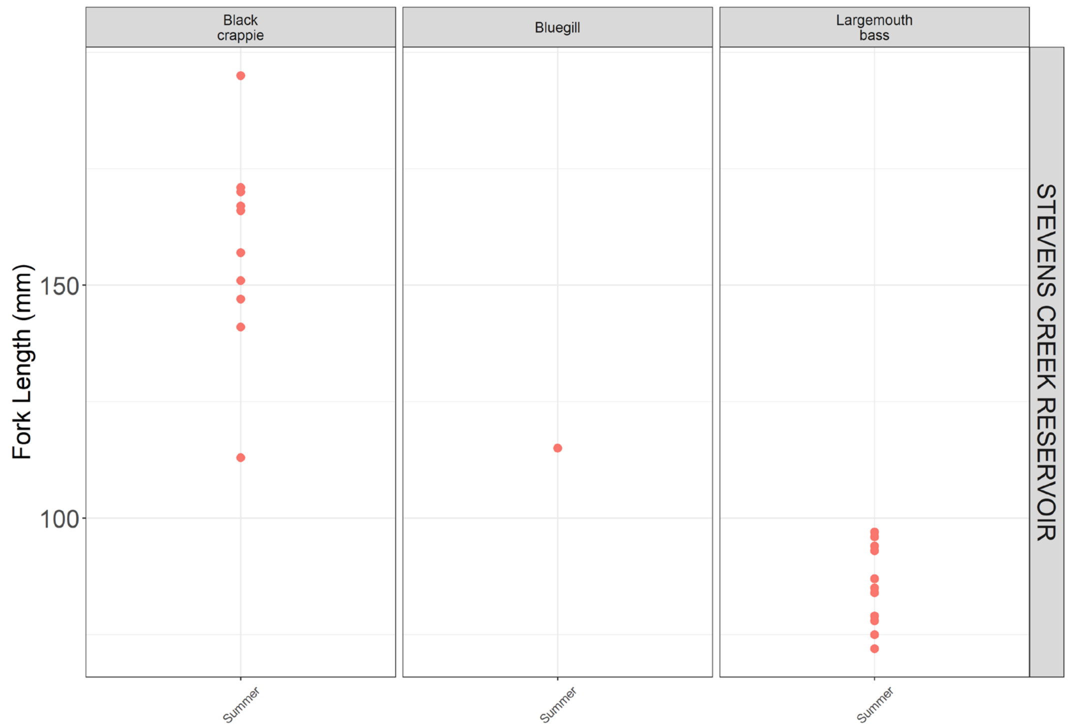

Figure 24: Size distribution of fish species caught in Stevens Creek Reservoir summer 2021.

4.4.2 Fish Hg Monitoring

This section describes trends in fish tissue Hg concentrations measured during operation of the HOSs in the reservoirs. Due to dearth of pre-HOS fish data, reservoir-specific multiple linear regression models were used to interpret temporal trends in fish tissue concentrations since treatment system installation. Fish in the study reservoirs varied by species, length, and collection season (Seelos et al., 2021). To isolate the effect of collection date on fish Hg, it is important to control for the effects of these confounding variables. Thus, in addition to sample date, the models included three additional explanatory variables: fish species, fish length, and collection season (Equation 1,

Table 7). If the coefficient of the date term was statistically significant, we interpreted the reservoir as having a significant increasing (positive coefficient) or declining (negative coefficient) trend in fish Hg.

Equation 1: Linear regression model equation

$$Hg\left({}^{mg}/_{kg}\ ww\right) = \alpha + \beta_1\,Date + \beta_2 Species + \beta_3\,Length(mm) + \beta_4\,CollectionSeason$$

Table 7: Linear regression model parameters

	α	β_1	β_2	β_3	β_4
Almaden	**2.126**	**-0.000113**	BLGI 0.011 LMBA -0.001	**0.002**	**0.125**
Calero	**-0.223**	**0.000013**	BLGI 0.017 **LMBA 0.064**	**0.001**	**0.041**
Guadalupe	**5.755**	**-0.000336**	**BLGI 0.583** **LMBA 0.564**	**0.007**	**0.088**
Stevens Creek	**1.145**	**-0.000062**	BLGI-0.062 LMBA 0.019	**0.001**	**0.031**

Statistics: significant (p<0.05)/not significant

Full statistics Table A 2

In the 2018-2019 reporting period, there were significant declining trends in fish Hg in Guadalupe and Stevens Creek reservoirs (Seelos et al., 2021). With the inclusion of summer 2021 fish tissue data, there were significant trends in fish Hg in all reservoirs (

Table 7, Figure 25). Declining trends are meaningful in Almaden, Guadalupe, and Stevens Creek reservoirs. Average Hg concentrations in 100 mm length-standardized largemouth bass have decreased by about 46% in Almaden Reservoir, 45% in Guadalupe Reservoir, and 68% in Stevens Creek Reservoir. The fact that declining trends persisted in Guadalupe and Stevens Creek reservoirs despite nonoperation of the HOSs in 2021 suggests that fish Hg trends were dependent on factors other than HOS, such as source control or primary productivity. In Calero Reservoir, there was a statistically significant increasing trend in fish Hg that is too slight to be practically meaningful.

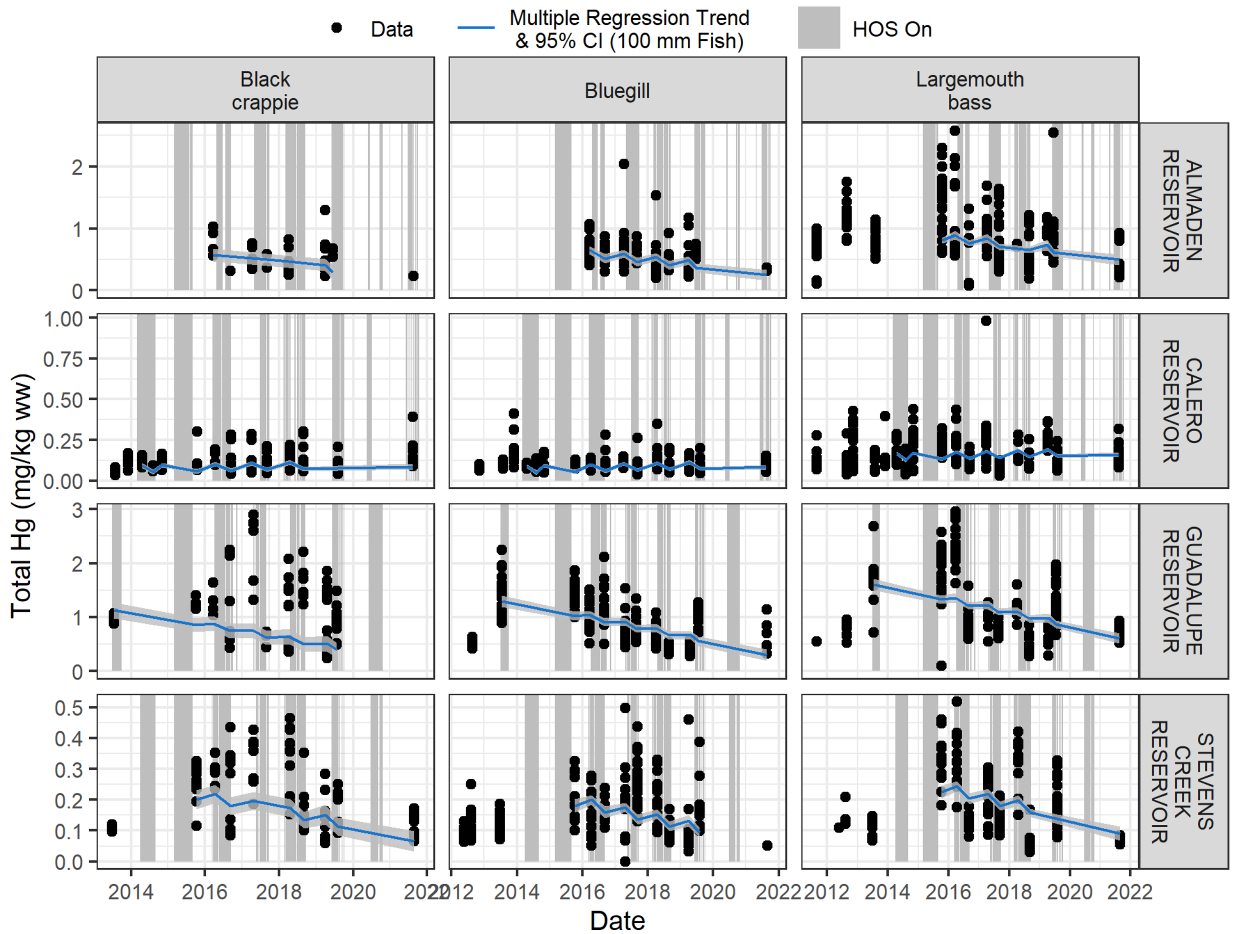

Figure 25: Linear regression models of Hg concentrations in black crappie, bluegill, and largemouth bass tissue.

4.5 Hg Loads from Reservoir Outlets

Section 9.4 of the Guadalupe River Watershed TMDL Staff Report requires the estimation of Hg loads at reservoir outlets. In this section, Hg and MeHg loads are estimated by integrating reservoir outlet gauge data with Hg and MeHg concentrations measured during sampling events in the hypolimnion (Almaden, Calero, Stevens Creek Reservoir) or outlet (Guadalupe Reservoir). Loads are calculated as the total volume of water transferred between sampling events multiplied by measured Hg and MeHg concentrations. Figure 26 and Figure 27 show hydrographs of discharge at each reservoir as well as Hg and MeHg concentration at each sample date. Tables 7 through 10 show the calculated annual total Hg and MeHg loads from each reservoir.

Figure 26: Hydrograph of outlet flow and measured total Hg concentrations at Almaden, Calero, Guadalupe, and Stevens Creek reservoirs.

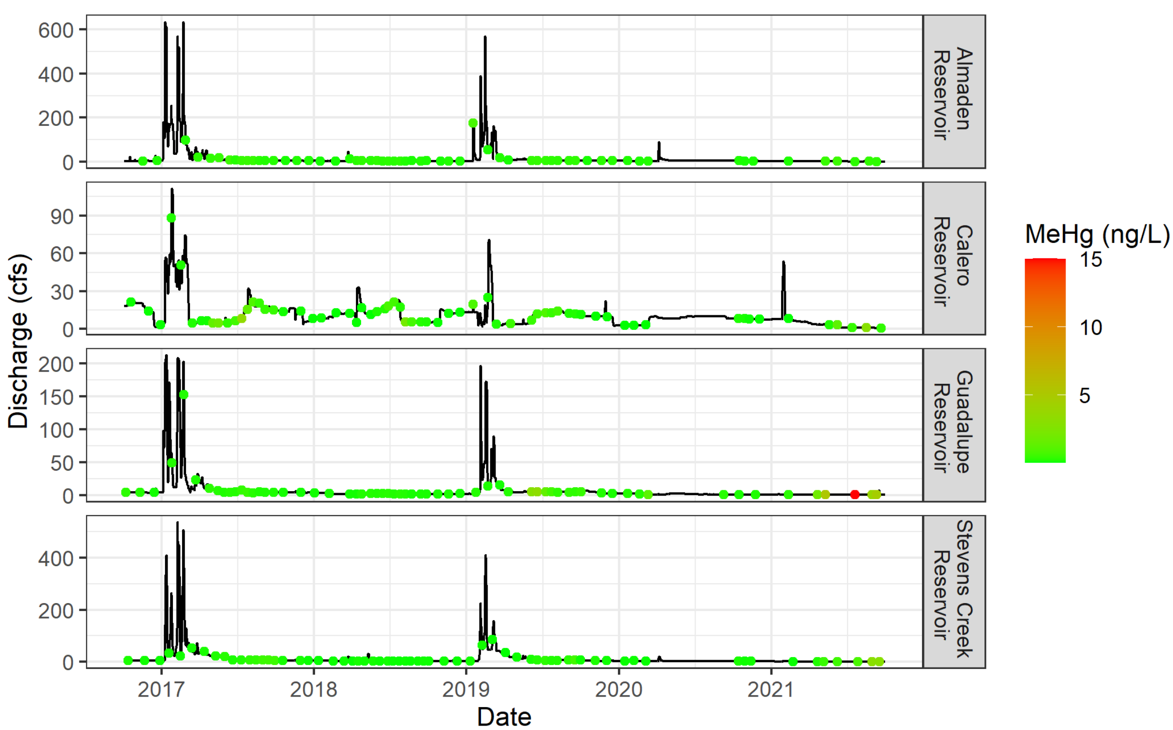

Figure 27: Hydrograph of outlet flow and measured MeHg concentrations at Almaden, Calero, Guadalupe, and Stevens Creek reservoirs.

Table 8: Annual total Hg and MeHg loads (g) at Almaden Reservoir

Almaden Reservoir

Water Year	Million Gallons Released	Load (g)		Flow Weighted Mean Conc. (ng/L)
2017	9651.32	Hg	354.13	9.69
		MeHg	7.09	0.19
2018	979.28	Hg	23.04	6.22
		MeHg	0.72	0.19
2019	5082.51	Hg	1854.53	96.39
		MeHg	9.58	0.5
2020	1156.26	Hg	19.15	4.38
		MeHg	0.88	0.2
2021	521.16	Hg	18.31	9.28
		MeHg	0.42	0.21

Table 9: Total Hg and MeHg loads (g) at Calero Reservoir

Calero Reservoir

Water Year	Million Gallons Discharged	Load (g)		Flow Weighted Mean Conc. (ng/L)
2017	4279.65	Hg	107.02	6.61
		MeHg	6.39	0.39
2018	2810.28	Hg	60.58	5.69
		MeHg	2.53	0.24
2019	2432.06	Hg	231.24	25.12
		MeHg	3.11	0.34
2020	1922.52	Hg	17.36	2.39
		MeHg	0.29	0.04
2021	1252.96	Hg	10.42	2.2
		MeHg	0.64	0.13

Table 10: Total Hg and MeHg loads (g) at Guadalupe Reservoir

Guadalupe Reservoir

Water Year	Million Gallons Discharged	Load (g)		Flow Weighted Mean Conc. (ng/L)
2017	4764.77	Hg	544.34	30.18
		MeHg	3.01	0.17
2018	670.48	Hg	50.43	19.87
		MeHg	0.32	0.13
2019	2428.23	Hg	372.03	40.47
		MeHg	3.29	0.36
2020	567.55	Hg	79.39	36.95
		MeHg	1.29	0.6
2021	242.42	Hg	21.62	23.56
		MeHg	2.86	3.12

Table 11: Total Hg and MeHg loads (g) at Stevens Creek Reservoir

Stevens Creek Reservoir

Water Year	Million Gallons Discharged	Load (g)		Flow Weighted Mean Conc. (ng/L)
2017	8722.94	Hg	423.23	12.82
		MeHg	3.52	0.11
2018	951.28	Hg	33.1	9.19
		MeHg	0.36	0.1
2019	4804.42	Hg	154.9	8.52
		MeHg	1.57	0.09
2020	848.21	Hg	7.7	2.4
		MeHg	0.18	0.06
2021	339.69	Hg	4.53	3.52
		MeHg	0.38	0.3

Total Hg loading to downstream waters occurred primarily during the wet season when concentrations of Hg were relatively high and more water was discharged from reservoir outlets (Figure 26, Figure 28). Low rainfall during the wet seasons of 2018, 2020, and 2021 resulted in decreased water release, lowering Hg loading from reservoirs (Figure 26). The MeHg loads from Stevens Creek and Guadalupe reservoirs more than doubled between 2020 and 2021 when the HOSs were turned off. Though reservoir releases were lower due to drought, there were dramatic increases in the flow weighted mean (FWM) concentration of MeHg (Table 10, Table 11, Figure 29). The increased FWM concentration may be due to treatment system shut off in these reservoirs causing increased production of MeHg or MeHg concentrating in the hypolimnion rather than being mixed throughout the water column by the rising bubble plumes produced by the HOS.

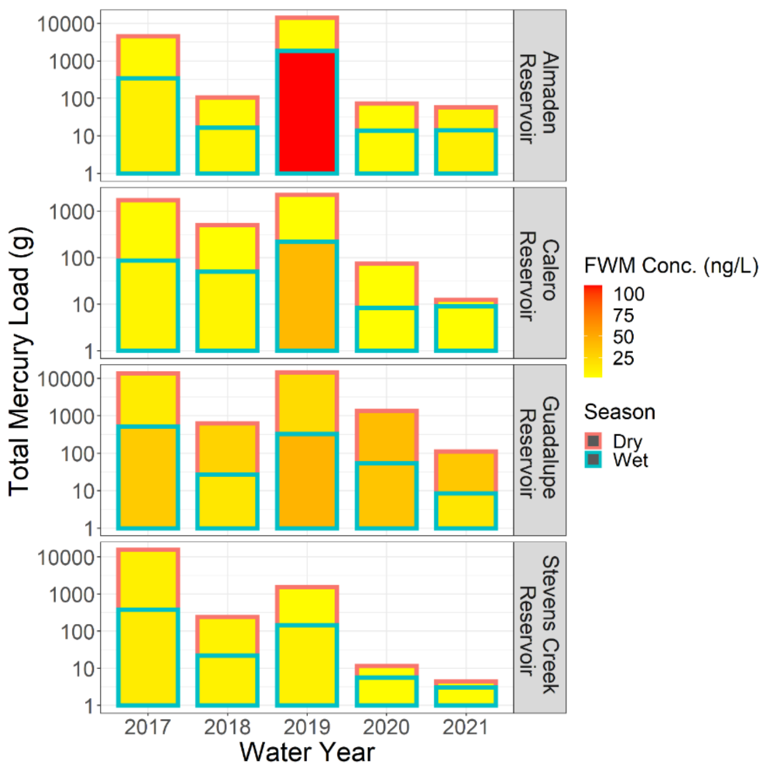

Figure 28: Total Hg load and flow weighted mean Hg concentration by season.

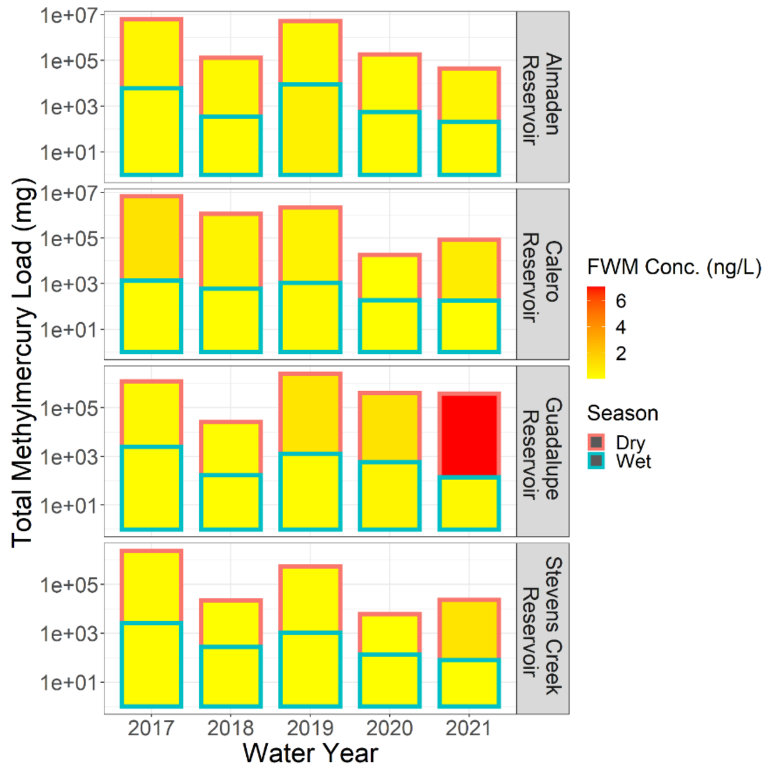

Figure 29: Total MeHg load and flow weighted mean MeHg concentration by season.

4.6 Discussion of Key Findings from Reporting Period (2020-2021)

MeHg and Ancillary Water Quality

Water quality results from 2020-2021 were consistent with those reported in Seelos et al., 2021. The HOSs were effective at oxygenating the sediment-water interface of all reservoirs except Calero. In Almaden, Guadalupe, and Stevens Creek reservoirs, high dissolved oxygen concentrations propagated throughout the hypolimnion, maintaining an oxic sediment-water interface throughout the reservoirs. Calero Reservoir's hypolimnion commonly remained hypoxic (DO < 3 mg/L) during oxygenation. This is likely due to the system at Calero Reservoir being undersized to meet unanticipated chemical oxygen demand and oxygen demand induced by the system.

Mixing effects of the HOSs degraded water quality. Bottom water temperatures increased significantly (1.8 – 5.5 °C) in all reservoirs except Almaden Reservoir. Temperature increase in reservoir bottom water is of concern because it equates to increases in outflow temperature, which can negatively affect downstream cold-water fish. Surprisingly, oxidation-reduction potential decreased significantly in surface waters of all reservoirs during oxygenation. This could be due to rising bubble plumes transporting reduced profundal water to the reservoir surface. This is concerning because profundal water is rich in nutrients that can stimulate algal blooms upon transport to the photic zone. This was evidenced by significant increases in chlorophyll *α* and phycocyanin in surface waters of each reservoir during oxygenation.

Though MeHg concentrations decreased significantly in bottom waters of all reservoirs during oxygenation, MeHg concentrations in surface waters were unchanged or increased. We previously determined that whole water column MeHg concentrations were similar before and after oxygenation (Seelos et al., 2021). Thus, it is likely that the observed decreases in hypolimnetic MeHg were due to dilution throughout the water column as opposed to the inhibition of MeHg production. Because the introduction of MeHg into pelagic food webs occurs largely in the photic zone, it is important to decrease MeHg in surface waters to achieve MeHg reductions in fish. It appears that MeHg production continued in sediments (profundal and littoral) and the water column during oxygenation.

Bottom-release reservoirs present a unique challenge for Hg management. In surface-release systems, MeHg is thought to accumulate in the hypolimnion during periods of anoxia and enter the pelagic food web during fall destratification (Herrin et al., 1998; Slotton et al., 1995). However, bottom-release reservoirs discharge profundal water throughout the period of stratification, decreasing the mass of MeHg available for biological uptake at turnover. In fact, hypolimnetic withdrawal is a common management strategy for nutrients that accumulate in the hypolimnion and cause algae blooms during mixing. Hypolimnetic withdrawal helps decrease MeHg concentrations in the reservoir but may make it available for bioaccumulation downstream. In bottom-release systems, MeHg production in the hypolimnion is of less importance than MeHg production in littoral sediments and the water column, which provide MeHg to the photic zone all year (Seelos et al., 2021). Thus, it is important to address these sources when managing a bottom-release reservoir.

Hg in Fish

With the inclusion of the summer 2021 sampling event, trends in fish tissue Hg differed slightly from those reported in Seelos et al., 2021. Previously, we noted declining trends in Guadalupe and Stevens Creek reservoirs. Strong declining trends in fish Hg persist in Guadalupe and Stevens Creek reservoirs despite Valley Water not operating their HOSs in summer 2021. However, fish Hg in Almaden Reservoir now had a statistically significant declining trend of -0.05 mg/kg/year. Despite noteworthy declines in fish Hg since the initiation of oxygenation in Almaden, Guadalupe, and Stevens Creek reservoirs, fish tissue Hg concentrations remain similar to those measured immediately prior to beginning the oxygenation program. Fish from all reservoirs exceed target concentrations (0.05 mg/kg for TL3 fish <150 mm), with 100 mm length-standardized largemouth bass about 2x the target in Stevens Creek Reservoir, and over 10x the target in Guadalupe Reservoir. The fact that declining trends in Guadalupe and Stevens Creek reservoirs persist despite nonoperation of the HOSs suggest that other factors contribute to the declining trends, such as source control efforts or changes in primary productivity.

Fish Hg in Calero Reservoir now had a statistically significant increasing trend of +0.005 mg/kg/year. While this trend is statistically significant, it is too small to be practically meaningful. Additionally, the statistical significance of this trend could easily be lost with the addition of another sampling event that differs from recent data. Thus, fish tissue Hg concentrations in Calero Reservoir should be thought of as unchanged.

Hg and MeHg Loads

Estimated Hg and MeHg loads from reservoirs were relatively low during the reporting period due to do minimal reservoir outflow during drought conditions. Reservoir outflow has a large influence on Hg and MeHg loads because it is more variable than Hg and MeHg concentrations. Wet years may result in greater Hg and MeHg loads to downstream creeks because high-flow releases transport sediments to which Hg and MeHg are strongly sorbed. Hg and MeHg loading therefore should not be used to determine the effectiveness of source control efforts or engineered treatment systems.

Flow-weighted mean Hg and MeHg concentrations are useful to assess relative differences in Hg and MeHg yield over time and between different reservoirs. Flow-weighted mean total Hg concentrations were greatest in the wet seasons of high-water years when high-volume outflows mobilized sediments. Flow-weighted mean MeHg concentrations were highest during the dry season when MeHg production peaked. Without oxygenation, flow weighted mean MeHg concentrations in Guadalupe and Stevens Creek reservoirs were notably higher in 2021 than in recent years (Table 10, Table 11).

4.7 Lessons Learned and Recommendations for Reporting Period 2022-2023.

Along with significant operational and maintenance challenges, recent findings have highlighted the questionable effectiveness of line-diffuser hypolimnetic oxygenation as a Hg management strategy in bottom-release reservoirs, as well as problematic side effects such as vertical mixing and increase in outflow temperature. We make recommendations for future HOS installations, and major program modifications for implementation of the Guadalupe River Watershed Hg TMDL during the 2022-2023 reporting period. These recommendations emphasize reallocating resources away from routine monitoring and into studies that aim to minimize harmful side-effects of oxygenation and develop management alternatives. Our recommendations are separated into four categories: treatment system improvements (of both line-diffuser HOS and solar circulators), routine monitoring cuts, oxygenation studies and adaptive management, and additional studies.

Recommendation 1: Treatment System Improvements

1.1) Avoid Onsite Oxygen Generation Where Possible

The major challenge in keeping the HOSs operational was onsite oxygen generation. Oxygen generation requires consistent 480-volt power to operate the air compressors. The reservoirs are in rural areas and have power distribution systems that often experience failures or voltage fluctuations. This caused frequent shutdowns that had to be manually reset. Additionally, the high ambient air temperatures at the reservoirs during summer operation resulted in additional compressor shutdowns due to overheating. Sometimes compressors could be manually reset after overheating, but occasionally overheating events necessitated major repairs. To avoid overheating, Valley Water staff shut down the systems prior to forecasted periods of high temperature, when they were most needed to combat biochemical oxygen demand. Additionally, maintaining functionality of the air compressors and oxygen generators necessitated biweekly inspections and biannual maintenance, which was costly and labor intensive. We recommend the use of liquid oxygen for future HOS installations where possible. The use of liquid oxygen would avoid many of the operation and maintenance challenges described above. However, liquid oxygen deliveries require the use of multi-axle tanker trucks that exceed the weight and length limits of many rural roads and access roads, including most that serve Valley Water reservoirs.

1.2) Use Supersaturation Systems in Small Reservoirs to Minimize Mixing

The line diffuser HOSs degraded water quality primarily due to mixing induced by rising bubble plumes. This mixing increased temperature and turbidity in reservoir outflow, and likely transported profundal nutrients and metals into surface waters. The transfer efficiency of fine bubbles is relatively low in shallow reservoirs, as evidenced by surface bubbling during HOS operation. Low transfer efficiency is wasteful, and it increases mixing effects. A better alternative to line diffuser systems would minimize mixing effects while increasing oxygen transfer efficiency. The Speece cone and side-stream HOSs are supersaturation systems that intake water, dissolve oxygen in it, and discharge oxygen-rich (but bubble-free) water into the hypolimnion. Though these systems could be preferable alternatives to line diffusers in small reservoirs, oxygen supersaturation can increase water temperature. For example, discharge of oxygenated water into the hypolimnion and loss of excess oxygen can also cause unintended mixing effects that may present the same problems as line diffuser systems. Nonetheless, supersaturation systems may avoid some of the harmful mixing effects that the line-diffuser systems cause and result in better water quality.

1.3) Conduct Proper Sizing Studies that Account for Induced Oxygen Demand

The delivery capacity of the Calero Reservoir HOS (675 kg O_2/day) was designed to exceed oxygen demands of 310 kg O_2/day, estimated using springtime water column DO depletion rates from 1999 to 2002 (Brown and Caldwell, 2005). This method likely underestimated true biochemical oxygen demands in Calero Reservoir and did not account for additional oxygen demands induced by system operation. Increased turbulence and DO concentration at the sediment-water interface can enhance oxygen flux into sediment, a phenomenon known as induced oxygen demand (Beutel, 2003; Gantzer et al., 2009). Induced oxygen demands during oxygenation (turbulent, high-oxygen conditions) can exceed oxygen demands under quiescent, low-oxygen conditions many times over (Beutel, 2003). Thus, it is essential to upscale estimated oxygen demands to account for induced oxygen demand when sizing HOSs. Sonde profile DO measurements do not incorporate the spatial variability of reservoir oxygen demand throughout a reservoir, nor do they include "oxygen debt" incurred by the accumulation of reduced compounds that consume oxygen (NH_3, Fe^{2+}, Mn^{2+}, HS^-, etc.). Careful sediment and water incubation studies are needed to adequately quantify biochemical oxygen demands on a whole-reservoir scale over the range of possible oxidation-reduction conditions. Failure to incorporate these factors could lead to a system that is undersized to exceed natural oxygen demands.

1.4) Use Less Energy-Intensive Systems

Climate change is expected to degrade water quality in reservoirs by increasing surface temperatures and prolonging summer stratification (Feldbauer et al., 2020). There is overwhelming consensus among the scientific community that climate change is caused by human activities including fossil fuel combustion for power generation (Lynas et al., 2021). Though hypolimnetic oxygenation may mitigate the effects of climate change in some reservoirs, oxygen generation is an energy intensive process. From 2016 to 2019, when the operation of the HOSs was most consistent, the four systems consumed an average of about 540,000 kW h per year, totaling nearly $86,000 annually (Table 1). This annual energy consumption is equal to approximately 50 single family homes (United States Energy Information Administration). Not only could these high energy costs be prohibitive for some reservoir owners, but excessive energy usage from non-renewable sources exacerbates anthropogenic climate change. Industrial production of liquid oxygen is also an energy intensive process. Cost-benefit analyses are needed to weigh the carbon emissions incurred by the operation of reservoir HOSs against potential reductions in greenhouse gas efflux from reservoirs due to the systems.

<u>1.5) Halt use of solar circulators in Almaden Lake</u>

The four solar circulators in Almaden Lake were ineffective at improving dissolved oxygen saturation in bottom water (Figure 3, Figure 7). Though the circulators caused exchange between surface and bottom waters, they did not destratify the water column in their immediate vicinity or the lake at large. Since the sediment-water interface remained anoxic, reducing processes continued unabated. Reduced species like nutrients and metals were likely mixed throughout the water column, likely causing decreases in the hypolimnion from dilution rather than decreased internal loading. High nutrients and metals in surface waters can cause harmful algal blooms and degrade water quality. We also propose decreasing monitoring frequency at Almaden Lake (Recommendation 2.2 below).

Artificial destratification is not recommended in bottom-release reservoirs due to probable outflow temperature increases, but it may be a viable option in hydrologically disconnected lakes and ponds. When artificial destratification is used, it should be applied with an “all-or-nothing” approach. Exchange of surface and bottom waters is problematic if the sediment-water interface remains anoxic. Fountains or bubble plume destratification systems will likely outperform solar circulators in achieving complete destratification.

Recommendation 2: Cuts in Routine Monitoring

2.1) Decrease reservoir water sampling to monthly.

After over five years of bimonthly (twice per month) water sampling, a high monitoring frequency is no longer necessary to evaluate the effects of the reservoir HOSs. Valley Water proposes decreasing water sampling in each reservoir to a monthly frequency throughout the year. If a rare environmental event, such as rapid draining or refilling is anticipated, Valley Water may decide to increase monitoring frequency as needed. Likewise, if a major management change is implemented (e.g., changing the type of HOS), Valley Water may decide to return to more frequent monitoring.

2.2) Decrease Almaden Lake water sampling to quarterly.

Almaden Lake will be separated from Alamitos Creek through a capital project scheduled to begin construction in 2022. Valley Water has been collecting water quality data in Almaden Lake since 2005, providing ample information to establish baseline conditions. Further intensive monitoring of Almaden Lake is not warranted. We propose decreasing monitoring of Almaden Lake to quarterly, with the primary goal of assessing general water quality relevant to recreational uses (e.g., harmful algal blooms).

2.3) Decrease fish Hg sampling to once annually, unless water levels permit access by electrofishing boat.

Consistently low reservoir levels have led Valley Water to rely on hook-and-line fish sampling during summer in Almaden, Guadalupe, and Stevens Creek reservoirs. This sampling method is inefficient, requiring extensive staff time, and may not yield results that are comparable to the random sampling that electrofishing produces. We propose decreasing fish sampling to once-annually, completed in the springtime, unless water levels permit access by electrofishing boat during the late summer. If a summer sampling event is missed due to low water levels, extra remediation effectiveness indicator fish will be collected when possible.

Recommendation 3: Oxygenation Studies and Adaptive Management

3.1) Conduct engineering calculations to determine if HOS operation can be optimized to meet creek temperature targets.

The mixing effects of line diffuser HOSs cause hypolimnetic warming that threatens downstream cold water fish habitat. It is unknown whether system operation can be optimized to maintain oxic conditions at the sediment-water interface while minimizing temperature increases. Valley Water will hire Gantzer Water Resources Engineering, LLC to estimate potential hypolimnetic warming attributable to HOS operation under three flow rates (3, 6, and 12 standard cubic feet per minute) and reservoir levels (high, medium, and low capacity). This will help Valley Water determine whether they can operate the HOSs in such a way to maintain cold water outflows and meet temperature targets. It will not, however, predict oxygenation effectiveness.

3.2) Halt oxygenation if unacceptable temperature increase cannot be avoided during HOS operation.

If Valley Water determines that it is impossible to operate HOSs in a way that preserves cold water outflows, it will halt oxygenation in Guadalupe and Stevens Creek reservoirs. Guadalupe and Stevens Creek reservoirs are of particular importance because they provide water to cold water management zones downstream as part of the Fisheries and Aquatic Habitat Collaborative Effort. Valley Water will study alternatives to oxygenation for reservoir Hg control as described below, with the intention of developing an effective system for reservoirs that does not cause mixing or temperature increase.

<u>Recommendation 4: Additional Studies</u>

4.1) Study local atmospheric deposition of Hg in the New Almaden Mining District

The various sources of Hg to impaired reservoirs are incompletely quantified. Past studies of Hg sources near the New Almaden Mining District have focused on sediment runoff from the mines as a source of Hg to the Guadalupe River Watershed and the San Francisco Bay. However, little attention has been paid to local atmospheric sources, namely gaseous Hg emissions from the mines followed by dry deposition to the surface. Part of the reason for this data gap is that atmospheric Hg monitoring is difficult and expensive. However, the use of lichens as natural bioindicators of atmospheric deposition is a cost-effective solution. Through uptake of atmospheric Hg into the tissue of the lichen, the Hg concentration in lichen represents a time-averaged indicator of local atmospheric deposition. Detailed sampling is needed to identify areas that may be contributing atmospheric Hg to Valley Water reservoirs. The identification of these areas could help Valley Water and mine owners address key hot spots that provide Hg to the watershed. Valley Water plans to partner with the Weiss-Penzias Laboratory (University of California, Santa Cruz) to study local atmospheric deposition of Hg in the New Almaden Mining District. Valley Water and UCSC will work with the Regional Board to identify sampling sites and develop a study plan.

4.2) Study sorbent treatment methods as an alternative to oxygenation in Guadalupe Reservoir.

Recent studies have shown that sorbents (activated carbon, modified clays, surface-functionalized materials, etc.) can be effective for remediation of Hg in aquatic systems. Sorbent treatment methods are preferable to oxygenation because they are usually static and thus do not cause mixing. Sorbent amendments could be applied as a sediment cap, passive “teabag” absorbent, or a filter element in pump-through systems. Valley Water proposes conducting laboratory studies to evaluate the use of various sorbents and application methods using Guadalupe Reservoir water and sediment. The goal of these experiments will be to develop a method that could be used in a field trial in Guadalupe Reservoir in lieu of hypolimnetic oxygenation. Valley Water plans to enter a collaborative agreement with the Beutel and O’Day Laboratories (University of California, Merced) to conduct a two-year laboratory evaluation. Valley Water will submit a scope of work to the Regional Board for comment prior to beginning the study.

5 Additional Activities Updates

5.1 Presentations

Valley Water presented findings at several conferences and meetings during the reporting period:

- Seelos, Mark; Rivas, Edwin. “Manganese Oxide and Activated Carbon Amendments for Sediment Hg Remediation" Poster Presentation, Waste Management Symposium. Phoenix, AZ, March 2020.
- Seelos, Mark. “Reservoir Oxygenation for Hg Remediation Update" Oral Presentation, Delta Tributaries Hg Council. Virtual, September 2020.
- Seelos, Mark. Lake Management Expert Panel Discussion, California Lake Management Society Annual Conference. Virtual, October 2020.
- Seelos, Mark. “Slow Progress with Quicksilver" Keynote Address, California Lake Management Society Annual Conference. Virtual, October 2020.
- Seelos, Mark. “Hypolimnetic Oxygenation to Control Hg Bioaccumulation in Lakes: Two Case Studies" Oral Presentation, California Aquatic Bioassessment Workgroup (State Water Resources Control Board). Virtual, October 2020.
- Seelos, Mark. “Line Diffuser HOS: A Pyrrhic Victory for DO?" North American Lake Management Society Annual Conference. Virtual, November 2020.
- Seelos, Mark. “Hg Cycling in Lakes and Reservoirs." Guest Lecture: Mixing and Transport in Estuaries and Wetlands graduate-level course. University of California, Davis. April 2021.

- Wilkinson, Elisabeth. “Slow Progress with Quicksilver: Lowering Fish Hg in Mine Impacted Reservoirs using Hypolimnetic Oxygenation” Oral Presentation, National Water Quality Monitoring Council 12th National Monitoring Conference. Virtual, April 2021.

- Trevino, Olivia. “Guadalupe River Watershed Hg TMDL Program” Poster Presentation, CASQA Annual Conference Scholarship Program. Virtual, October 2021.

5.2 USGS Water Column Methylation Study

Valley Water, in collaboration with the U.S. Geological Survey (USGS), designed a study to assess variability in the rates of water column MeHg production potential (WC.MPP) between Almaden, Calero, Guadalupe, and Stevens Creek Reservoir. The collaborative effort also examined seasonal variability of WC.MPP rates within each reservoir, vertical variability of WC.MPP rates within the water column, and the effects of water column particulates and dissolved oxygen concentration on the WC.MPP rate.

An adapted Hg stable isotope amendment was used to measure WC.MPP rates in the laboratory from water samples collected from the reservoirs May 14-16, 2019 and August 27-28, 2019. During these sampling events, a vertical profile was taken using a multiparameter sonde to measure temperature, pH, specific conductivity, oxidation-reduction potential, fluorescent algal pigments, and dissolved oxygen. Five depths associated with temperature and dissolved oxygen inflection points were identified in the water column profile on site and selected as sampling depths. Approximately 2 liters of water were collected at each of five water sampling depths. A water column seston (10 μm or 64 μm fraction) was also collected using a vertical plankton tow to collect water column particulates.

In the laboratory, each 2-liter sample was sub-sampled into 8 100ml serum bottles providing two sets of samples per depth at each site. Two experimental treatments were applied to the set of water samples. The experimental treatments included raw (unfiltered) water samples and raw water amended with additional suspended particulate matter (SPM) that was collected using the water column seston. Additional SPM increases the abundance of naturally occurring bacteria involved in water column MeHg production and thus increases the signal for detecting the microbial process of methylation. Incubations were initiated by the addition of the enriched ^{200}Hg(II) stable isotope tracer and carried out for 24 hours until the incubations were arrested by acidification. The produced and isotopically enriched Me^{200}Hg were extracted from the original sample via distillation and quantified via isotope dilution Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Sub-samples were also collected from samples taken at each depth at each site and were analyzed for reactive inorganic Hg that was then used in the calculation of the WC.MPP rate. Dissolved oxygen was measured at the beginning and end of the incubation period and sub-samples of the concentration seston from each reservoir was freeze-dried to calculate the dry weight mass that was added to amended incubation bottles. Samples collected in August were subject to an additional amendment of isotopically enriched $Me^{201}Hg$ to measure water column MeHg degradation.

The primary, non-interpretive data are publicly available as a USGS Science Base product that was prepared in accordance with USGS review and approval procedures (https://doi.org/10.5066/P9N7LEER). These data will support a final interpretive product in the form of a USGS Open-File report. Valley Water will notify the Regional Board when this report is publicly available.

5.3 Food Web Study

In summer 2019, Valley Water initiated a study aiming to assess the factors governing the uptake of Hg and MeHg into SPM and zooplankton in the four reservoirs over four seasons from 2019 to 2021. We focused on uptake into the base of the pelagic food web because this is known to be the key step that controls MeHg concentration in fish (Lehnherr, 2014; Ogorek et al., 2021; Wu et al., 2019). Combining water chemistry data, algal and zooplankton taxonomic composition, and stable C and N isotope values of SPM and zooplankton samples, we investigated key differences between the reservoirs that may contribute to discrepancies in Hg and MeHg biomagnification. Valley Water completed four seasonal monitoring events (Summer 2019, Winter 2020, Fall 2020, Spring 2021). Laboratory data analysis has been completed. Valley Water is currently working with coauthors to develop a technical report or manuscript detailing the results. This deliverable is expected to be completed prior to August 2022.

5.4 Evaluation of Manganese Oxide Amendments for Hg Remediation in Contaminated Aquatic Sediments

University of California, Merced received funding from the United States Department of Energy Minority Serving Institution Partnership Program (MSIPP) to study the use of reactive amendments for Hg control in contaminated aquatic sediments. This project was managed by the Savannah River National Laboratory under SRNS Contract DE-AC09-08SR22470. Valley Water Associate Water Resources Specialist Mark Seelos served as lead author to an initial study using slurry incubations to assess the effects of manganese oxide and activated carbon amendments on Hg speciation and distribution in sediments collected from Guadalupe Reservoir. The goal of the work was an early-stage assessment of the feasibility of applying solid phase sediment amendments in a field setting.

Manganese oxide and activated carbon amendments decreased MeHg in sediment porewater with similar effectiveness. However, amended sediments experienced increases in solid phase MeHg that could not be accounted for by sorption from the aqueous phase. This indicates that the amendments did not inhibit Hg methylation. Sediments amended with manganese oxide experienced notable release of sulfate and inorganic Hg into porewater. This could stimulate MeHg production if the oxidation-reduction potential dropped to potentials that favor Hg methylation. The manganese oxide amendments were rapidly converted to Mn^{2+} as aqueous and sorbed species. This reductive dissolution occurred too quickly for amendment longevity in a field setting. Further development is needed to slow reductive dissolution of the manganese amendments and limit the release of potentially problematic byproducts such as Mn^{2+} and Hg(II). A manuscript was published in Environmental Science and Technology Engineering (https://doi.org/10.1021/acsestengg.1c00267).

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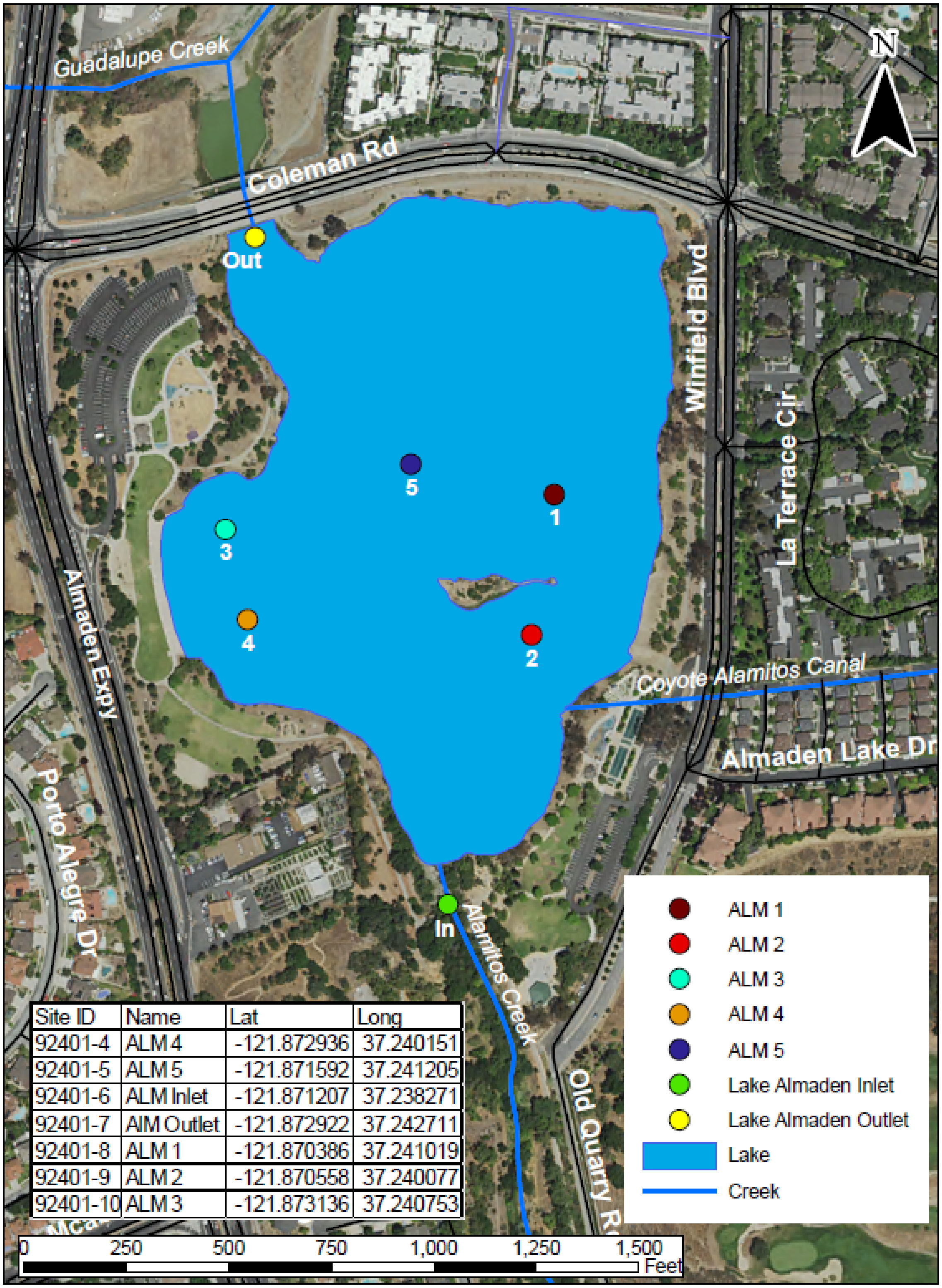
Appendix A



Site ID	Name	Lat	Long
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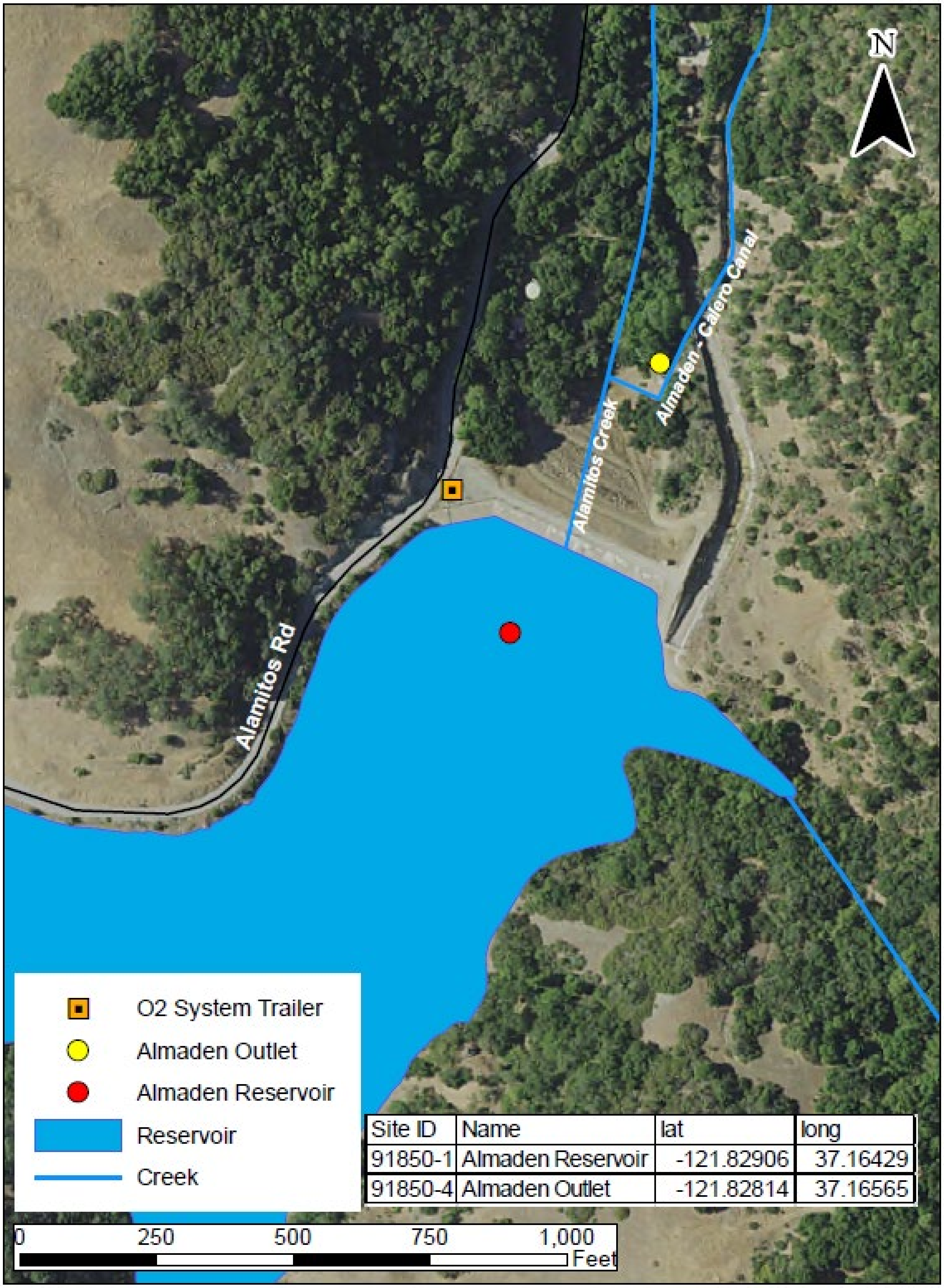
92401-5	ALM 5	-121.871592	37.241205
92401-6	ALM Inlet	-121.871207	37.238271
92401-7	AlM Outlet	-121.872922	37.242711
92401-8	ALM 1	-121.870386	37.241019
92401-9	ALM 2	-121.870558	37.240077
92401-10	ALM 3	-121.873136	37.240753

Figure A 1: Almaden Lake sampling sites



Site ID	Name	lat	long
91850-1	Almaden Reservoir	-121.82906	37.16429
91850-4	Almaden Outlet	-121.82814	37.16565

Figure A 2: Almaden Reservoir sampling site

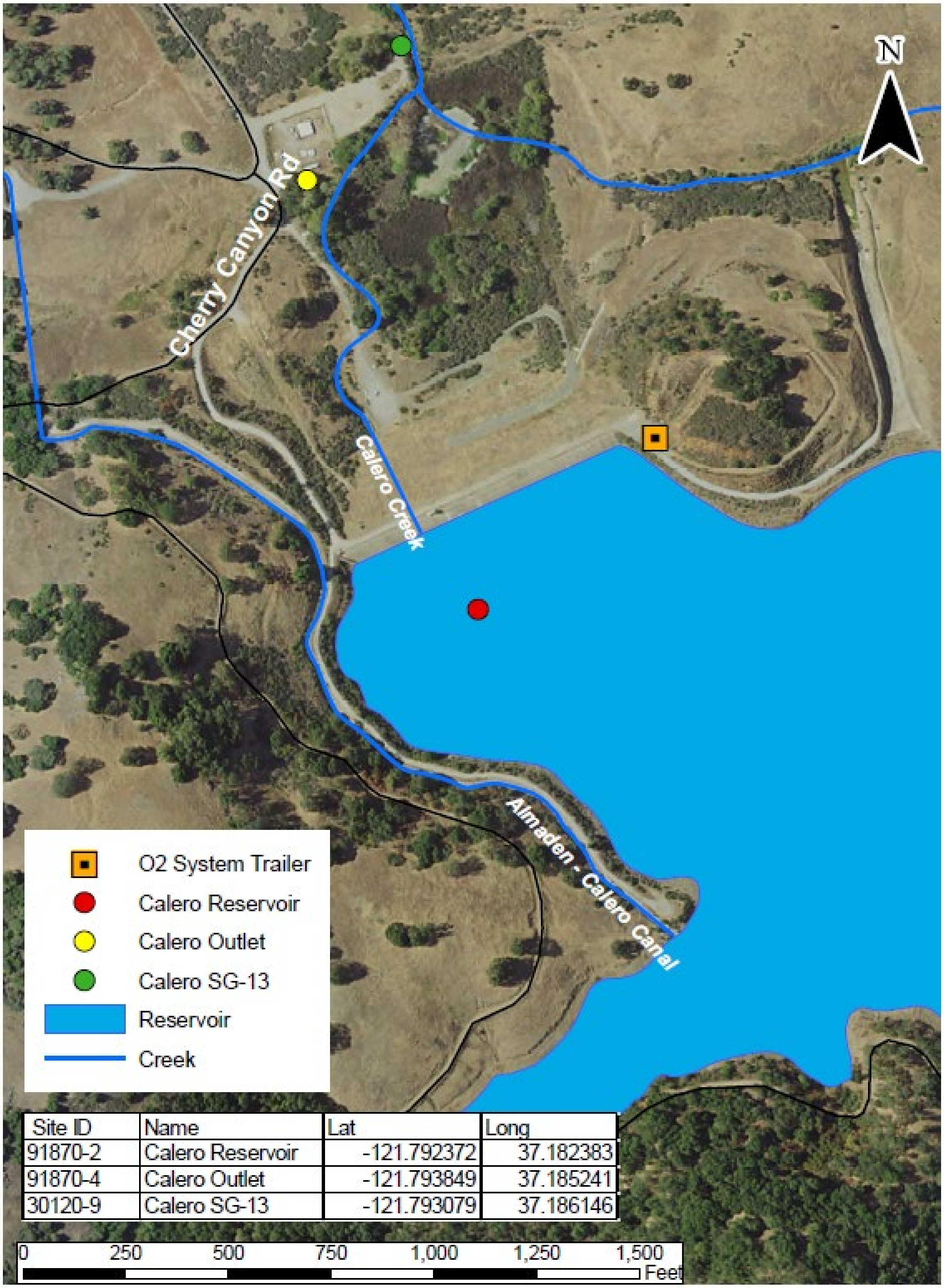
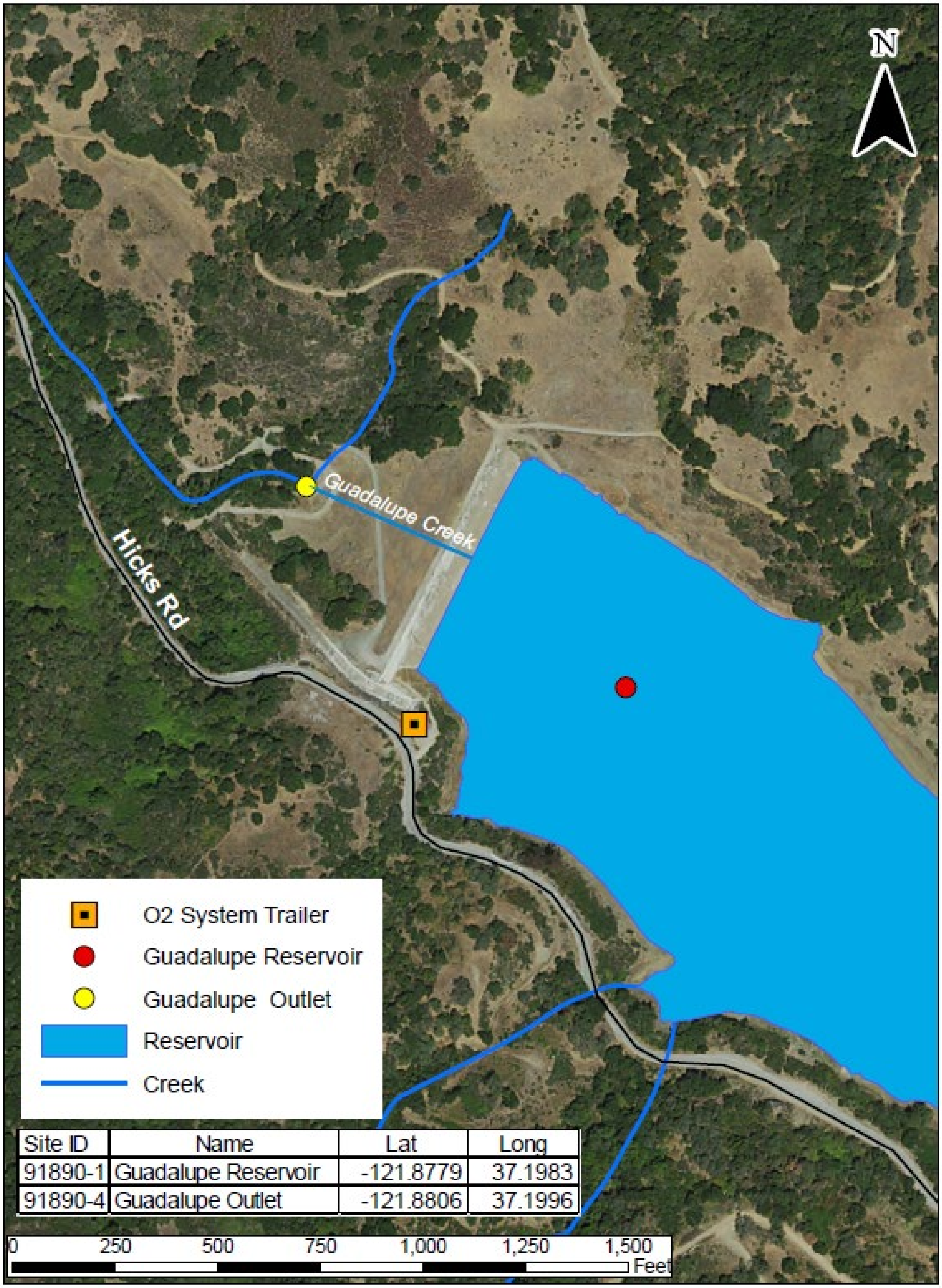


Figure A 3: Calero Reservoir sampling site



Site ID	Name	Lat	Long
91890-1	Guadalupe Reservoir	-121.8779	37.1983
91890-4	Guadalupe Outlet	-121.8806	37.1996

Figure A 4: Guadalupe Reservoir sampling site

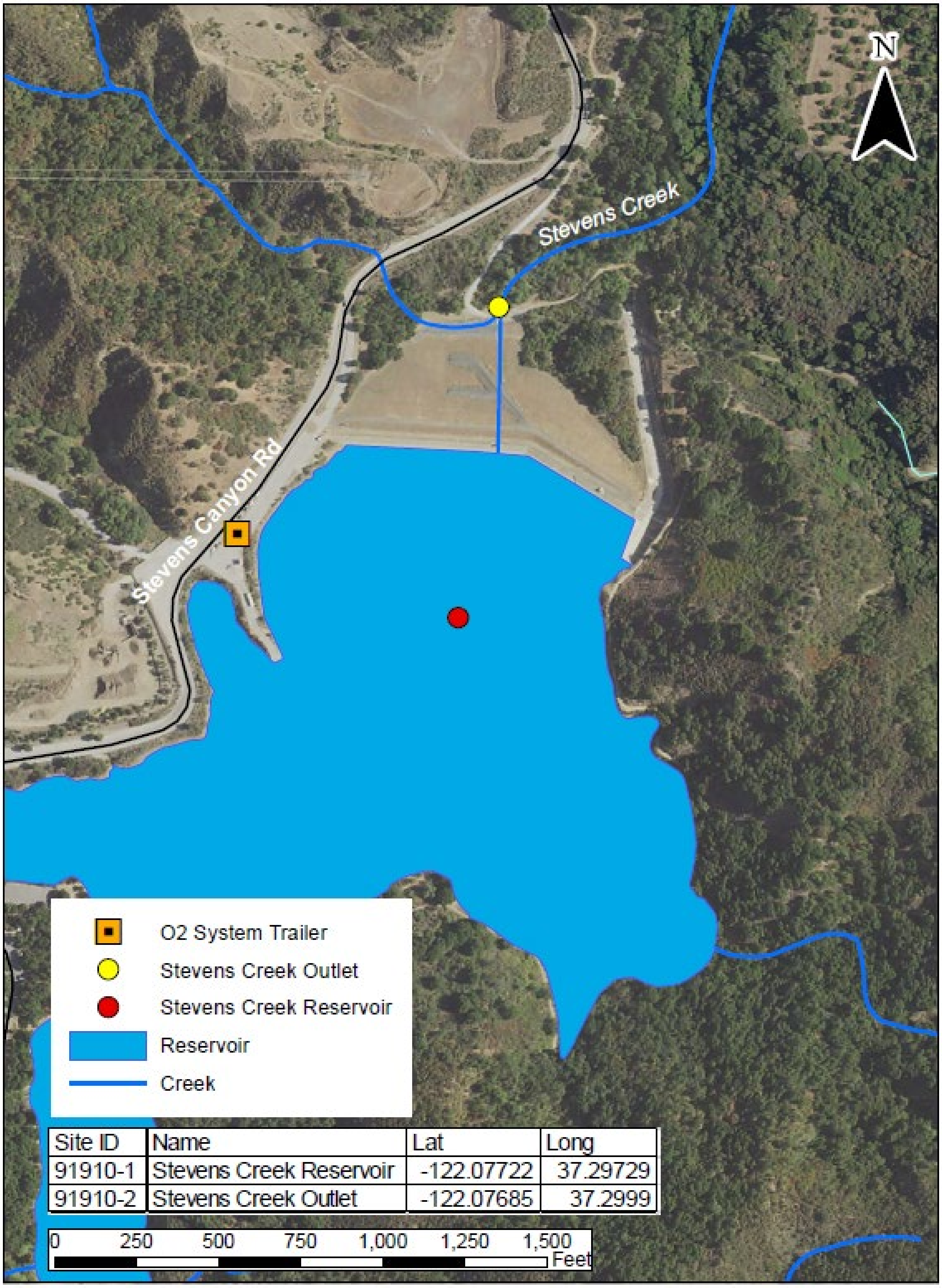


Figure A 5: Stevens Creek Reservoir sampling site

Table A 1: Statistical summary of water quality data comparing dry season (May-Sept) data from pre-HOS years (OFF) to when HOS was operational (ON)

Line	Reservoir	Depth	HOS	Analyte	Mean	Med	Sd	n	Method	P-value	Sig.Level[a]
1	Almaden Lake	EPI	OFF	Ammonia (mg/L)	0.114909	0.095	0.068938	24	CENDIFF	0.172	
2	Almaden Lake		ON		0.326491	0.12	1.597759	97	CENDIFF	0.172	
3	Almaden Reservoir		OFF		0.129578	0.098	0.121435	85	CENDIFF	0.187	
4	Almaden Reservoir		ON		0.10177	0.085	0.107685	39	CENDIFF	0.187	
5	Calero Reservoir		OFF		0.179599	0.096	0.245689	83	CENDIFF	0.061	
6	Calero Reservoir		ON		0.113277	0.085	0.080391	39	CENDIFF	0.061	
7	Guadalupe Reservoir		OFF		0.144868	0.108	0.199156	83	CENDIFF	0.004	**
8	Guadalupe Reservoir		ON		0.097727	0.081	0.051014	44	CENDIFF	0.004	**
9	Stevens Creek Reservoir		OFF		0.097043	0.077	0.101522	31	CENDIFF	0.013	*
10	Stevens Creek Reservoir		ON		0.118832	0.096	0.050782	35	CENDIFF	0.013	*
11	Almaden Lake	HYP	OFF		2.81676	2.6	2.064881	25	CENDIFF	0	***
12	Almaden Lake		ON		0.922125	0.59	1.135228	96	CENDIFF	0	***
13	Almaden Reservoir		OFF		0.210723	0.16	0.265141	84	CENDIFF	0	***
14	Almaden Reservoir		ON		0.104201	0.092	0.093651	39	CENDIFF	0	***
15	Calero Reservoir		OFF		0.271051	0.18	0.262213	83	CENDIFF	0.054	
16	Calero Reservoir		ON		0.181403	0.13	0.144847	40	CENDIFF	0.054	
17	Guadalupe Reservoir		OFF		0.45406	0.369	0.408318	83	CENDIFF	0	***
18	Guadalupe Reservoir		ON		0.140301	0.11	0.090197	44	CENDIFF	0	***
19	Stevens Creek Reservoir		OFF		0.191367	0.141	0.127972	31	CENDIFF	0.05	
20	Stevens Creek Reservoir		ON		0.142904	0.11	0.098355	35	CENDIFF	0.05	
21	Almaden Lake	EPI	OFF	Chlorophyll (ug/L)	18.26455	8.43	22.72632	11	Kruskal Wallis	0.194	
22	Almaden Lake		ON		21.13232	13.83	19.0196	95	Kruskal Wallis	0.194	
23	Almaden Reservoir		OFF		3.445342	1.93	3.946787	73	Kruskal Wallis	0.001	**
24	Almaden Reservoir		ON		4.456842	4.325	3.086182	38	Kruskal Wallis	0.001	**
25	Calero Reservoir		OFF		8.422	7.13	4.871513	70	ANOVA	0	***
26	Calero Reservoir		ON		12.06795	12	5.092358	44	ANOVA	0	***

27	Guadalupe Reservoir		OFF		1.8945	1.64	0.987022	70	Kruskal Wallis	0.646	
28	Guadalupe Reservoir		ON		1.919048	1.595	1.292237	42	Kruskal Wallis	0.646	
29	Stevens Creek Reservoir		OFF		2.739318	1.73	3.105208	44	ANOVA	0.018	*
30	Stevens Creek Reservoir		ON		3.035714	2.66	1.461762	35	ANOVA	0.018	*
31	Almaden Reservoir		OFF		4.445455	4.31	2.824438	33	Kruskal Wallis	0.365	
32	Almaden Reservoir		ON		5.072105	4.39	3.21387	38	Kruskal Wallis	0.365	
33	Calero Reservoir		OFF		8.540244	6.41	6.963379	41	ANOVA	0.004	**
34	Calero Reservoir	EPIM	ON		11.19605	10.77	5.179408	43	ANOVA	0.004	**
35	Guadalupe Reservoir		OFF		3.893721	4.12	2.272163	43	Kruskal Wallis	0.018	*
36	Guadalupe Reservoir		ON		5.58878	2.08	17.98234	41	Kruskal Wallis	0.018	*
37	Stevens Creek Reservoir		OFF		3.8612	2.72	2.88044	25	ANOVA	0.224	
38	Stevens Creek Reservoir		ON		4.515152	3.48	3.285374	33	ANOVA	0.224	
39	Almaden Lake		OFF		15.56545	7.78	23.2247	11	Kruskal Wallis	0.078	
40	Almaden Lake		ON		5.779167	3.725	6.686882	96	Kruskal Wallis	0.078	
41	Almaden Reservoir		OFF		3.493514	2.285	3.23625	74	Kruskal Wallis	0.002	**
42	Almaden Reservoir		ON		4.732368	4.225	3.259494	38	Kruskal Wallis	0.002	**
43	Calero Reservoir	MID	OFF		2.627286	2.175	1.270561	70	Kruskal Wallis	0	***
44	Calero Reservoir		ON		5.659767	4.7	3.297574	43	Kruskal Wallis	0	***
45	Guadalupe Reservoir		OFF		1.941286	1.64	1.58519	70	Kruskal Wallis	0	***
46	Guadalupe Reservoir		ON		2.632143	2.3	1.158425	42	Kruskal Wallis	0	***
47	Stevens Creek Reservoir		OFF		2.578372	2.01	2.186359	43	ANOVA	0.004	**
48	Stevens Creek Reservoir		ON		3.842941	3.305	2.431837	34	ANOVA	0.004	**
49	Almaden Reservoir		OFF		2.311818	1.47	2.335967	33	Kruskal Wallis	0.002	**
50	Almaden Reservoir		ON		3.449189	3.02	2.574152	37	Kruskal Wallis	0.002	**
51	Calero Reservoir		OFF		2.0245	1.65	1.252315	40	Kruskal Wallis	0	***
52	Calero Reservoir	MIDH	ON		3.170698	2.4	1.917219	43	Kruskal Wallis	0	***
53	Guadalupe Reservoir		OFF		2.343333	1.51	4.281294	45	Kruskal Wallis	0.434	
54	Guadalupe Reservoir		ON		1.86881	1.555	1.007298	42	Kruskal Wallis	0.434	
55	Stevens Creek Reservoir		OFF		2.1952	1.91	1.384076	25	ANOVA	0.559	

56	Stevens Creek Reservoir		ON		2.054412	1.81	1.265994	34	ANOVA	0.559	
57	Almaden Lake		OFF		2.920769	2.14	1.987341	13	Kruskal Wallis	0.771	
58	Almaden Lake		ON		2.728351	2.22	1.995853	97	Kruskal Wallis	0.771	
59	Almaden Reservoir		OFF		2.012895	1.18	2.299682	76	Kruskal Wallis	0.003	**
60	Almaden Reservoir		ON		2.693421	1.875	2.503945	38	Kruskal Wallis	0.003	**
61	Calero Reservoir	HYP	OFF		1.821528	1.595	1.078322	72	Kruskal Wallis	0	***
62	Calero Reservoir		ON		2.707273	2.265	1.498609	44	Kruskal Wallis	0	***
63	Guadalupe Reservoir		OFF		1.461918	1.41	0.625126	73	Kruskal Wallis	0.151	
64	Guadalupe Reservoir		ON		1.413333	1.285	0.741865	42	Kruskal Wallis	0.151	
65	Stevens Creek Reservoir		OFF		1.827727	1.335	1.391474	44	Kruskal Wallis	0.321	
66	Stevens Creek Reservoir		ON		1.836857	1.55	1.275218	35	Kruskal Wallis	0.321	
67	Almaden Lake		OFF		290.917	274	90.601	12	Kruskal Wallis	0.002	**
68	Almaden Lake		ON		205.97	203	74.785	99	Kruskal Wallis	0.002	**
69	Almaden Reservoir		OFF		300.986	288	62.903	73	ANOVA	0	***
70	Almaden Reservoir		ON		204.532	185	94.497	38	ANOVA	0	***
71	Calero Reservoir	EPI	OFF		272.786	299.5	107.802	70	Kruskal Wallis	0	***
72	Calero Reservoir		ON		152.864	92.5	111.169	44	Kruskal Wallis	0	***
73	Guadalupe Reservoir		OFF		324.027	318	59.275	71	Kruskal Wallis	0	***
74	Guadalupe Reservoir		ON		221.762	195.5	99.28	42	Kruskal Wallis	0	***
75	Stevens Creek Reservoir		OFF	ORP (mV)	269.545	301	106.758	44	Kruskal Wallis	0	***
76	Stevens Creek Reservoir		ON		120.457	75	94.672	35	Kruskal Wallis	0	***
77	Almaden Reservoir		OFF		302.875	306.5	67.395	32	ANOVA	0	***
78	Almaden Reservoir		ON		205.024	185.5	96.416	38	ANOVA	0	***
79	Calero Reservoir		OFF		245.122	298	130.217	41	Kruskal Wallis	0	***
80	Calero Reservoir	EPIM	ON		139.744	82	109.092	43	Kruskal Wallis	0	***
81	Guadalupe Reservoir		OFF		338.172	346	62.764	43	Kruskal Wallis	0	***
82	Guadalupe Reservoir		ON		223.667	195.5	105.646	42	Kruskal Wallis	0	***
83	Stevens Creek Reservoir		OFF		246.4	279	103.339	25	Kruskal Wallis	0	***
84	Stevens Creek Reservoir		ON		117.029	75	95.076	34	Kruskal Wallis	0	***

85	Almaden Lake		OFF		252.583	254	154.152	12	ANOVA	0.03	*
86	Almaden Lake		ON		177.247	179	105.642	97	ANOVA	0.03	*
87	Almaden Reservoir		OFF		304.08	304	79.442	75	ANOVA	0	***
88	Almaden Reservoir		ON		204.321	188	92.953	38	ANOVA	0	***
89	Calero Reservoir	MID	OFF		221.529	219.5	138.94	70	Kruskal Wallis	0.002	**
90	Calero Reservoir		ON		141.295	82.5	115.864	44	Kruskal Wallis	0.002	**
91	Guadalupe Reservoir		OFF		319.325	344	93.425	72	Kruskal Wallis	0	***
92	Guadalupe Reservoir		ON		222.214	202	100.82	42	Kruskal Wallis	0	***
93	Stevens Creek Reservoir		OFF		255.302	293	124.321	43	Kruskal Wallis	0	***
94	Stevens Creek Reservoir		ON		126.686	82	104.221	35	Kruskal Wallis	0	***
95	Almaden Reservoir		OFF		265.563	295.5	121.52	32	ANOVA	0.021	*
96	Almaden Reservoir		ON		202.013	190.5	104.049	38	ANOVA	0.021	*
97	Calero Reservoir		OFF		167.421	100.5	172.119	38	Kruskal Wallis	0.429	
98	Calero Reservoir		ON		123.535	84	133.595	43	Kruskal Wallis	0.429	
99	Guadalupe Reservoir	MIDH	OFF		292.484	335	111.109	45	Kruskal Wallis	0.004	**
100	Guadalupe Reservoir		ON		224.214	204.5	98.455	42	Kruskal Wallis	0.004	**
101	Stevens Creek Reservoir		OFF		185.48	170	133.55	25	Kruskal Wallis	0.044	*
102	Stevens Creek Reservoir		ON		122.676	79.5	110.18	34	Kruskal Wallis	0.044	*
103	Almaden Lake		OFF		11.786	23	193.604	14	Kruskal Wallis	0.21	
104	Almaden Lake		ON		67.362	64	145.575	94	Kruskal Wallis	0.21	
105	Almaden Reservoir		OFF		263.773	297	136.435	75	ANOVA	0.01	*
106	Almaden Reservoir		ON		198.147	194	101.627	38	ANOVA	0.01	*
107	Calero Reservoir	HYP	OFF		176.523	126	177.531	65	Kruskal Wallis	0.034	*
108	Calero Reservoir		ON		96.068	82.5	175.163	44	Kruskal Wallis	0.034	*
109	Guadalupe Reservoir		OFF		207.293	196	136.871	71	Kruskal Wallis	0.399	
110	Guadalupe Reservoir		ON		218.857	195.5	95.781	42	Kruskal Wallis	0.399	
111	Stevens Creek Reservoir		OFF		174.214	165.5	179.513	42	Kruskal Wallis	0.278	
112	Stevens Creek Reservoir		ON		124.943	81	106.185	35	Kruskal Wallis	0.278	
113	Almaden Lake	EPI	OFF		9.281	9.12	3.316	23	ANOVA	0.003	**

114	Almaden Lake		ON		7.28	7.29	2.732	99	ANOVA	0.003	**
115	Almaden Reservoir		OFF		8.55	8.32	0.815	84	Kruskal Wallis	0	***
116	Almaden Reservoir		ON		9.412	9.4	0.903	38	Kruskal Wallis	0	***
117	Calero Reservoir		OFF		8.659	8.57	1.123	81	Kruskal Wallis	0.006	**
118	Calero Reservoir		ON		9.07	9.34	2.039	44	Kruskal Wallis	0.006	**
119	Guadalupe Reservoir		OFF		8.295	8.2	0.756	83	Kruskal Wallis	0.114	
120	Guadalupe Reservoir		ON		8.314	8.54	1.512	42	Kruskal Wallis	0.114	
121	Stevens Creek Reservoir		OFF		8.442	8.375	1.111	56	Kruskal Wallis	0.114	
122	Stevens Creek Reservoir		ON		8.789	8.77	1.002	35	Kruskal Wallis	0.114	
123	Almaden Reservoir		OFF		7.458	8.13	3.008	33	Kruskal Wallis	0.001	**
124	Almaden Reservoir		ON		9.425	9.63	1.539	38	Kruskal Wallis	0.001	**
125	Calero Reservoir		OFF		5.697	6.13	3.235	41	Kruskal Wallis	0.061	
126	Calero Reservoir	EPIM	ON		6.942	8.01	3.388	43	Kruskal Wallis	0.061	
127	Guadalupe Reservoir		OFF	Dissolved Oxygen (mg/L)	5.9	6.41	2.224	43	Kruskal Wallis	0	***
128	Guadalupe Reservoir		ON		7.942	8.45	2.383	42	Kruskal Wallis	0	***
129	Stevens Creek Reservoir		OFF		7.233	7.93	2.024	25	Kruskal Wallis	0.041	*
130	Stevens Creek Reservoir		ON		8.254	8.465	1.202	34	Kruskal Wallis	0.041	*
131	Almaden Lake		OFF		1.374	0.82	1.486	19	Kruskal Wallis	0.165	
132	Almaden Lake		ON		1.206	0.32	1.652	97	Kruskal Wallis	0.165	
133	Almaden Reservoir		OFF		4.804	5.205	3.256	84	Kruskal Wallis	0	***
134	Almaden Reservoir		ON		9.259	9.91	3.536	38	Kruskal Wallis	0	***
135	Calero Reservoir	MID	OFF		1.611	0.47	1.883	79	Kruskal Wallis	0.002	**
136	Calero Reservoir		ON		3.019	1.99	2.505	44	Kruskal Wallis	0.002	**
137	Guadalupe Reservoir		OFF		3.303	3.155	2.608	80	Kruskal Wallis	0	***
138	Guadalupe Reservoir		ON		7.994	8.775	3.652	42	Kruskal Wallis	0	***
139	Stevens Creek Reservoir		OFF		2.804	1.54	2.978	52	Kruskal Wallis	0.001	**
140	Stevens Creek Reservoir		ON		5.253	5.25	3.661	35	Kruskal Wallis	0.001	**
141	Almaden Reservoir	MIDH	OFF		3.823	4.19	3.272	33	Kruskal Wallis	0	***
142	Almaden Reservoir		ON		11.122	11.06	3.718	38	Kruskal Wallis	0	***

143	Calero Reservoir		OFF		1.411	0.28	1.872	40	Kruskal Wallis	0.009	**
144	Calero Reservoir		ON		2.588	1.86	2.434	43	Kruskal Wallis	0.009	**
145	Guadalupe Reservoir		OFF		1.731	1.08	1.794	45	Kruskal Wallis	0	***
146	Guadalupe Reservoir		ON		9.593	11.1	4.328	42	Kruskal Wallis	0	***
147	Stevens Creek Reservoir		OFF		2.365	0.32	2.793	25	Kruskal Wallis	0	***
148	Stevens Creek Reservoir		ON		7.498	7.08	3.014	34	Kruskal Wallis	0	***
149	Almaden Lake	HYP	OFF		0.092	0.07	0.078	26	Kruskal Wallis	0.854	
150	Almaden Lake		ON		0.181	0.07	0.564	98	Kruskal Wallis	0.854	
151	Almaden Reservoir		OFF		2.595	1.98	2.538	87	Kruskal Wallis	0	***
152	Almaden Reservoir		ON		10.937	10.94	4.325	38	Kruskal Wallis	0	***
153	Calero Reservoir		OFF		0.807	0.13	1.379	82	Kruskal Wallis	0.009	**
154	Calero Reservoir		ON		1.521	0.645	1.864	44	Kruskal Wallis	0.009	**
155	Guadalupe Reservoir		OFF		0.541	0.165	1.208	84	Kruskal Wallis	0	***
156	Guadalupe Reservoir		ON		9.434	11.04	5.185	42	Kruskal Wallis	0	***
157	Stevens Creek Reservoir		OFF		1.581	0.22	2.166	55	Kruskal Wallis	0	***
158	Stevens Creek Reservoir		ON		8.611	8.7	2.708	35	Kruskal Wallis	0	***
159	Almaden Lake	EPI	OFF	DO Saturation (%)	108.7	106.6	41.147	23	ANOVA	0.001	**
160	Almaden Lake		ON		82.931	83.9	30.947	99	ANOVA	0.001	**
161	Almaden Reservoir		OFF		101.19	99.7	9.328	84	Kruskal Wallis	0	***
162	Almaden Reservoir		ON		113.271	112.85	11.043	38	Kruskal Wallis	0	***
163	Calero Reservoir		OFF		100.881	99.5	13.635	81	Kruskal Wallis	0	***
164	Calero Reservoir		ON		107.759	111.75	24.445	44	Kruskal Wallis	0	***
165	Guadalupe Reservoir		OFF		98.358	99.6	8.527	83	Kruskal Wallis	0	***
166	Guadalupe Reservoir		ON		101.131	104.2	18.532	42	Kruskal Wallis	0	***
167	Stevens Creek Reservoir		OFF		99.25	99.5	10.578	56	Kruskal Wallis	0.002	**
168	Stevens Creek Reservoir		ON		105.703	103.4	12.207	35	Kruskal Wallis	0.002	**
169	Almaden Reservoir	EPIM	OFF		84.842	91	32.818	33	Kruskal Wallis	0	***
170	Almaden Reservoir		ON		112.889	113.85	18.529	38	Kruskal Wallis	0	***
171	Calero Reservoir		OFF		64.863	70.1	37.01	41	Kruskal Wallis	0.016	*

172	Calero Reservoir		ON		82.133	94.4	40.553	43	Kruskal Wallis	0.016	*
173	Guadalupe Reservoir		OFF		65.723	69.6	25.811	43	Kruskal Wallis	0	***
174	Guadalupe Reservoir		ON		95.536	103.95	28.88	42	Kruskal Wallis	0	***
175	Stevens Creek Reservoir		OFF		83.244	91.4	22.211	25	Kruskal Wallis	0.003	**
176	Stevens Creek Reservoir		ON		98.103	101.3	14.269	34	Kruskal Wallis	0.003	**
177	Almaden Lake	MID	OFF		15.1	9.1	16.561	19	Kruskal Wallis	0.163	
178	Almaden Lake		ON		12.984	3.4	17.596	97	Kruskal Wallis	0.163	
179	Almaden Reservoir		OFF		51.958	57	34.393	84	Kruskal Wallis	0	***
180	Almaden Reservoir		ON		105.87	114	41.583	38	Kruskal Wallis	0	***
181	Calero Reservoir		OFF		17.218	4.9	20.298	79	Kruskal Wallis	0.001	**
182	Calero Reservoir		ON		33.366	23.15	27.434	44	Kruskal Wallis	0.001	**
183	Guadalupe Reservoir		OFF		32.378	29.5	26.048	80	Kruskal Wallis	0	***
184	Guadalupe Reservoir		ON		91.121	101.9	42.229	42	Kruskal Wallis	0	***
185	Stevens Creek Reservoir		OFF		29.367	17.8	31.568	52	Kruskal Wallis	0	***
186	Stevens Creek Reservoir		ON		58.16	58	39.798	35	Kruskal Wallis	0	***
187	Almaden Reservoir	MIDH	OFF		40.464	42.3	35.206	33	Kruskal Wallis	0	***
188	Almaden Reservoir		ON		124.537	126.4	43.573	38	Kruskal Wallis	0	***
189	Calero Reservoir		OFF		14.998	2.8	20.1	40	Kruskal Wallis	0.007	**
190	Calero Reservoir		ON		28.121	20.8	26.187	43	Kruskal Wallis	0.007	**
191	Guadalupe Reservoir		OFF		16.251	10.1	16.588	45	Kruskal Wallis	0	***
192	Guadalupe Reservoir		ON		104.695	125.15	48.355	42	Kruskal Wallis	0	***
193	Stevens Creek Reservoir		OFF		24.356	3.1	29.092	25	Kruskal Wallis	0	***
194	Stevens Creek Reservoir		ON		79.856	73.15	31.691	34	Kruskal Wallis	0	***
195	Almaden Lake	HYP	OFF		0.915	0.7	0.775	26	Kruskal Wallis	0.914	
196	Almaden Lake		ON		1.952	0.8	6.23	98	Kruskal Wallis	0.914	
197	Almaden Reservoir		OFF		27.425	19.9	27.337	87	Kruskal Wallis	0	***
198	Almaden Reservoir		ON		121.792	126.15	49.437	38	Kruskal Wallis	0	***
199	Calero Reservoir		OFF		8.418	1.3	14.725	82	Kruskal Wallis	0.007	**
200	Calero Reservoir		ON		16.72	6.95	20.925	44	Kruskal Wallis	0.007	**

201	Guadalupe Reservoir		OFF		5.26	1.5	12.479	84	Kruskal Wallis	0	***
202	Guadalupe Reservoir		ON		101.264	120.35	56.343	42	Kruskal Wallis	0	***
203	Stevens Creek Reservoir		OFF		15.756	2.2	21.815	55	Kruskal Wallis	0	***
204	Stevens Creek Reservoir		ON		91.254	97.1	28.276	35	Kruskal Wallis	0	***
205	Almaden Lake	EPI	OFF	pH	8.314	8.29	0.378	23	Kruskal Wallis	0.024	*
206	Almaden Lake		ON		8.716	8.54	0.81	99	Kruskal Wallis	0.024	*
207	Almaden Reservoir		OFF		8.978	8.94	0.519	83	Kruskal Wallis	0	***
208	Almaden Reservoir		ON		8.365	8.365	0.483	38	Kruskal Wallis	0	***
209	Calero Reservoir		OFF		9.088	9.035	0.596	80	Kruskal Wallis	0.772	
210	Calero Reservoir		ON		9.102	9.05	0.505	44	Kruskal Wallis	0.772	
211	Guadalupe Reservoir		OFF		8.71	8.675	0.545	82	Kruskal Wallis	0	***
212	Guadalupe Reservoir		ON		8.205	8.06	0.607	42	Kruskal Wallis	0	***
213	Stevens Creek Reservoir		OFF		8.692	8.52	0.517	55	Kruskal Wallis	0	***
214	Stevens Creek Reservoir		ON		8.317	8.25	0.337	35	Kruskal Wallis	0	***
215	Almaden Reservoir	EPIM	OFF		8.928	8.95	0.436	33	ANOVA	0	***
216	Almaden Reservoir		ON		8.323	8.37	0.348	38	ANOVA	0	***
217	Calero Reservoir		OFF		8.878	8.79	0.587	41	Kruskal Wallis	0.668	
218	Calero Reservoir		ON		8.871	8.83	0.413	43	Kruskal Wallis	0.668	
219	Guadalupe Reservoir		OFF		8.181	8.22	0.645	43	ANOVA	0.312	
220	Guadalupe Reservoir		ON		8.066	7.985	0.344	42	ANOVA	0.312	
221	Stevens Creek Reservoir		OFF		8.79	8.83	0.6	25	Kruskal Wallis	0	***
222	Stevens Creek Reservoir		ON		8.237	8.18	0.286	34	Kruskal Wallis	0	***
223	Almaden Lake	MID	OFF		7.548	7.56	0.278	19	Kruskal Wallis	0.002	**
224	Almaden Lake		ON		8.051	7.91	0.898	97	Kruskal Wallis	0.002	**
225	Almaden Reservoir		OFF		8.376	8.395	0.545	84	Kruskal Wallis	0	***
226	Almaden Reservoir		ON		7.943	7.935	0.273	38	Kruskal Wallis	0	***
227	Calero Reservoir		OFF		7.992	7.94	0.538	79	ANOVA	0.378	
228	Calero Reservoir		ON		8.064	8.01	0.39	44	ANOVA	0.378	
229	Guadalupe Reservoir		OFF		7.784	7.795	0.541	80	ANOVA	0.52	

230	Guadalupe Reservoir		ON		7.715	7.665	0.358	42	ANOVA	0.52	
231	Stevens Creek Reservoir		OFF		8.123	7.96	0.545	52	Kruskal Wallis	0.019	*
232	Stevens Creek Reservoir		ON		7.818	7.81	0.263	35	Kruskal Wallis	0.019	*
233	Almaden Reservoir	MIDH	OFF		8.489	8.53	0.482	33	Kruskal Wallis	0	***
234	Almaden Reservoir		ON		7.76	7.73	0.32	38	Kruskal Wallis	0	***
235	Calero Reservoir		OFF		8.031	7.935	0.549	40	Kruskal Wallis	0.053	
236	Calero Reservoir		ON		7.795	7.77	0.432	43	Kruskal Wallis	0.053	
237	Guadalupe Reservoir		OFF		7.696	7.77	0.581	45	Kruskal Wallis	0.063	
238	Guadalupe Reservoir		ON		7.534	7.47	0.419	42	Kruskal Wallis	0.063	
239	Stevens Creek Reservoir		OFF		8.254	8.42	0.528	25	Kruskal Wallis	0	***
240	Stevens Creek Reservoir		ON		7.591	7.5	0.277	34	Kruskal Wallis	0	***
241	Almaden Lake	HYP	OFF		7.154	7	0.342	27	Kruskal Wallis	0	***
242	Almaden Lake		ON		7.859	7.68	0.919	98	Kruskal Wallis	0	***
243	Almaden Reservoir		OFF		8.108	8.08	0.526	86	ANOVA	0	***
244	Almaden Reservoir		ON		7.588	7.525	0.371	38	ANOVA	0	***
245	Calero Reservoir		OFF		7.772	7.775	0.519	82	Kruskal Wallis	0.198	
246	Calero Reservoir		ON		7.654	7.605	0.446	44	Kruskal Wallis	0.198	
247	Guadalupe Reservoir		OFF		7.561	7.59	0.492	83	Kruskal Wallis	0.013	*
248	Guadalupe Reservoir		ON		7.372	7.275	0.46	42	Kruskal Wallis	0.013	*
249	Stevens Creek Reservoir		OFF		7.942	7.88	0.466	54	Kruskal Wallis	0	***
250	Stevens Creek Reservoir		ON		7.457	7.37	0.292	35	Kruskal Wallis	0	***
251	Almaden Lake	EPI	OFF	Phycocyanin (cells/mL)	3189	2613	1780.101	12	Kruskal Wallis	0.463	
252	Almaden Lake		ON		3122.551	2444.5	2481.33	98	Kruskal Wallis	0.463	
253	Almaden Reservoir		OFF		1056.571	576	1227.035	70	ANOVA	0.023	*
254	Almaden Reservoir		ON		1418.426	1588.5	832.13	38	ANOVA	0.023	*
255	Calero Reservoir		OFF		1634.1	1411	1111.545	70	ANOVA	0	***
256	Calero Reservoir		ON		3974.814	3976	2689.157	43	ANOVA	0	***
257	Guadalupe Reservoir		OFF		434.61	239	514.787	59	Kruskal Wallis	0.033	*
258	Guadalupe Reservoir		ON		827.81	711.5	670.232	42	Kruskal Wallis	0.033	*

259	Stevens Creek Reservoir		OFF		883.14	472	914.087	43	Kruskal Wallis	0.011	*
260	Stevens Creek Reservoir		ON		1273.543	1658	761.76	35	Kruskal Wallis	0.011	*
261	Almaden Reservoir		OFF		792.697	544	630.747	33	Kruskal Wallis	0.002	**
262	Almaden Reservoir		ON		1429.743	1622	849.35	38	Kruskal Wallis	0.002	**
263	Calero Reservoir		OFF		1390.829	891	1251.309	41	Kruskal Wallis	0	***
264	Calero Reservoir	EPIM	ON		3343.643	3356	2000.839	42	Kruskal Wallis	0	***
265	Guadalupe Reservoir		OFF		483.286	324.5	521.667	42	Kruskal Wallis	0.009	**
266	Guadalupe Reservoir		ON		997.119	1367.5	875.625	42	Kruskal Wallis	0.009	**
267	Stevens Creek Reservoir		OFF		820.72	502	859.085	25	Kruskal Wallis	0.006	**
268	Stevens Creek Reservoir		ON		1327.353	1675.5	770.658	34	Kruskal Wallis	0.006	**
269	Almaden Lake		OFF		4133.917	1946	7734.617	12	Kruskal Wallis	0	***
270	Almaden Lake		ON		953.937	588	1096.31	95	Kruskal Wallis	0	***
271	Almaden Reservoir		OFF		662.514	411	721.225	74	Kruskal Wallis	0	***
272	Almaden Reservoir		ON		1356.782	1642	792.607	38	Kruskal Wallis	0	***
273	Calero Reservoir		OFF		690.706	384.5	682.475	68	Kruskal Wallis	0	***
274	Calero Reservoir	MID	ON		2007.884	2069	1676.55	43	Kruskal Wallis	0	***
275	Guadalupe Reservoir		OFF		550.712	300	579.106	66	Kruskal Wallis	0.002	**
276	Guadalupe Reservoir		ON		928.857	955.5	661.016	42	Kruskal Wallis	0.002	**
277	Stevens Creek Reservoir		OFF		766.93	449	686.931	43	Kruskal Wallis	0.012	*
278	Stevens Creek Reservoir		ON		1193	1543	731.492	35	Kruskal Wallis	0.012	*
279	Almaden Reservoir		OFF		445.091	251	533.605	33	Kruskal Wallis	0	***
280	Almaden Reservoir		ON		1180.953	1490.5	735.481	38	Kruskal Wallis	0	***
281	Calero Reservoir		OFF		652.35	324	708.603	40	Kruskal Wallis	0.008	**
282	Calero Reservoir	MIDH	ON		1561.952	1526.5	1539.657	42	Kruskal Wallis	0.008	**
283	Guadalupe Reservoir		OFF		537.432	396	526.06	44	Kruskal Wallis	0.113	
284	Guadalupe Reservoir		ON		921.238	983	667.929	42	Kruskal Wallis	0.113	
285	Stevens Creek Reservoir		OFF		742.88	365	764.951	25	Kruskal Wallis	0.008	**
286	Stevens Creek Reservoir		ON		1122.588	1529	659.307	34	Kruskal Wallis	0.008	**
287	Almaden Lake	HYP	OFF		1733.714	1527	923.295	14	Kruskal Wallis	0	***

288	Almaden Lake		ON		775.542	403.5	801.152	96	Kruskal Wallis	0	***
289	Almaden Reservoir		OFF		990.6	366	3102.089	75	Kruskal Wallis	0	***
290	Almaden Reservoir		ON		1348.9	1492.5	986.63	38	Kruskal Wallis	0	***
291	Calero Reservoir		OFF		659.043	378	748.829	69	Kruskal Wallis	0.001	**
292	Calero Reservoir		ON		1465.14	1528	1473.037	43	Kruskal Wallis	0.001	**
293	Guadalupe Reservoir		OFF		711.648	558	602.167	71	Kruskal Wallis	0.025	*
294	Guadalupe Reservoir		ON		1046.927	896	723.627	41	Kruskal Wallis	0.025	*
295	Stevens Creek Reservoir		OFF		1305.432	974	1321.334	44	Kruskal Wallis	0.174	
296	Stevens Creek Reservoir		ON		1338.824	1719	626.967	34	Kruskal Wallis	0.174	
297	Almaden Lake		OFF		526.461	542	122.016	23	Kruskal Wallis	0	***
298	Almaden Lake		ON		596.919	588	77.74	99	Kruskal Wallis	0	***
299	Almaden Reservoir		OFF		366.415	369	20.183	82	Kruskal Wallis	0	***
300	Almaden Reservoir		ON		381.461	380	19.616	38	Kruskal Wallis	0	***
301	Calero Reservoir	EPI	OFF		439.573	430.5	99.654	80	Kruskal Wallis	0	***
302	Calero Reservoir		ON		521.25	517.5	82.724	44	Kruskal Wallis	0	***
303	Guadalupe Reservoir		OFF		366.99	352.5	99.669	82	Kruskal Wallis	0.309	
304	Guadalupe Reservoir		ON		370.429	368.5	44.814	42	Kruskal Wallis	0.309	
305	Stevens Creek Reservoir		OFF		485.645	492	130.057	55	Kruskal Wallis	0.028	*
306	Stevens Creek Reservoir		ON	Specific Conductivity (uS/cm)	522.314	528	39.392	35	Kruskal Wallis	0.028	*
307	Almaden Reservoir		OFF		377.909	385	20.725	33	ANOVA	0.295	
308	Almaden Reservoir		ON		383.063	381	20.363	38	ANOVA	0.295	
309	Calero Reservoir		OFF		458.902	436	67.877	41	Kruskal Wallis	0.001	**
310	Calero Reservoir	EPIM	ON		522.256	504	84.914	43	Kruskal Wallis	0.001	**
311	Guadalupe Reservoir		OFF		366.421	350	72.305	43	ANOVA	0.56	
312	Guadalupe Reservoir		ON		369.952	367	44.12	42	ANOVA	0.56	
313	Stevens Creek Reservoir		OFF		525.12	511	52.37	25	Kruskal Wallis	0.597	
314	Stevens Creek Reservoir		ON		523.618	534	38.606	34	Kruskal Wallis	0.597	
315	Almaden Lake	MID	OFF		550.789	554	48.524	19	Kruskal Wallis	0.005	**
316	Almaden Lake		ON		599.206	584	80.431	97	Kruskal Wallis	0.005	**

317	Almaden Reservoir		OFF		382.446	387	21.295	83	Kruskal Wallis	0.009	**
318	Almaden Reservoir		ON		393.597	397	18.162	38	Kruskal Wallis	0.009	**
319	Calero Reservoir		OFF		439.803	429	88.25	79	Kruskal Wallis	0	***
320	Calero Reservoir		ON		519.909	515.5	74.154	44	Kruskal Wallis	0	***
321	Guadalupe Reservoir		OFF		338.934	323	84.149	80	ANOVA	0.081	
322	Guadalupe Reservoir		ON		355.619	347.5	45.283	42	ANOVA	0.081	
323	Stevens Creek Reservoir		OFF		491.51	490.5	100.747	52	Kruskal Wallis	0	***
324	Stevens Creek Reservoir		ON		536.171	536	31.719	35	Kruskal Wallis	0	***
325	Almaden Reservoir	MIDH	OFF		383.364	383	22.94	33	Kruskal Wallis	0.062	
326	Almaden Reservoir		ON		393.782	397	20.063	38	Kruskal Wallis	0.062	
327	Calero Reservoir		OFF		448.95	439.5	74.162	40	Kruskal Wallis	0	***
328	Calero Reservoir		ON		513.047	500	74.888	43	Kruskal Wallis	0	***
329	Guadalupe Reservoir		OFF		328.218	310	69.778	45	ANOVA	0.152	
330	Guadalupe Reservoir		ON		342.952	344	48.572	42	ANOVA	0.152	
331	Stevens Creek Reservoir		OFF		509.92	490	69.674	25	Kruskal Wallis	0.015	*
332	Stevens Creek Reservoir		ON		525.735	530	39.366	34	Kruskal Wallis	0.015	*
333	Almaden Lake	HYP	OFF		500.259	527	160.222	27	Kruskal Wallis	0	***
334	Almaden Lake		ON		610.48	597.5	92.3	98	Kruskal Wallis	0	***
335	Almaden Reservoir		OFF		386.659	391	24.153	85	Kruskal Wallis	0.079	
336	Almaden Reservoir		ON		394.937	398.5	21.372	38	Kruskal Wallis	0.079	
337	Calero Reservoir		OFF		421.863	414.5	96.269	82	Kruskal Wallis	0	***
338	Calero Reservoir		ON		516.727	500.5	79.421	44	Kruskal Wallis	0	***
339	Guadalupe Reservoir		OFF		364.295	353	77.164	83	Kruskal Wallis	0.073	
340	Guadalupe Reservoir		ON		341.357	340.5	49.567	42	Kruskal Wallis	0.073	
341	Stevens Creek Reservoir		OFF		471.591	474.5	122.896	54	Kruskal Wallis	0	***
342	Stevens Creek Reservoir		ON		539	543	61.192	35	Kruskal Wallis	0	***
343	Almaden Lake	EPI	OFF	Sulfate (mg/L)	33.68	33	4.897	25	Kruskal Wallis	0.076	
344	Almaden Lake		ON		36.557	35	8.123	97	Kruskal Wallis	0.076	
345	Almaden Reservoir		OFF		15.605	15	1.433	86	Kruskal Wallis	0.108	

346	Almaden Reservoir		ON		15.974	16	1.308	39	Kruskal Wallis	0.108	
347	Calero Reservoir		OFF		28.747	28	7.719	83	Kruskal Wallis	0	***
348	Calero Reservoir		ON		34.725	34	6.954	40	Kruskal Wallis	0	***
349	Guadalupe Reservoir		OFF		17.096	16	4.725	84	Kruskal Wallis	0.096	
350	Guadalupe Reservoir		ON		17.25	17.5	2.103	44	Kruskal Wallis	0.096	
351	Stevens Creek Reservoir		OFF		42.969	39	10.212	32	Kruskal Wallis	0.064	
352	Stevens Creek Reservoir		ON		44.771	45	6.102	35	Kruskal Wallis	0.064	
353	Almaden Lake	HYP	OFF		12.002	12	9.68	25	Kruskal Wallis	0	***
354	Almaden Lake		ON		31.749	31	10.152	97	Kruskal Wallis	0	***
355	Almaden Reservoir		OFF		14.407	14.5	1.552	86	Kruskal Wallis	0	***
356	Almaden Reservoir		ON		15.641	16	1.478	39	Kruskal Wallis	0	***
357	Calero Reservoir		OFF		23.67	23	7.754	83	Kruskal Wallis	0	***
358	Calero Reservoir		ON		30.4	30	6.246	40	Kruskal Wallis	0	***
359	Guadalupe Reservoir		OFF		11.868	11.5	3.858	84	ANOVA	0	***
360	Guadalupe Reservoir		ON		15.114	15	2.967	44	ANOVA	0	***
361	Stevens Creek Reservoir		OFF		37.875	33	10.859	32	Kruskal Wallis	0.011	*
362	Stevens Creek Reservoir		ON		41.114	38	6.601	35	Kruskal Wallis	0.011	*
363	Almaden Lake	EPI	OFF	Total MeHg (ng/L)	1.486	0.988	1.372	24	ANOVA	0.308	
364	Almaden Lake		ON		1.537	1.3	1.01	101	ANOVA	0.308	
365	Almaden Reservoir		OFF		0.738	0.548	0.476	86	ANOVA	0.85	
366	Almaden Reservoir		ON		0.677	0.65	0.374	39	ANOVA	0.85	
367	Calero Reservoir		OFF		0.234	0.147	0.293	84	Kruskal Wallis	0.092	
368	Calero Reservoir		ON		0.222	0.21	0.13	44	Kruskal Wallis	0.092	
369	Guadalupe Reservoir		OFF		0.585	0.44	0.541	85	ANOVA	0.06	
370	Guadalupe Reservoir		ON		0.461	0.31	0.375	45	ANOVA	0.06	
371	Stevens Creek Reservoir		OFF		0.132	0.1	0.125	55	ANOVA	0.118	
372	Stevens Creek Reservoir		ON		0.151	0.13	0.1	35	ANOVA	0.118	
373	Almaden Reservoir	EPIM	OFF		0.73	0.633	0.429	33	ANOVA	0.95	
374	Almaden Reservoir		ON		0.732	0.665	0.479	38	ANOVA	0.95	

375	Calero Reservoir		OFF		0.164	0.098	0.183	43	ANOVA	0.003	**
376	Calero Reservoir		ON		0.286	0.2	0.327	43	ANOVA	0.003	**
377	Guadalupe Reservoir		OFF		1.016	0.376	1.909	46	Kruskal Wallis	0.388	
378	Guadalupe Reservoir		ON		1.534	0.32	4.211	44	Kruskal Wallis	0.388	
379	Stevens Creek Reservoir		OFF		0.1	0.086	0.051	26	ANOVA	0.013	*
380	Stevens Creek Reservoir		ON		0.15	0.12	0.098	33	ANOVA	0.013	*
381	Almaden Lake	MID	OFF		13.489	1.76	32.109	21	Kruskal Wallis	0.08	
382	Almaden Lake		ON		2.073	1.1	2.701	100	Kruskal Wallis	0.08	
383	Almaden Reservoir		OFF		1.033	0.559	1.374	82	Kruskal Wallis	0.322	
384	Almaden Reservoir		ON		0.698	0.54	0.646	39	Kruskal Wallis	0.322	
385	Calero Reservoir		OFF		0.947	0.243	1.598	82	Kruskal Wallis	0.686	
386	Calero Reservoir		ON		0.389	0.21	0.44	44	Kruskal Wallis	0.686	
387	Guadalupe Reservoir		OFF		1.208	0.449	2.257	82	Kruskal Wallis	0.275	
388	Guadalupe Reservoir		ON		1.004	0.31	1.487	44	Kruskal Wallis	0.275	
389	Stevens Creek Reservoir		OFF		0.371	0.13	0.661	52	Kruskal Wallis	0.499	
390	Stevens Creek Reservoir		ON		0.326	0.17	0.397	35	Kruskal Wallis	0.499	
391	Almaden Reservoir	MIDH	OFF		1.258	0.485	1.776	33	Kruskal Wallis	0.247	
392	Almaden Reservoir		ON		0.544	0.4	0.744	38	Kruskal Wallis	0.247	
393	Calero Reservoir		OFF		0.957	0.321	1.163	43	ANOVA	0.644	
394	Calero Reservoir		ON		0.484	0.38	0.452	43	ANOVA	0.644	
395	Guadalupe Reservoir		OFF		1.851	1.48	1.68	46	Kruskal Wallis	0	***
396	Guadalupe Reservoir		ON		1.172	0.295	1.878	44	Kruskal Wallis	0	***
397	Stevens Creek Reservoir		OFF		0.414	0.179	0.483	26	ANOVA	0.758	
398	Stevens Creek Reservoir		ON		0.411	0.165	0.579	34	ANOVA	0.758	
399	Almaden Lake	HYP	OFF		32.306	30	21.048	25	Kruskal Wallis	0	***
400	Almaden Lake		ON		10.002	5.35	13.788	100	Kruskal Wallis	0	***
401	Almaden Reservoir		OFF		1.843	0.666	2.513	86	Kruskal Wallis	0.002	**
402	Almaden Reservoir		ON		0.512	0.33	0.83	39	Kruskal Wallis	0.002	**
403	Calero Reservoir		OFF		1.913	1.13	2.392	84	Kruskal Wallis	0.033	*

404	Calero Reservoir		ON		0.754	0.445	0.792	44	Kruskal Wallis	0.033	*
405	Guadalupe Reservoir		OFF		11.558	8.955	10.917	84	Kruskal Wallis	0	***
406	Guadalupe Reservoir		ON		1.831	0.34	3.219	45	Kruskal Wallis	0	***
407	Stevens Creek Reservoir		OFF		0.851	0.554	0.898	53	ANOVA	0	***
408	Stevens Creek Reservoir		ON		0.247	0.18	0.209	35	ANOVA	0	***
409	Almaden Lake	EPI	OFF	Water Temperature (Celsius)	22.337	22.39	2.247	23	ANOVA	0.019	*
410	Almaden Lake		ON		21.263	21.52	1.868	99	ANOVA	0.019	*
411	Almaden Reservoir		OFF		22.674	23.13	2.258	84	Kruskal Wallis	0.02	*
412	Almaden Reservoir		ON		23.565	24.125	1.859	38	Kruskal Wallis	0.02	*
413	Calero Reservoir		OFF		21.937	22.29	2.067	81	Kruskal Wallis	0.001	**
414	Calero Reservoir		ON		23.06	23.465	1.574	44	Kruskal Wallis	0.001	**
415	Guadalupe Reservoir		OFF		22.771	23.19	2.499	83	Kruskal Wallis	0.012	*
416	Guadalupe Reservoir		ON		23.736	24.63	2.129	42	Kruskal Wallis	0.012	*
417	Stevens Creek Reservoir		OFF		22.337	22.735	2.625	56	Kruskal Wallis	0.005	**
418	Stevens Creek Reservoir		ON		23.638	24.68	2.069	35	Kruskal Wallis	0.005	**
419	Almaden Reservoir	EPIM	OFF		21.153	21.51	2.79	33	Kruskal Wallis	0	***
420	Almaden Reservoir		ON		23.259	23.775	1.928	38	Kruskal Wallis	0	***
421	Calero Reservoir		OFF		20.928	21.08	1.665	41	Kruskal Wallis	0	***
422	Calero Reservoir		ON		22.511	22.95	1.655	43	Kruskal Wallis	0	***
423	Guadalupe Reservoir		OFF		19.34	19.72	3.818	43	Kruskal Wallis	0	***
424	Guadalupe Reservoir		ON		22.693	23.82	2.945	42	Kruskal Wallis	0	***
425	Stevens Creek Reservoir		OFF		21.608	22.17	2.461	25	Kruskal Wallis	0.004	**
426	Stevens Creek Reservoir		ON		23.042	23.955	2.692	34	Kruskal Wallis	0.004	**
427	Almaden Lake	MID	OFF		18.882	19.33	2.692	19	ANOVA	0.351	
428	Almaden Lake		ON		19.423	19.79	2.223	97	ANOVA	0.351	
429	Almaden Reservoir		OFF		19.317	19.885	3.372	84	Kruskal Wallis	0.043	*
430	Almaden Reservoir		ON		20.657	21.675	3.041	38	Kruskal Wallis	0.043	*
431	Calero Reservoir		OFF		18.035	17.6	2.266	79	Kruskal Wallis	0	***
432	Calero Reservoir		ON		20.068	20.26	2.345	44	Kruskal Wallis	0	***

433	Guadalupe Reservoir		OFF	13.986	12.695	3.457	80	Kruskal Wallis	0	***
434	Guadalupe Reservoir		ON	19.78	19.645	3.128	42	Kruskal Wallis	0	***
435	Stevens Creek Reservoir		OFF	16.934	16.37	3.801	52	Kruskal Wallis	0	***
436	Stevens Creek Reservoir		ON	20.263	21.13	2.856	35	Kruskal Wallis	0	***
437	Almaden Reservoir	MIDH	OFF	18.034	18.13	3.362	33	ANOVA	0.088	
438	Almaden Reservoir		ON	19.403	19.505	3.288	38	ANOVA	0.088	
439	Calero Reservoir		OFF	17.224	16.62	2.484	40	Kruskal Wallis	0.001	**
440	Calero Reservoir		ON	19.263	18.86	2.224	43	Kruskal Wallis	0.001	**
441	Guadalupe Reservoir		OFF	12.138	11.63	2.227	45	Kruskal Wallis	0	***
442	Guadalupe Reservoir		ON	17.684	17.235	3.594	42	Kruskal Wallis	0	***
443	Stevens Creek Reservoir		OFF	15.754	14.93	3.212	25	ANOVA	0.014	*
444	Stevens Creek Reservoir		ON	17.699	17.63	2.677	34	ANOVA	0.014	*
445	Almaden Lake	HYP	OFF	13.957	13.08	2.607	27	Kruskal Wallis	0	***
446	Almaden Lake		ON	17.767	17.92	2.502	98	Kruskal Wallis	0	***
447	Almaden Reservoir		OFF	17.66	17.34	3.539	87	Kruskal Wallis	0.039	*
448	Almaden Reservoir		ON	19.105	19.16	3.349	38	Kruskal Wallis	0.039	*
449	Calero Reservoir		OFF	16.293	15.86	2.273	83	Kruskal Wallis	0	***
450	Calero Reservoir		ON	18.711	18.55	2.381	44	Kruskal Wallis	0	***
451	Guadalupe Reservoir		OFF	11.366	11.31	1.472	84	Kruskal Wallis	0	***
452	Guadalupe Reservoir		ON	16.915	16.205	3.475	42	Kruskal Wallis	0	***
453	Stevens Creek Reservoir		OFF	14.56	13.25	3.334	55	Kruskal Wallis	0	***
454	Stevens Creek Reservoir		ON	17.299	17.28	2.607	35	Kruskal Wallis	0	***

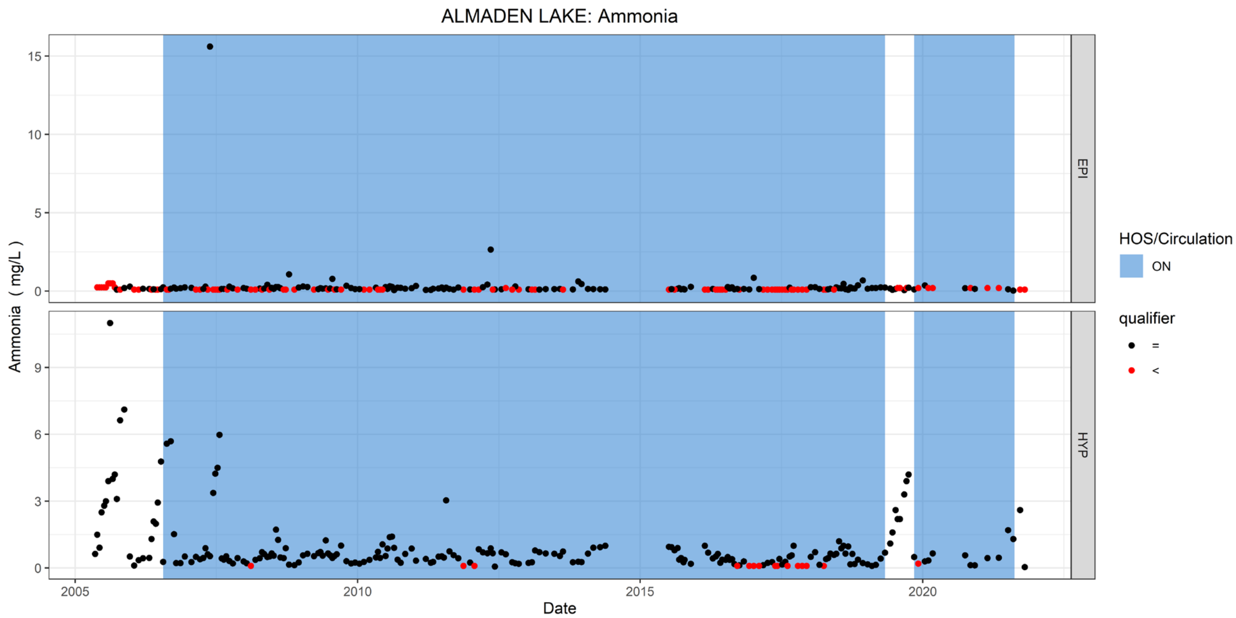
[a] Significance Level: *** = p<0.001, **= p<0.01, * = p<0.05

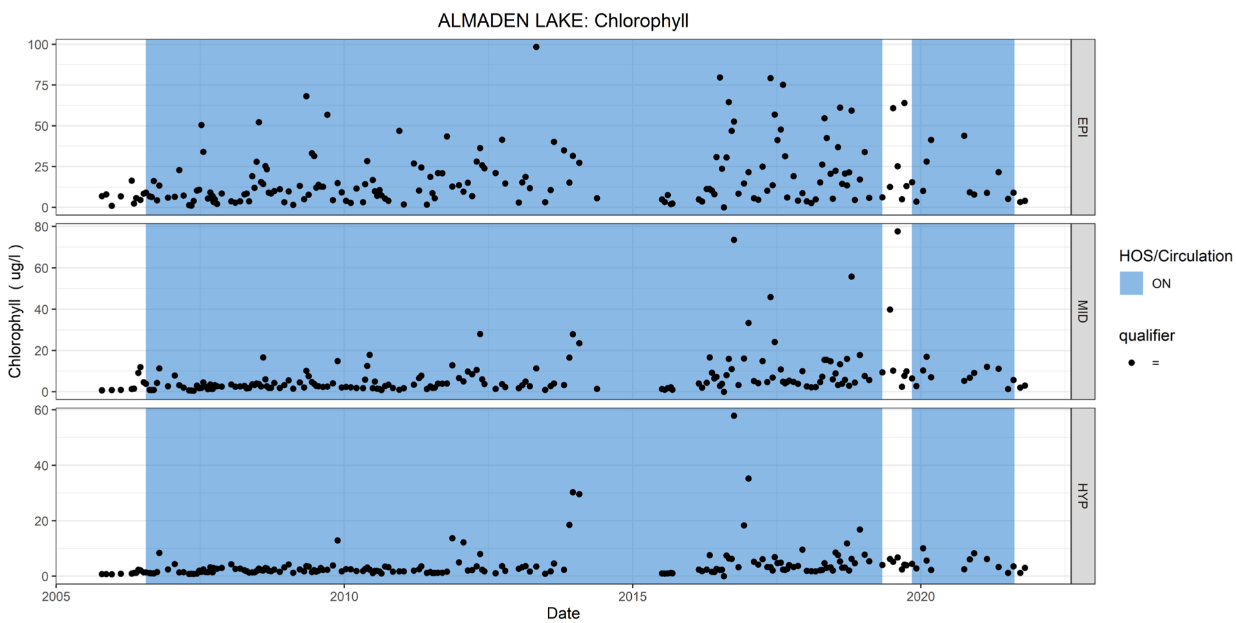
Table A 2: Summary Statistics of Fish Hg Models

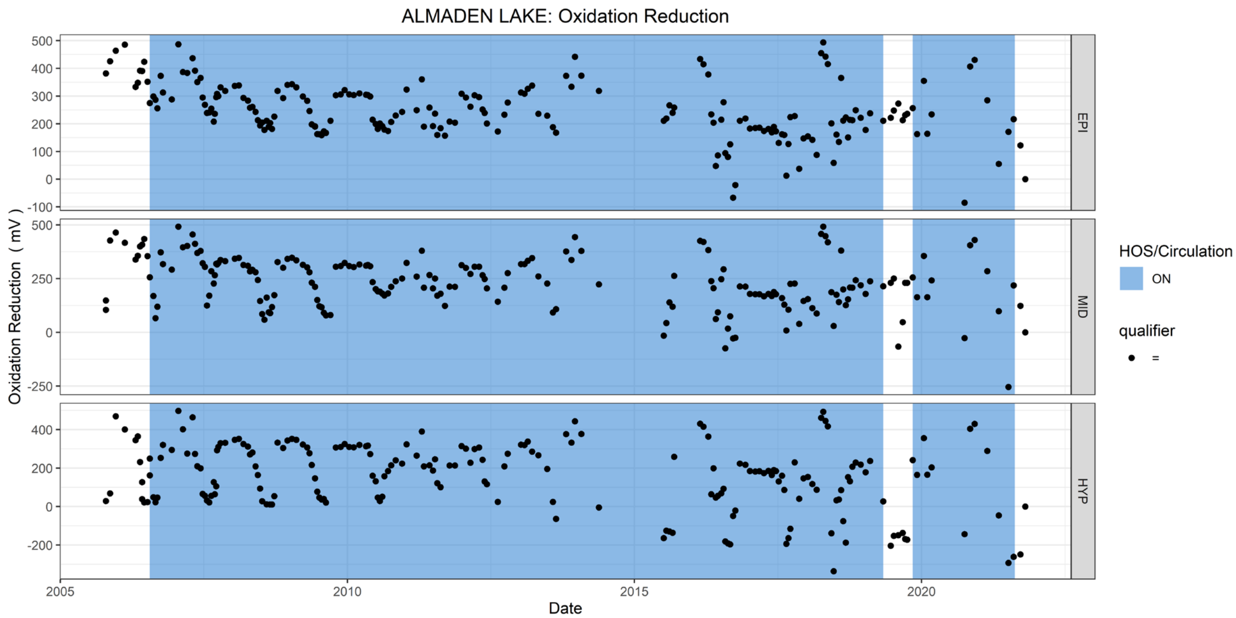
Line	Reservoir	term	estimate	std. Error	Statistic	p value	Sig. Level
1	Almaden Reservoir	α	2.126	0.625	3.401	0.001	***
2		species - Bluegill	0.011	0.138	0.080	0.936	
3		species - Largemouth Bass	-0.001	0.125	-0.012	0.991	
4		length (mm)	0.002	0.001	2.688	0.008	**
5		year	-0.041	0.000	-3.321	0.001	***
6		season	0.125	0.042	3.011	0.003	**
7		species (Bluegill): length (mm)	0.001	0.001	0.681	0.496	
8		species (Largemouth Bass): length (mm)	0.003	0.001	3.510	0.001	***
9	Calero Reservoir	α	-0.223	0.069	-3.220	0.001	**
10		species - Bluegill	0.017	0.019	0.902	0.367	
11		species - Largemouth Bass	0.064	0.017	3.736	0.000	***
12		length (mm)	0.001	0.000	7.767	0.000	***
13		year	0.005	0.000	3.323	0.001	***
14		season	0.041	0.006	6.630	0.000	***
15		species (Bluegill): length (mm)	0.000	0.000	-1.495	0.135	
16		species (Largemouth Bass): length (mm)	0.000	0.000	0.864	0.388	
17	Guadalupe Reservoir	α	5.755	0.470	12.237	0.000	***
18		species - Bluegill	0.583	0.158	3.689	0.000	***
19		species - Largemouth Bass	0.564	0.146	3.859	0.000	***
20		length (mm)	0.007	0.001	10.262	0.000	***
21		year	-0.123	0.000	-12.599	0.000	***
22		season	0.088	0.040	2.187	0.029	*
23		species (Bluegill): length (mm)	-0.004	0.001	-3.948	0.000	***
24		species (Largemouth Bass): length (mm)	-0.001	0.001	-0.980	0.328	
25	Stevens Creek Reservoir	α	1.145	0.139	8.267	0.000	***
26		species - Bluegill	-0.062	0.038	-1.651	0.100	
27		species - Largemouth Bass	0.019	0.034	0.542	0.588	
28		length (mm)	0.001	0.000	5.078	0.000	***

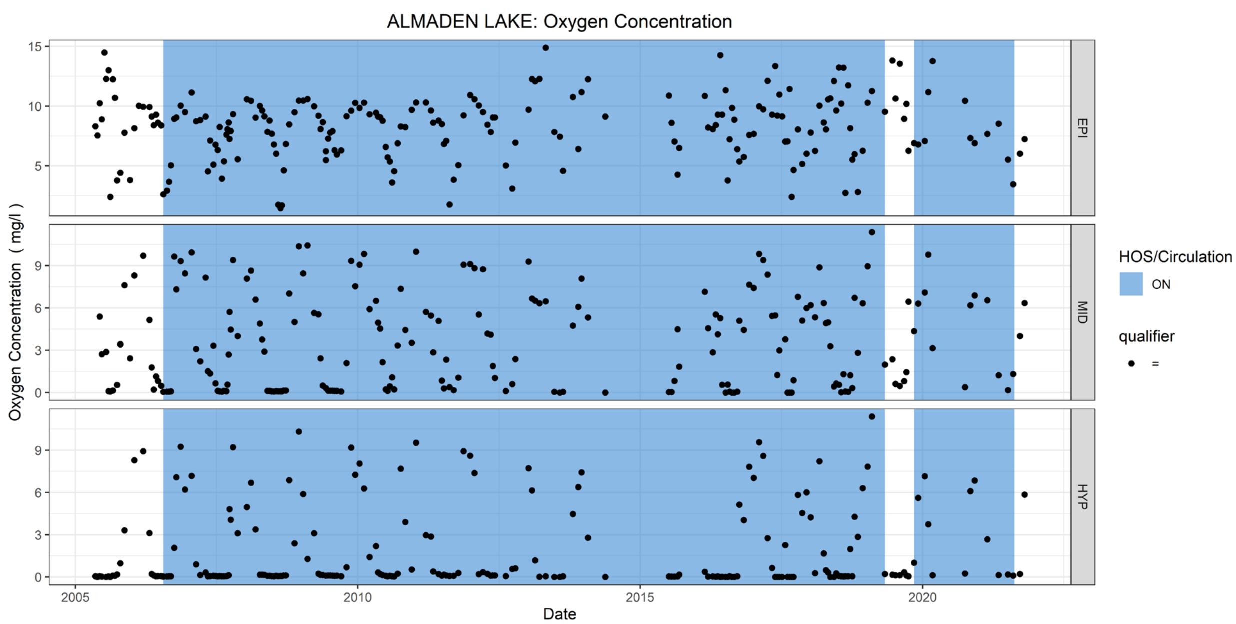
29		year	-0.023	0.000	-7.992	0.000	***
30		season	0.031	0.009	3.357	0.001	***
31		species (Bluegill): length (mm)	0.000	0.000	1.644	0.101	
32		species (Largemouth Bass): length (mm)	0.000	0.000	0.239	0.811	

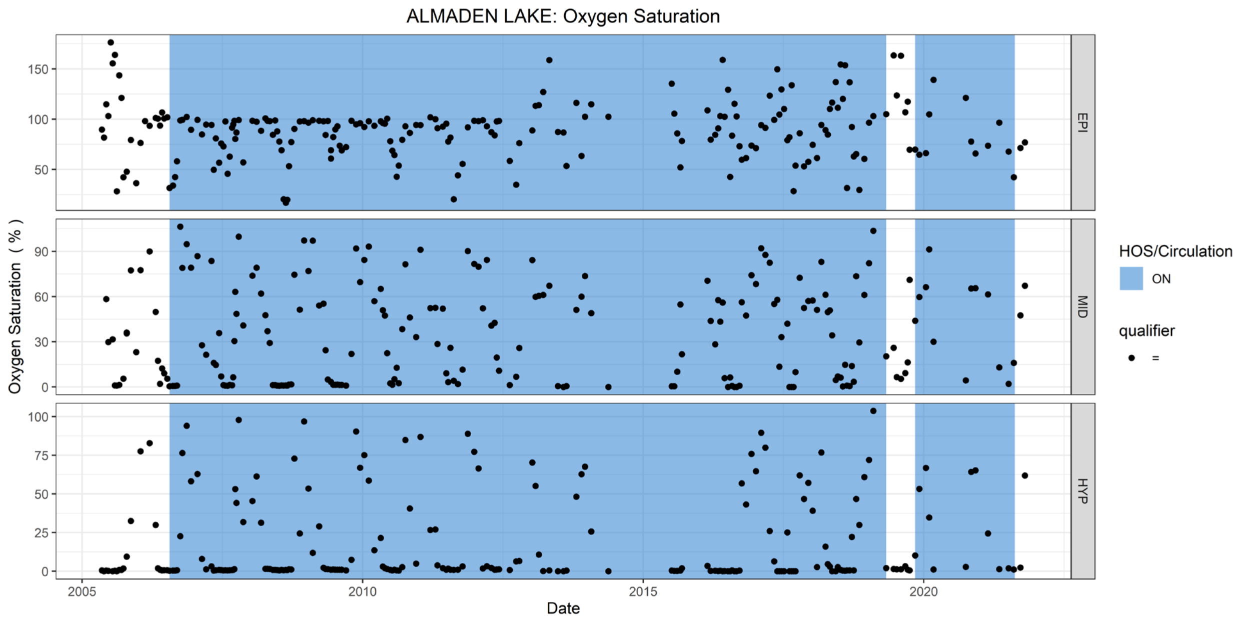
Appendix B: Time Series Figures (Unreferenced)

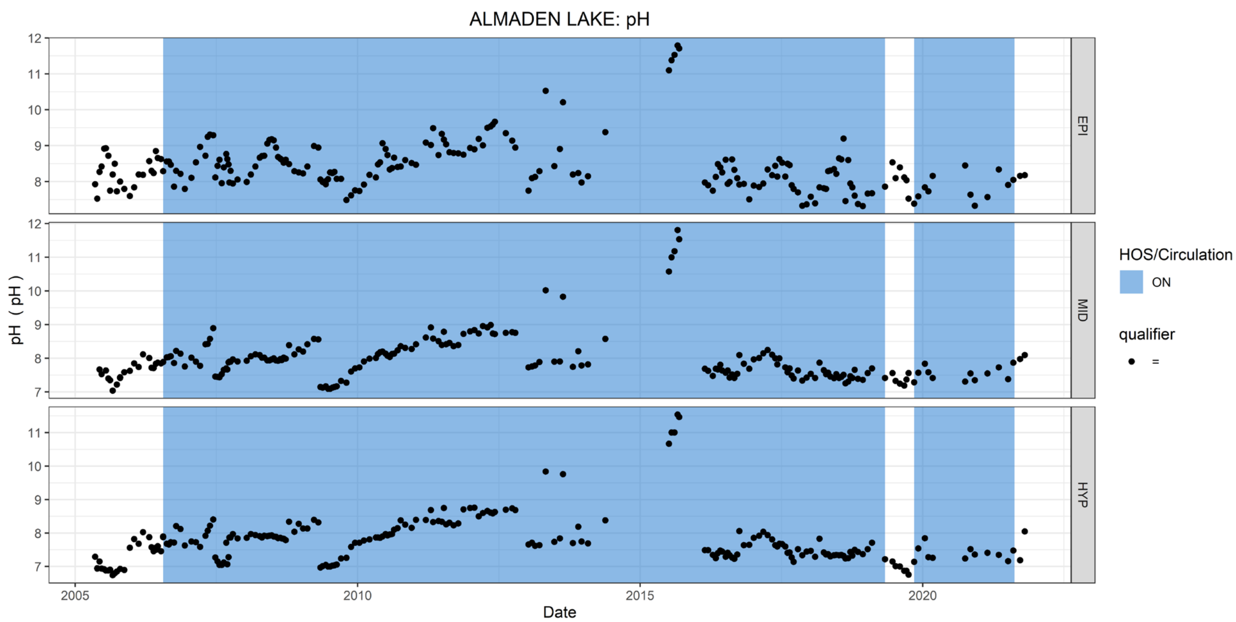


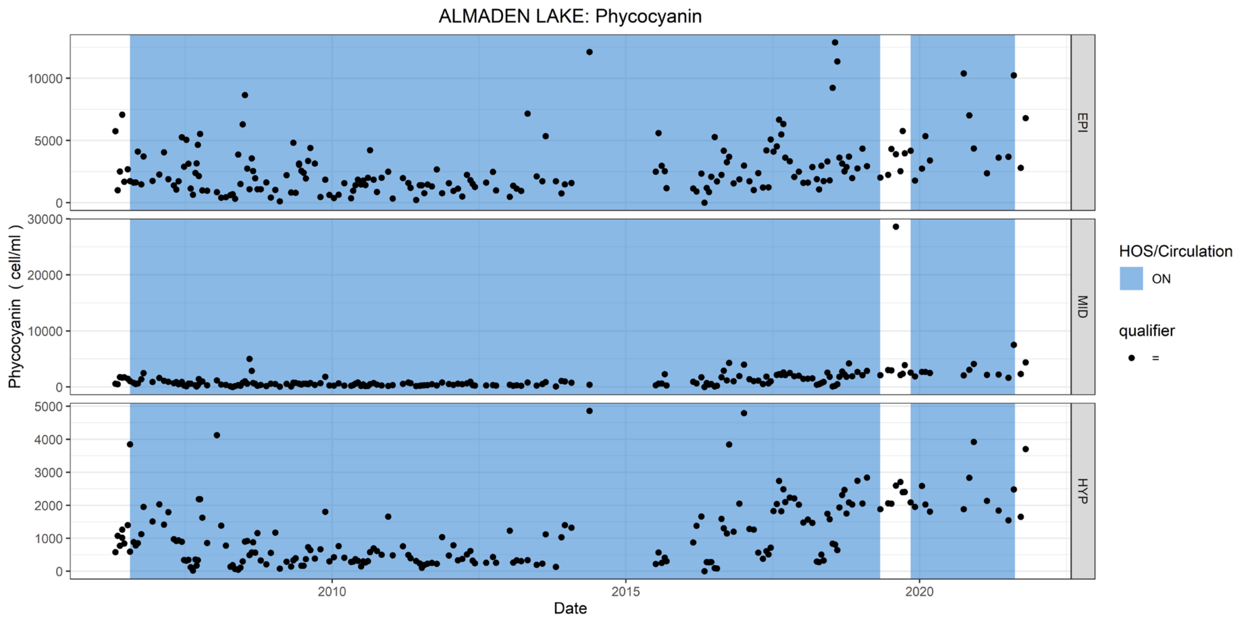


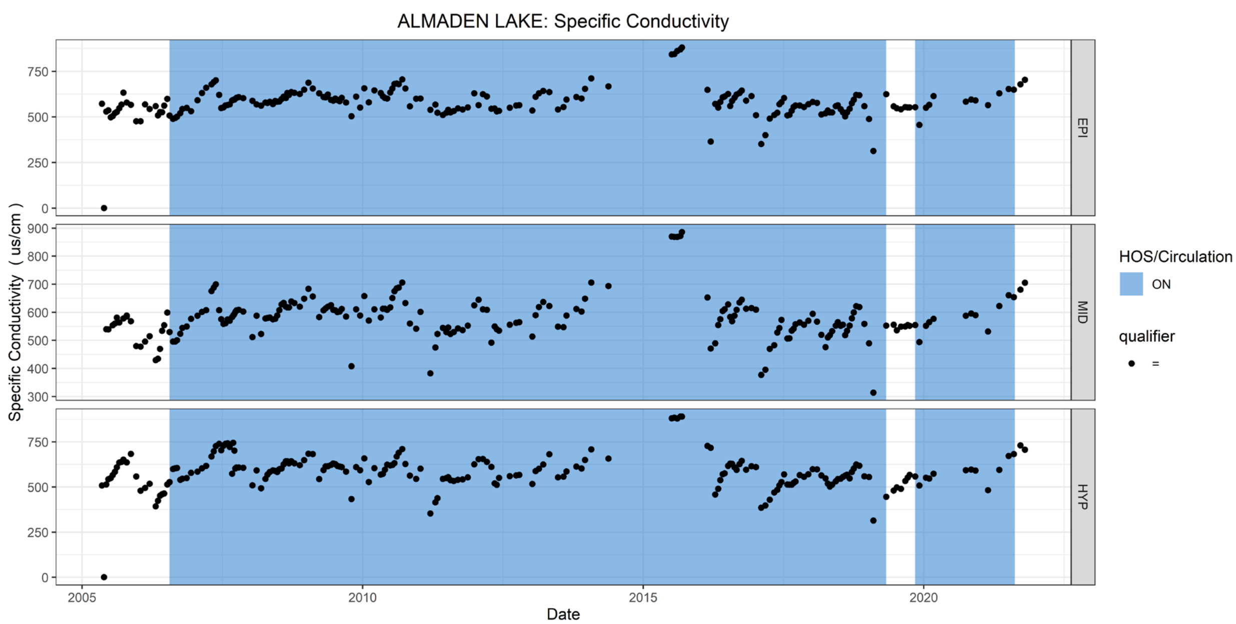

ALMADEN LAKE: Oxidation Reduction
Oxidation Reduction (mV)
Date
EPI
MID
HYP
HOS/Circulation
ON
qualifier
=

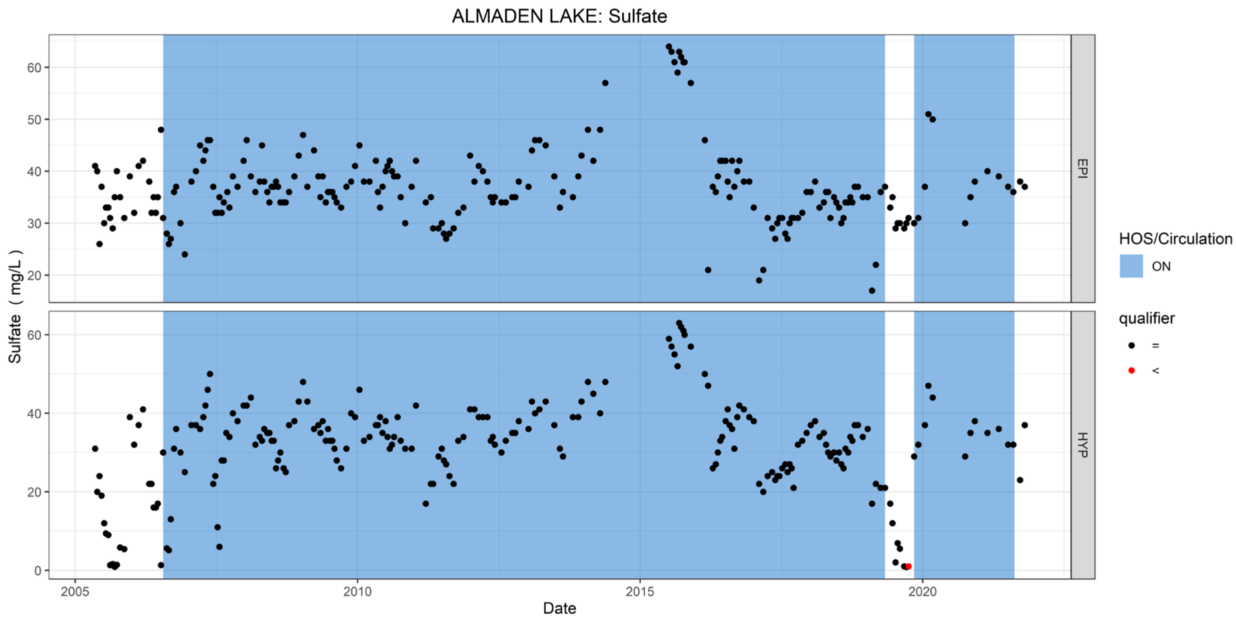

ALMADEN LAKE: Oxygen Concentration
Oxygen Concentration (mg/l)
Date
EPI
MID
HYP
HOS/Circulation
ON
qualifier
=

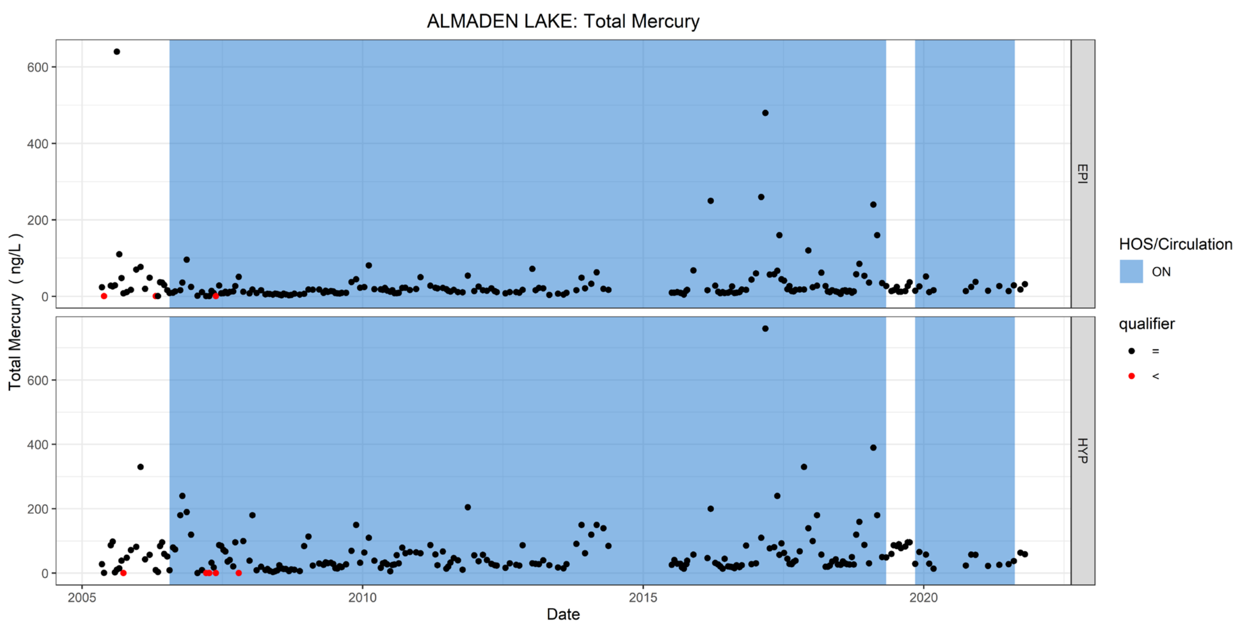

ALMADEN LAKE: Oxygen Saturation
Oxygen Saturation (%)
EPI
MID
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=

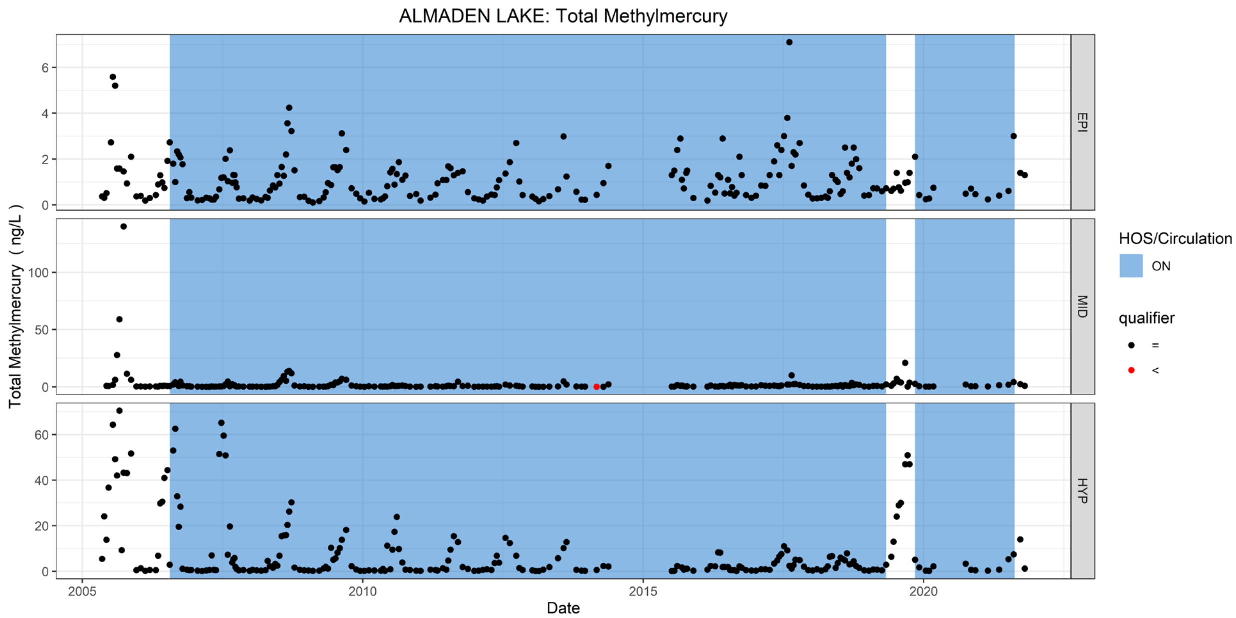

ALMADEN LAKE: pH
pH (pH)
EPI
MID
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=


ALMADEN LAKE: Phycocyanin
Phycocyanin (cell/ml)
Date
EPI
MID
HYP
HOS/Circulation
ON
qualifier
=
2010
2015
2020


ALMADEN LAKE: Specific Conductivity
Specific Conductivity (us/cm)
Date
EPI
MID
HYP
HOS/Circulation
ON
qualifier
=
2005
2010
2015
2020


ALMADEN LAKE: Sulfate
Sulfate (mg/L)
Date
EPI
HYP
HOS/Circulation
ON
qualifier
=
<
2005
2010
2015
2020


ALMADEN LAKE: Total Mercury
Total Mercury (ng/L)
Date
EPI
HYP
HOS/Circulation
ON
qualifier
=
<
2005
2010
2015
2020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Total Methylmercury (ng/L)
Date
EPI
MID
HYP
HOS/Circulation
ON
qualifier
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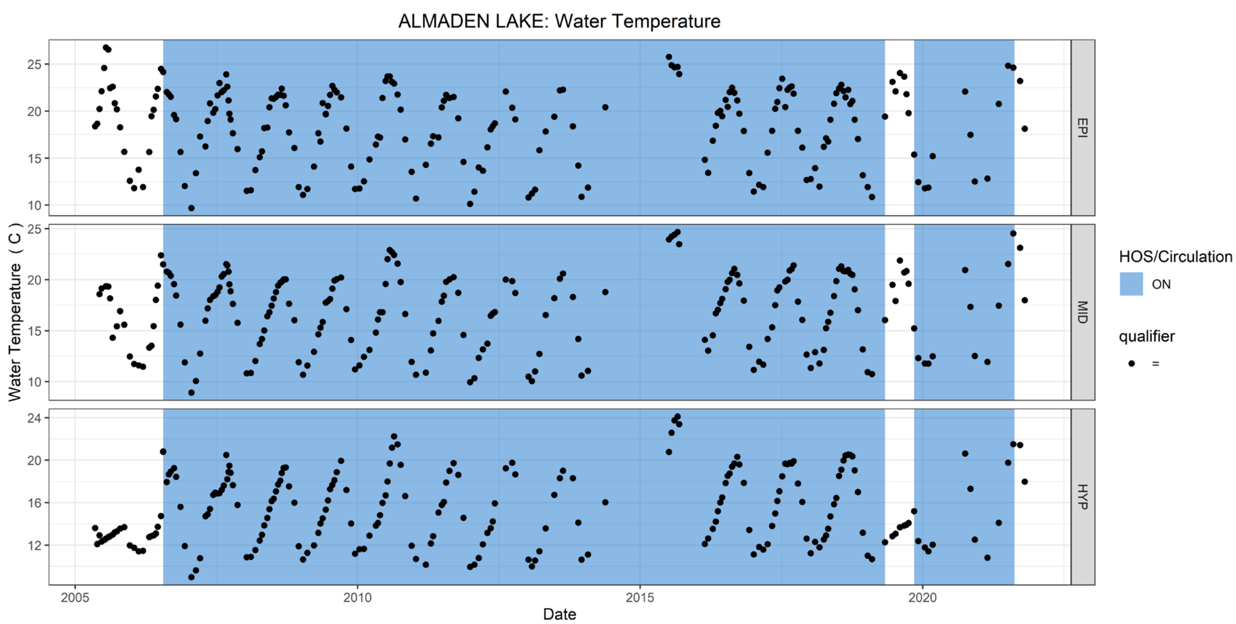
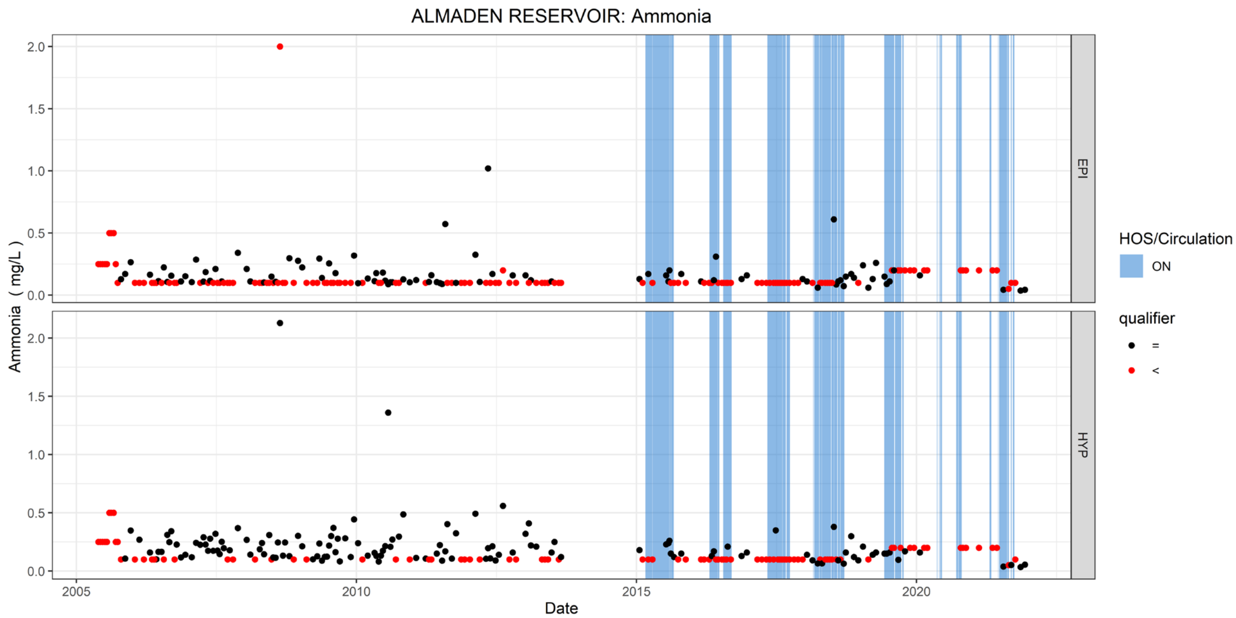
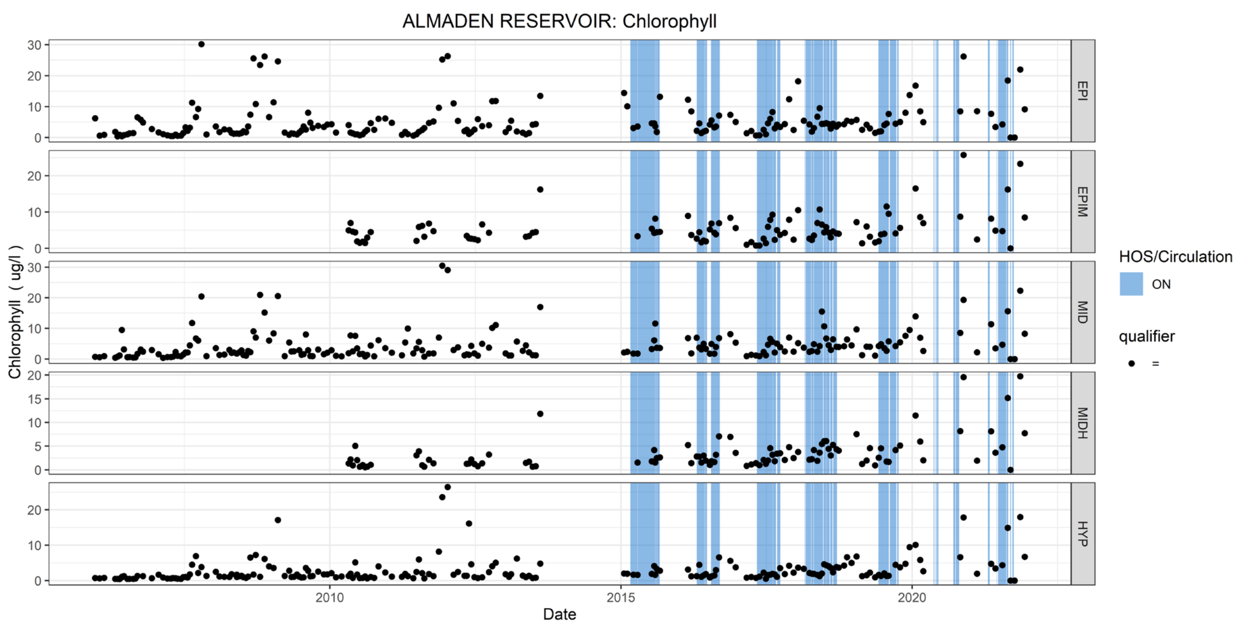
<
2005
2010
2015
2020

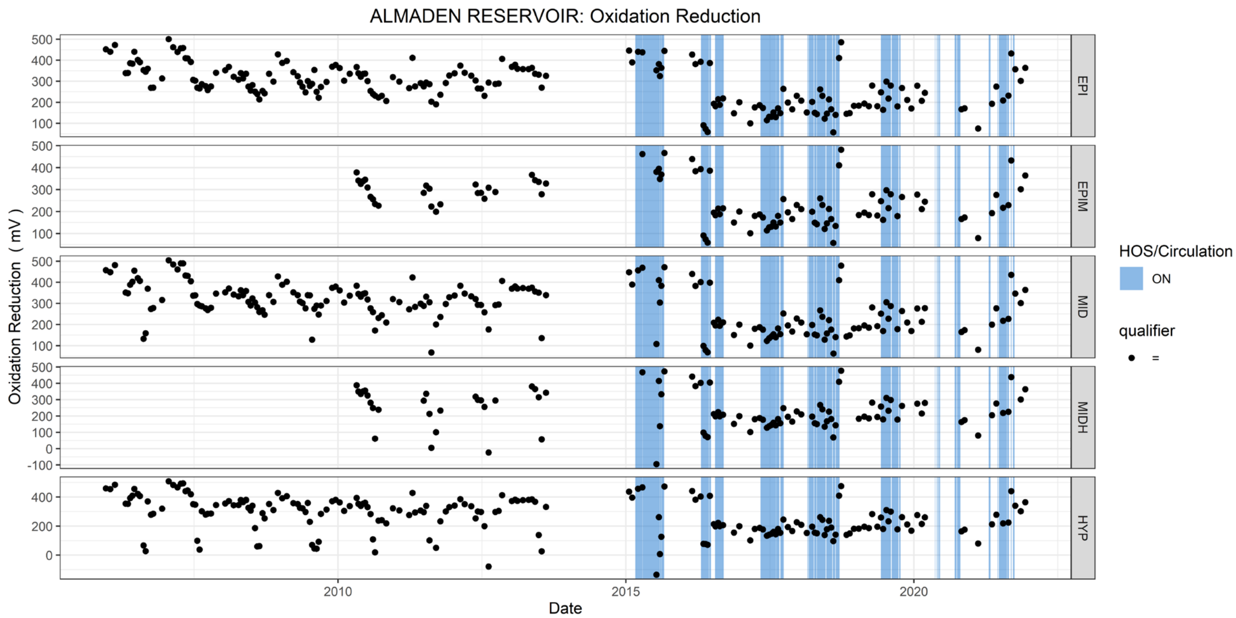

ALMADEN LAKE: Water Temperature
Water Temperature (C)
Date
EPI
MID
HYP
HOS/Circulation
ON
qualifier
=
2005
2010
2015
2020



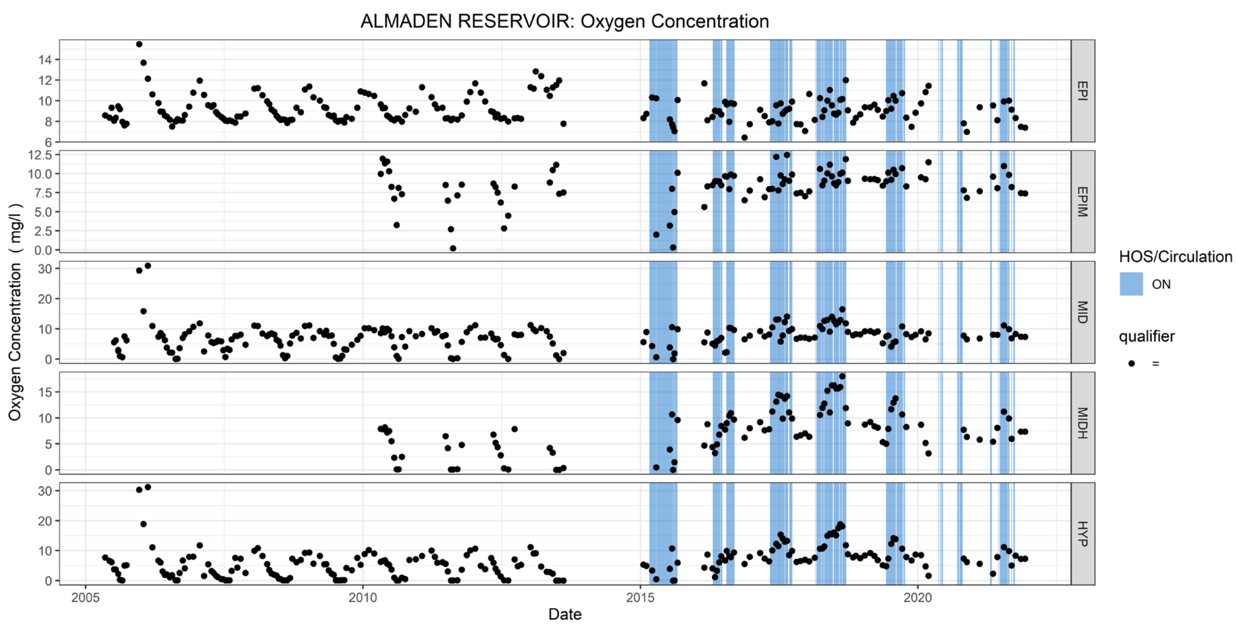
ALMADEN RESERVOIR: Ammonia
Ammonia (mg/L)
EPI
HYP
Date
HOS/Circulation
ON
qualifier
=
<



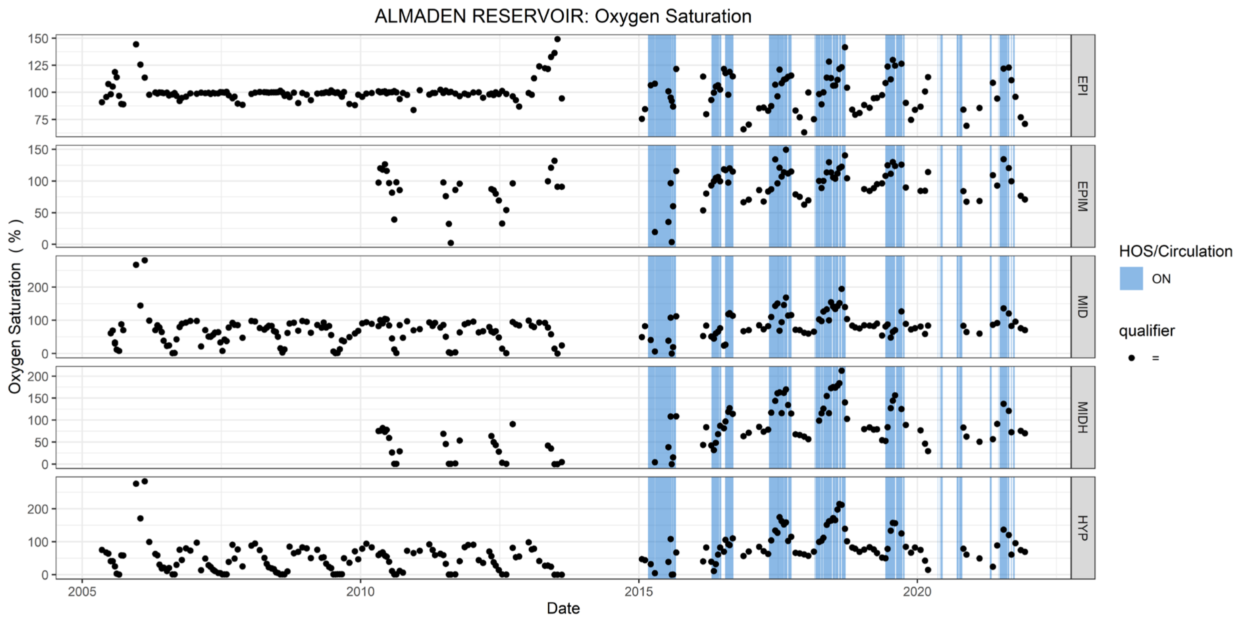
ALMADEN RESERVOIR: Chlorophyll
Chlorophyll (ug/l)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=



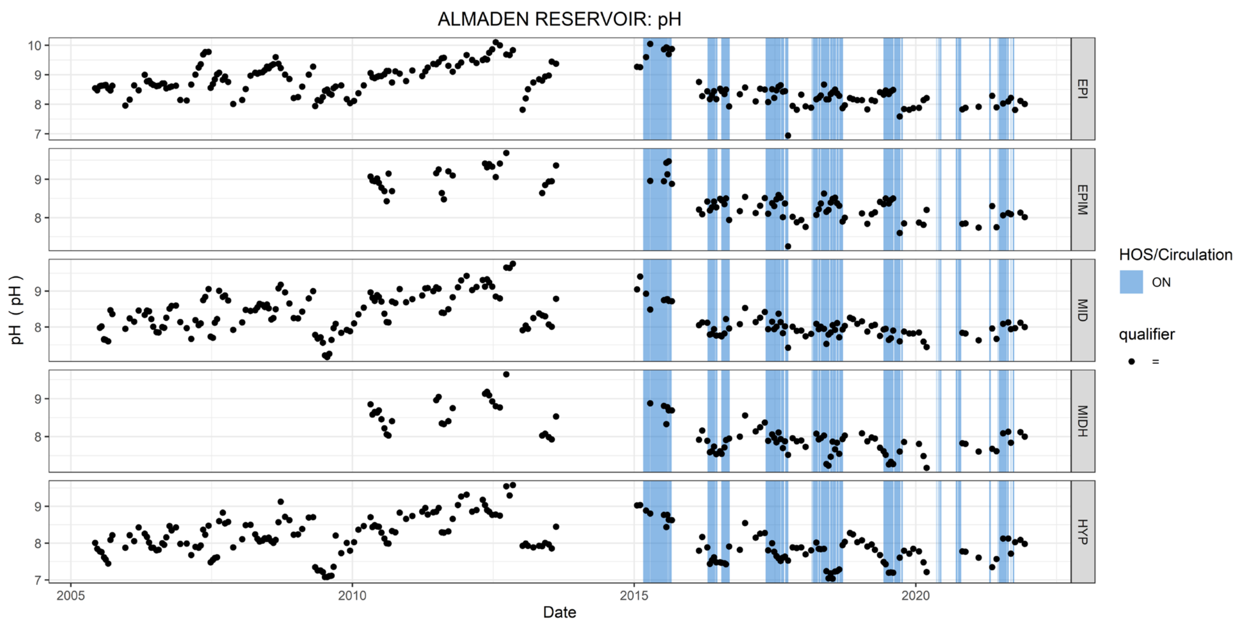
ALMADEN RESERVOIR: Oxidation Reduction
Oxidation Reduction (mV)
EPI
EPIM
MID
MIDH
HYP
Date
2010
2015
2020
HOS/Circulation
ON
qualifier
=



ALMADEN RESERVOIR: Oxygen Concentration
Oxygen Concentration (mg/l)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=

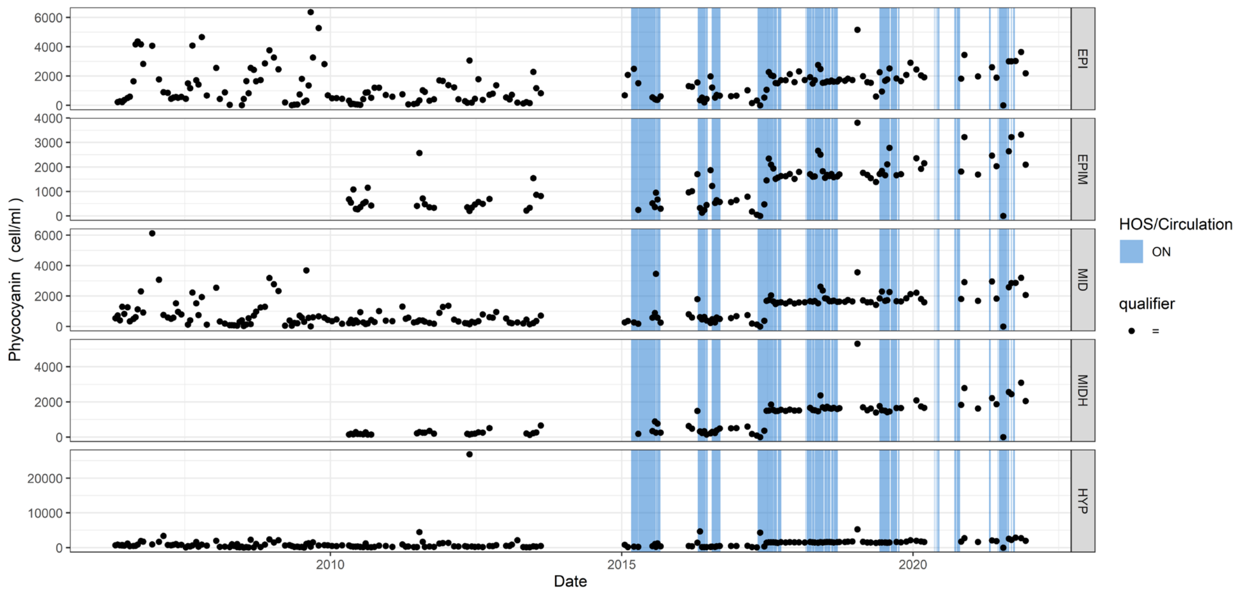


ALMADEN RESERVOIR: Oxygen Saturation
Oxygen Saturation (%)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=

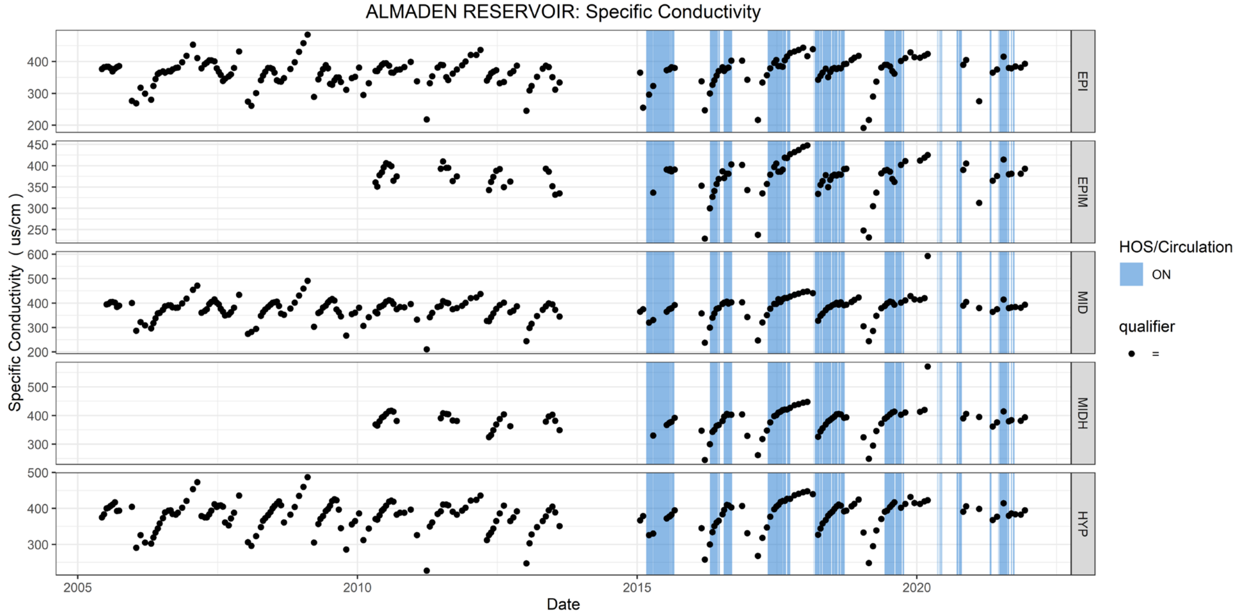


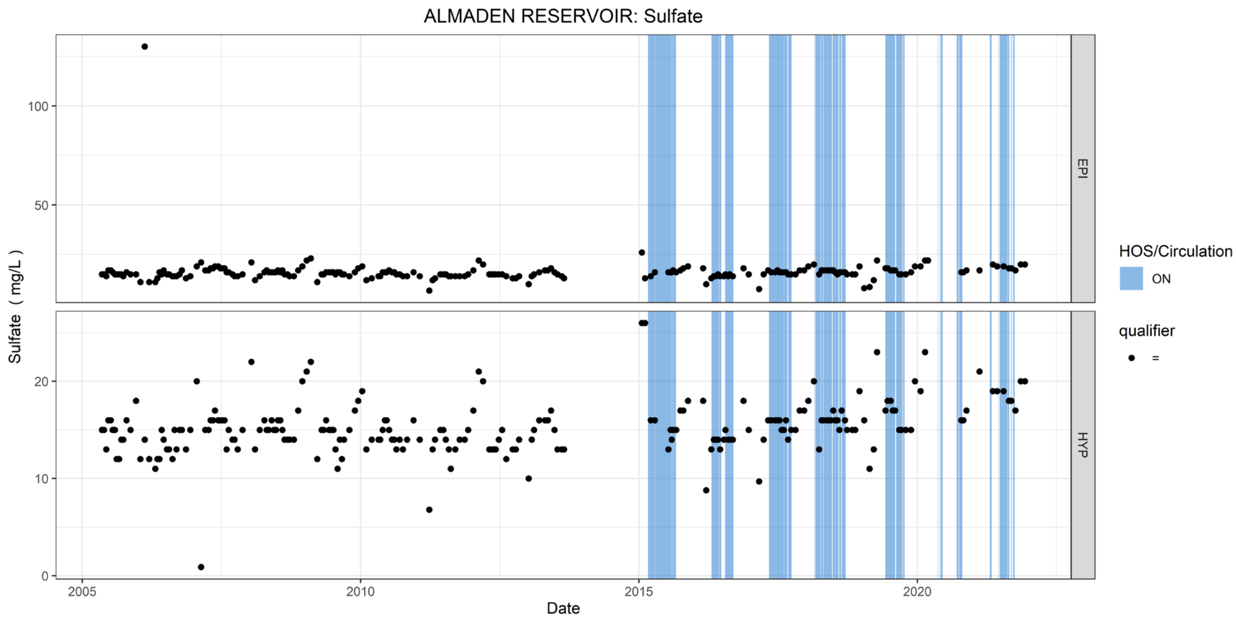
ALMADEN RESERVOIR: pH
pH (pH)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=

ALMADEN RESERVOIR: Phycocyanin



ALMADEN RESERVOIR: Specific Conductivity




ALMADEN RESERVOIR: Sulfate
Sulfate (mg/L)
Date
EPI
HYP
HOS/Circulation
ON
qualifier
=
100
50
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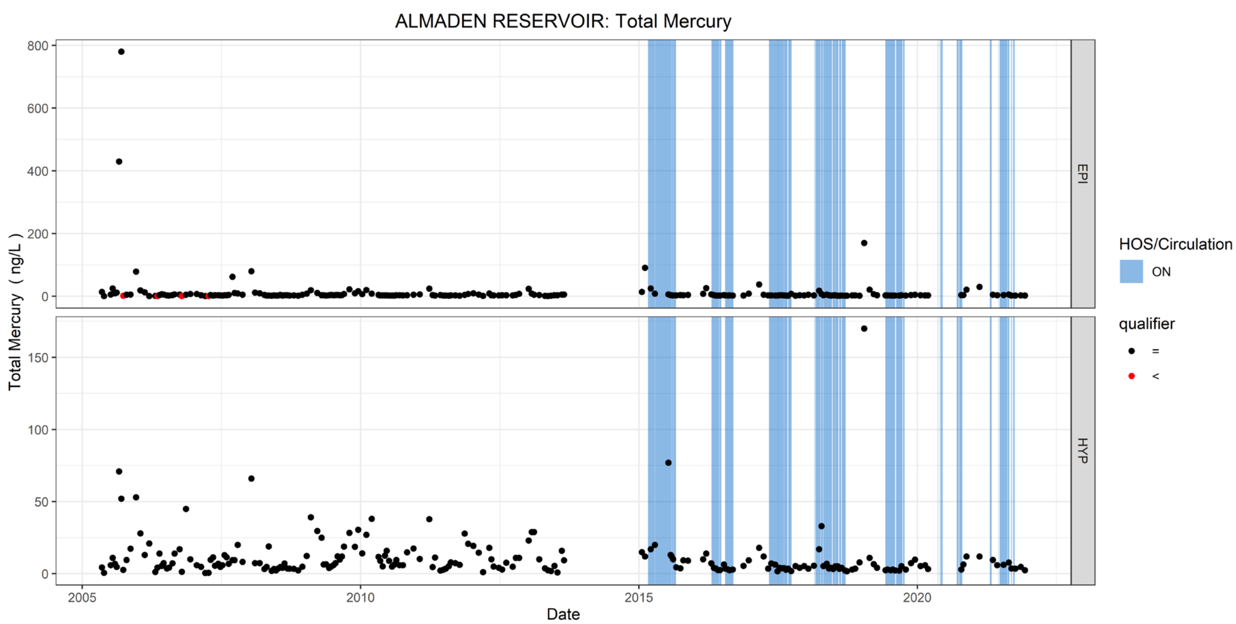
0
2005
2010
2015
2020


ALMADEN RESERVOIR: Total Mercury
Total Mercury (ng/L)
Date
EPI
HYP
HOS/Circulation
ON
qualifier
=
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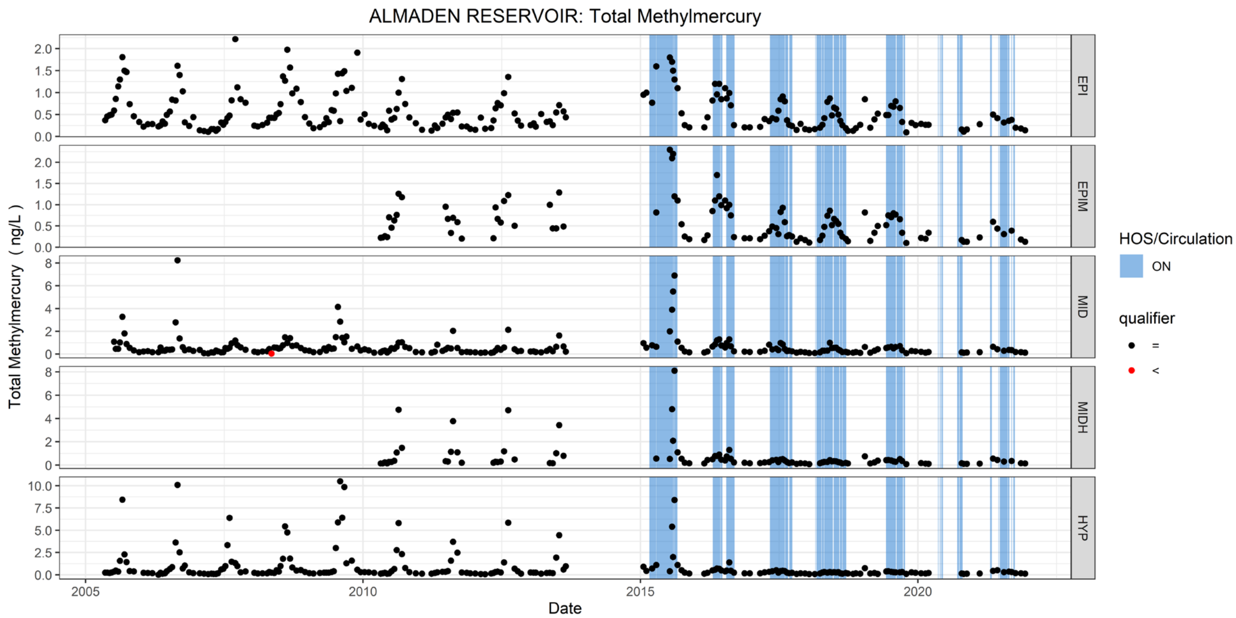
400
200
0
150
100
50
2005
2010
2015
2020


ALMADEN RESERVOIR: Total Methylmercury
Total Methylmercury (ng/L)
EPI
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MID
MIDH
HYP
Date
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2015
2020
HOS/Circulation
ON
qualifier
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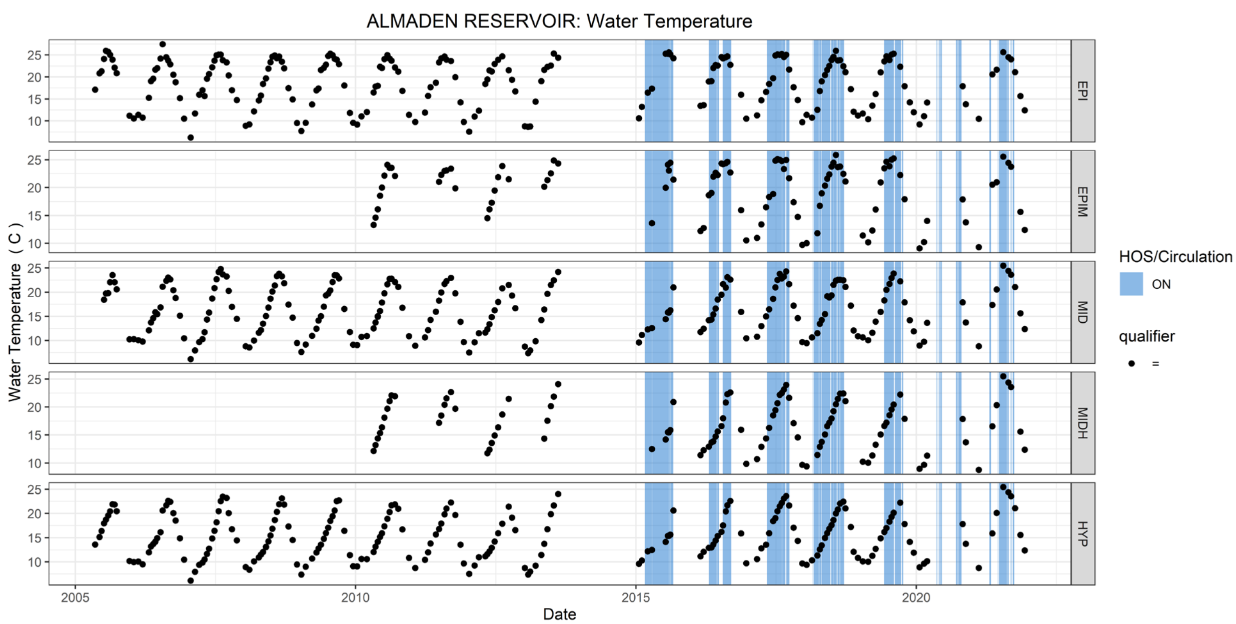
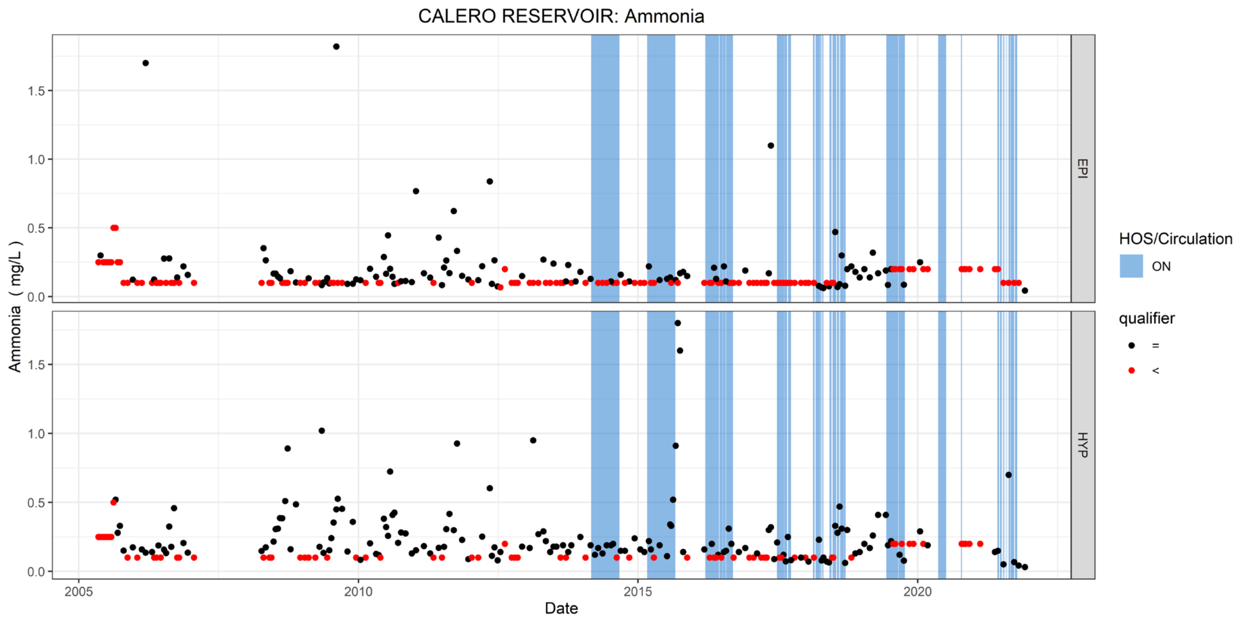

ALMADEN RESERVOIR: Water Temperature
Water Temperature (C)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=


CALERO RESERVOIR: Ammonia
Ammonia (mg/L)
EPI
HYP
Date
HOS/Circulation
ON
qualifier
=
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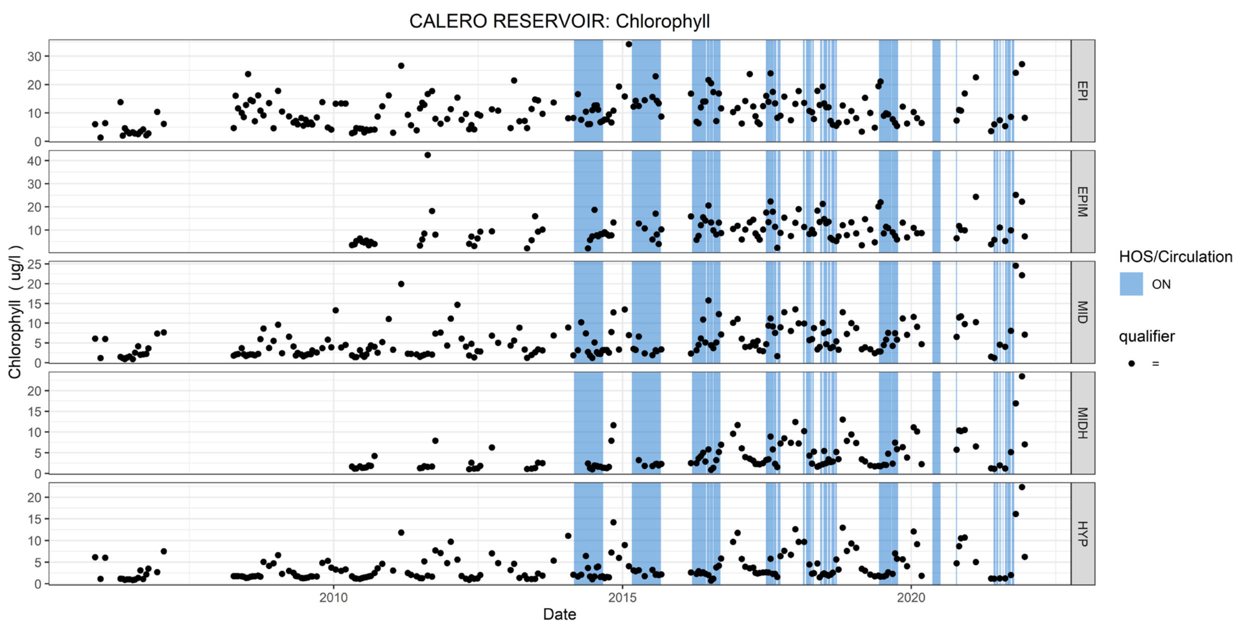
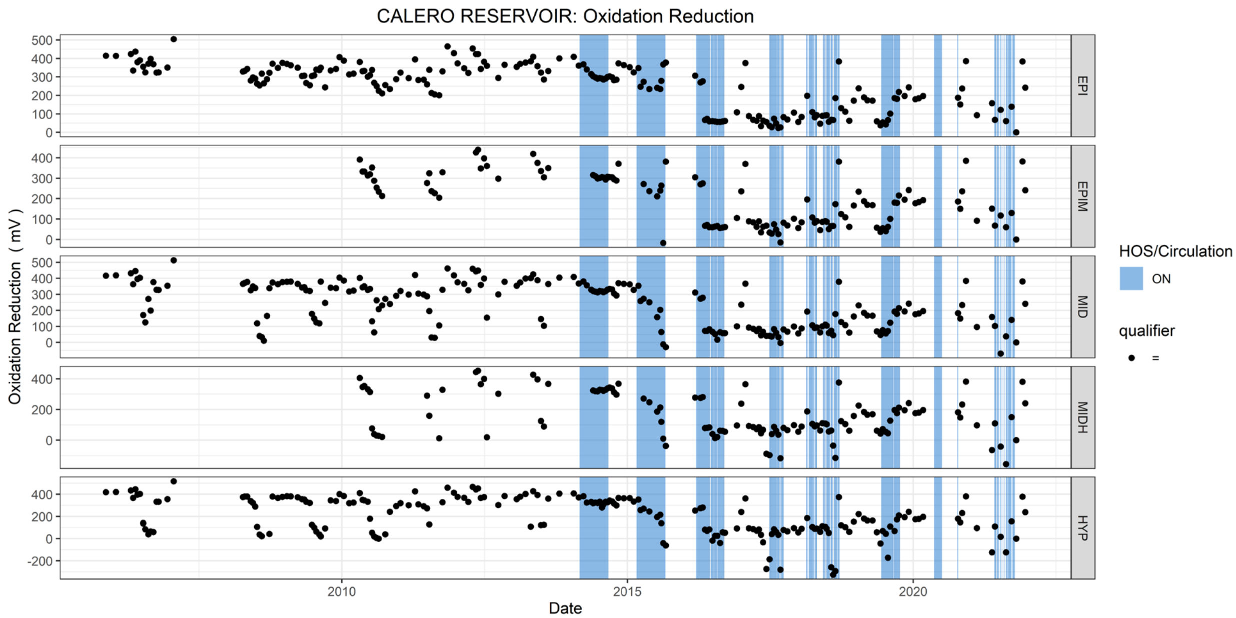
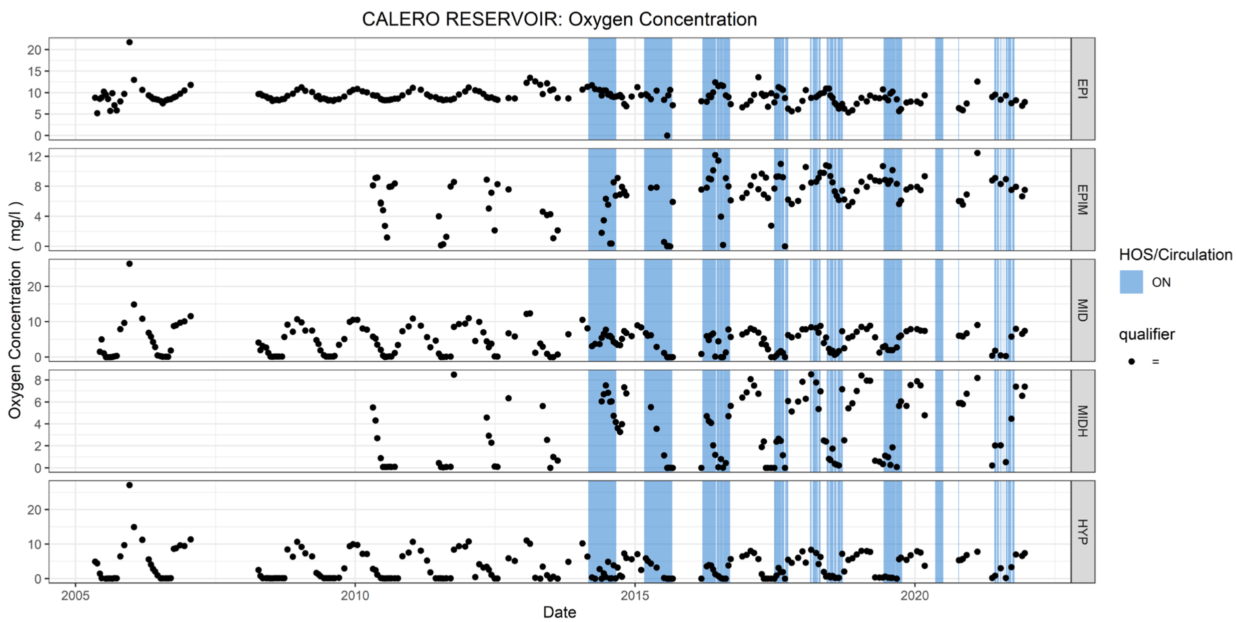
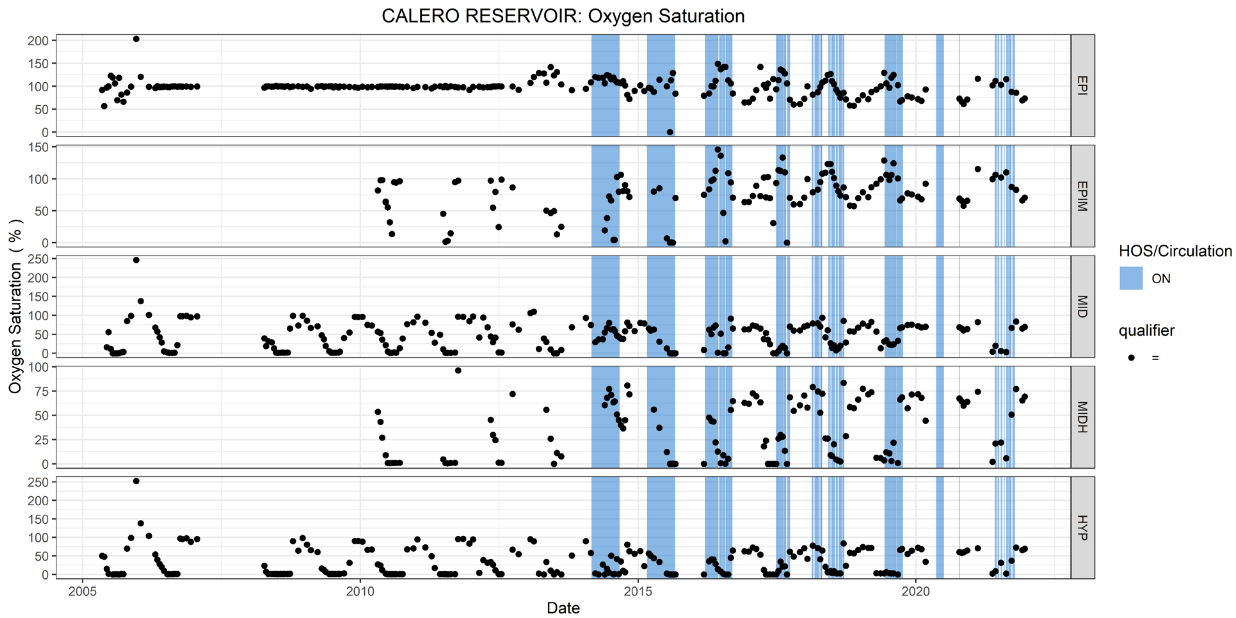
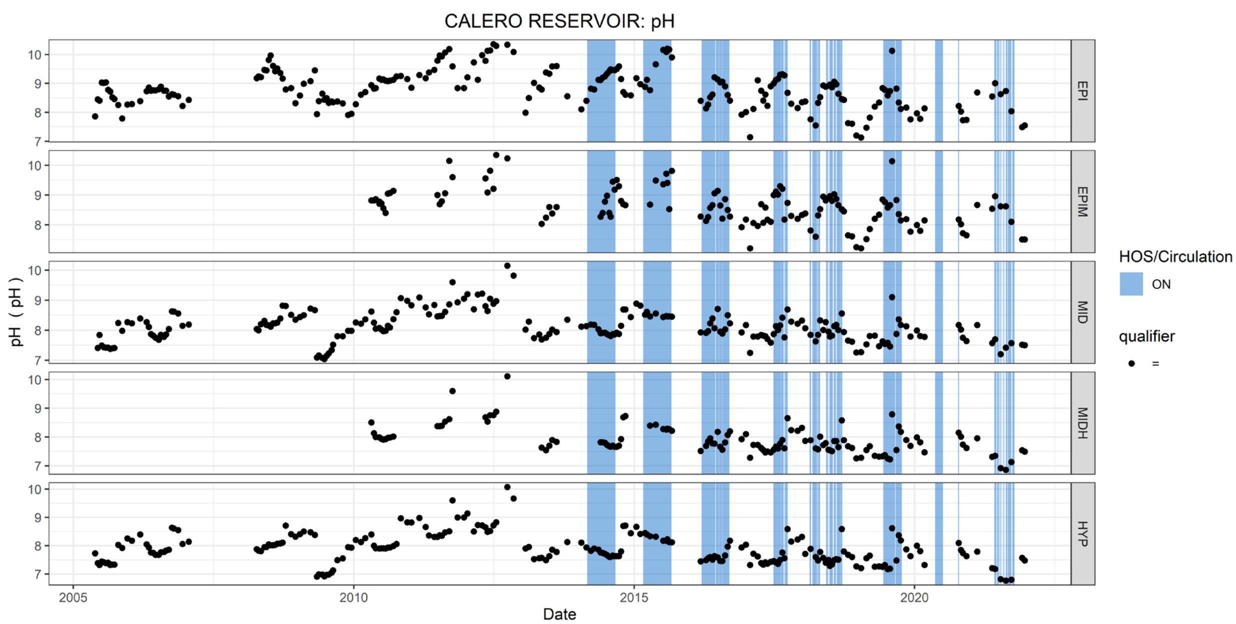
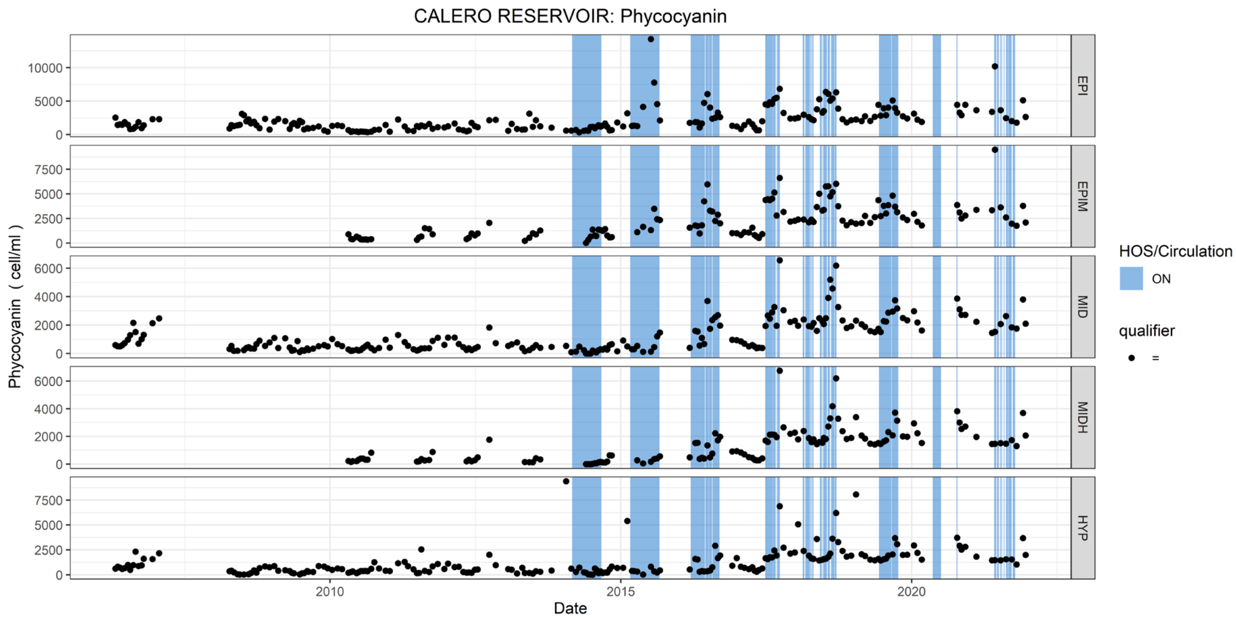

CALERO RESERVOIR: Chlorophyll
Chlorophyll (ug/l)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=

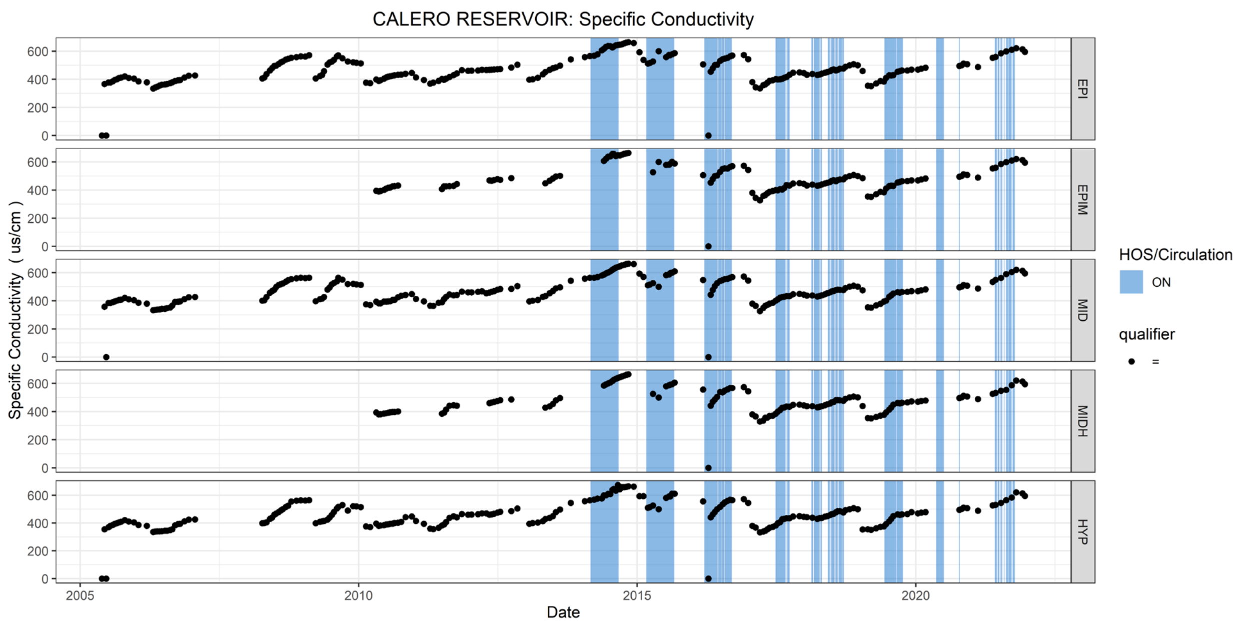

CALERO RESERVOIR: Oxidation Reduction
Oxidation Reduction (mV)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=

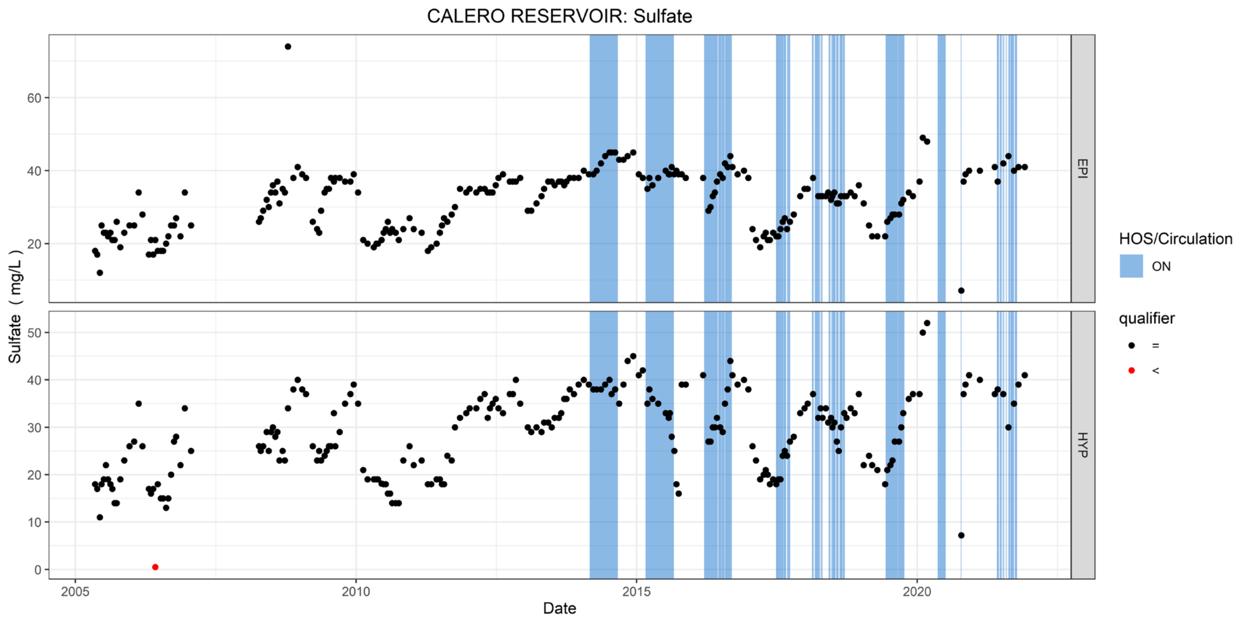

CALERO RESERVOIR: Oxygen Concentration
Oxygen Concentration (mg/l)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=


CALERO RESERVOIR: Oxygen Saturation
Oxygen Saturation (%)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=


CALERO RESERVOIR: pH
pH (pH)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=


CALERO RESERVOIR: Phycocyanin
Phycocyanin (cell/ml)
Date
EPI
EPIM
MID
MIDH
HYP
HOS/Circulation
ON
qualifier
=


CALERO RESERVOIR: Specific Conductivity
Specific Conductivity (us/cm)
Date
EPI
EPIM
MID
MIDH
HYP
HOS/Circulation
ON
qualifier
=


CALERO RESERVOIR: Sulfate
Sulfate (mg/L)
EPI
HYP
Date
HOS/Circulation
ON
qualifier
=
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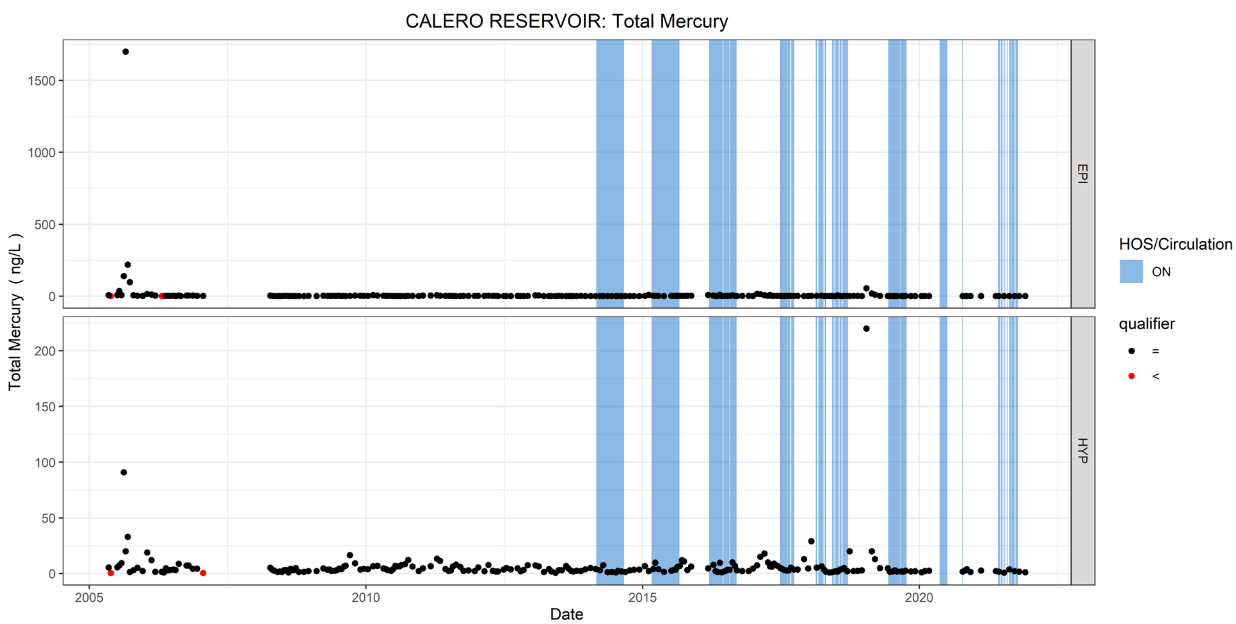
CALERO RESERVOIR: Total Mercury
Total Mercury (ng/L)
EPI
HYP
Date
HOS/Circulation
ON
qualifier
=
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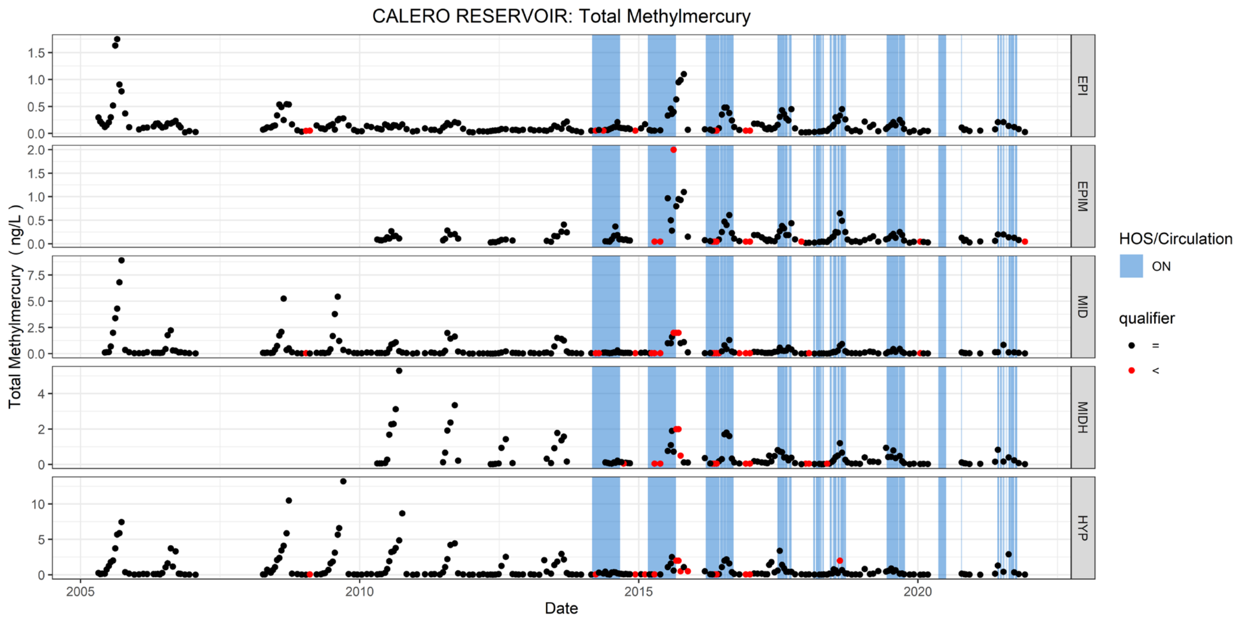

CALERO RESERVOIR: Total Methylmercury
Total Methylmercury (ng/L)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=
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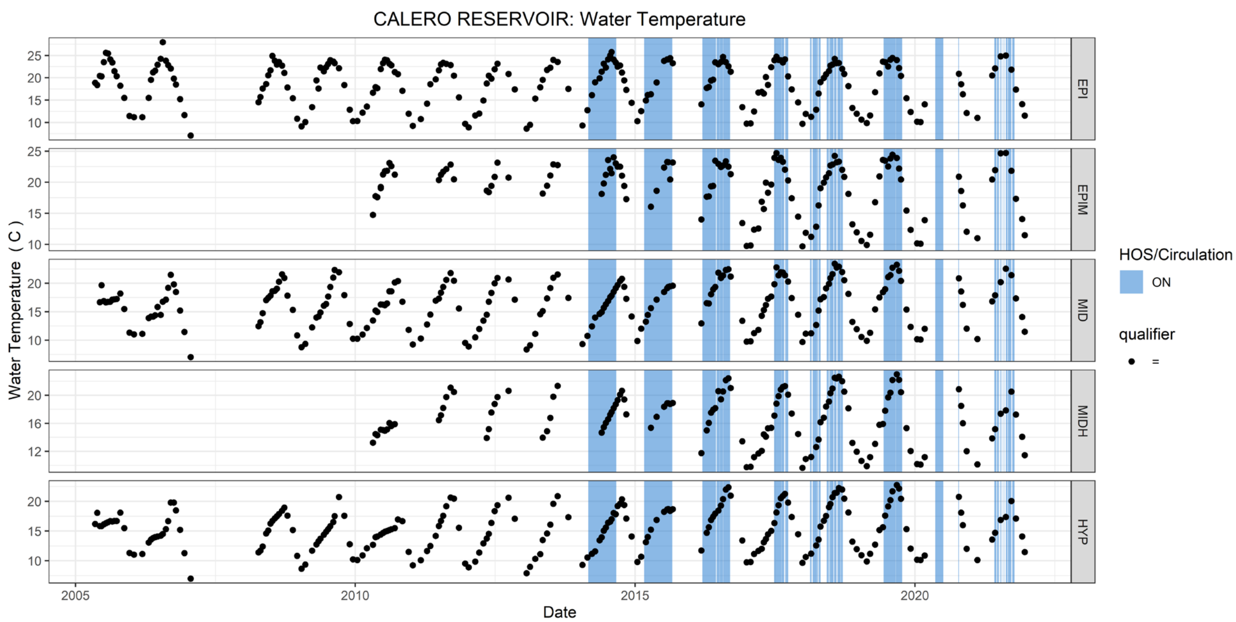
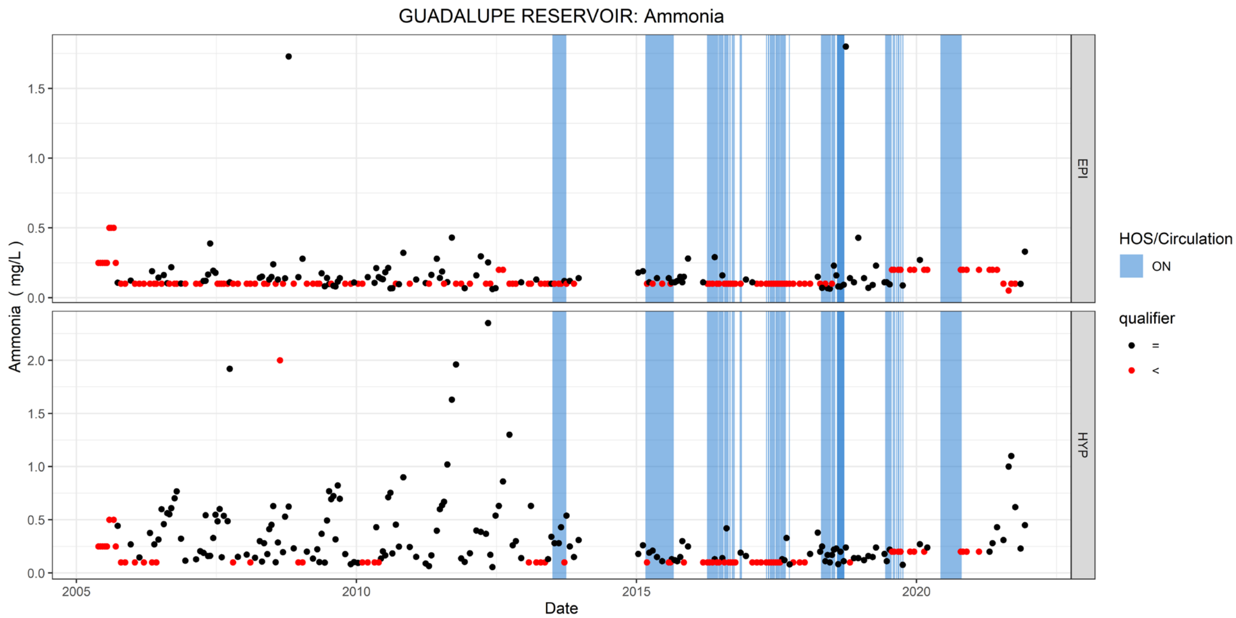
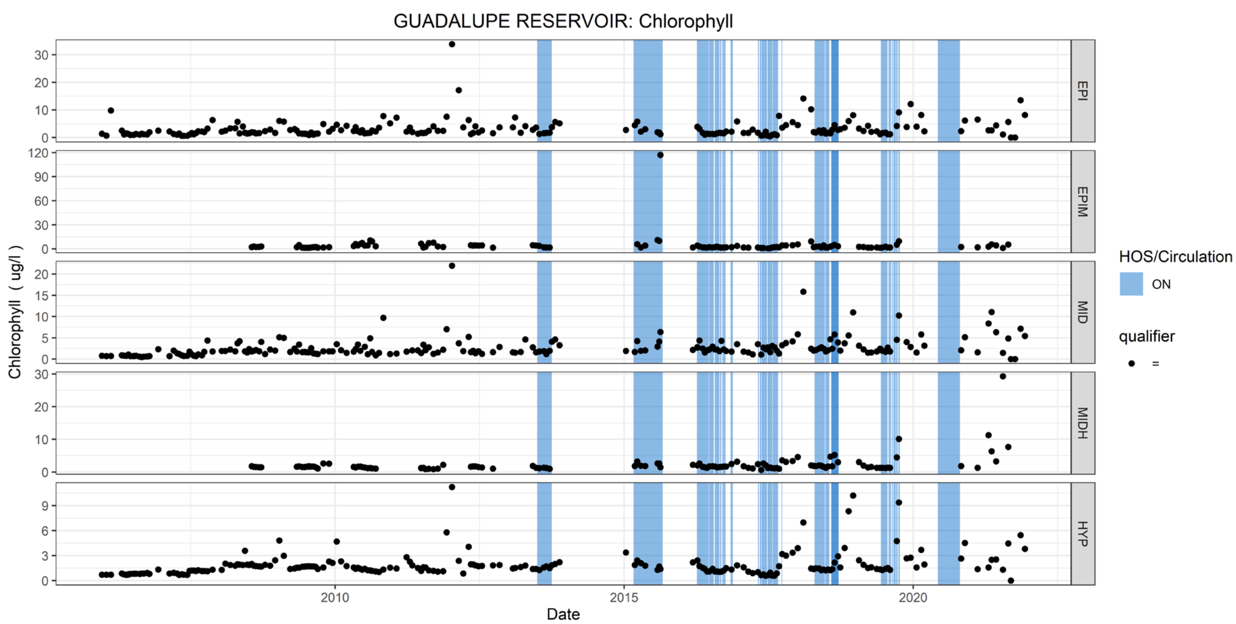


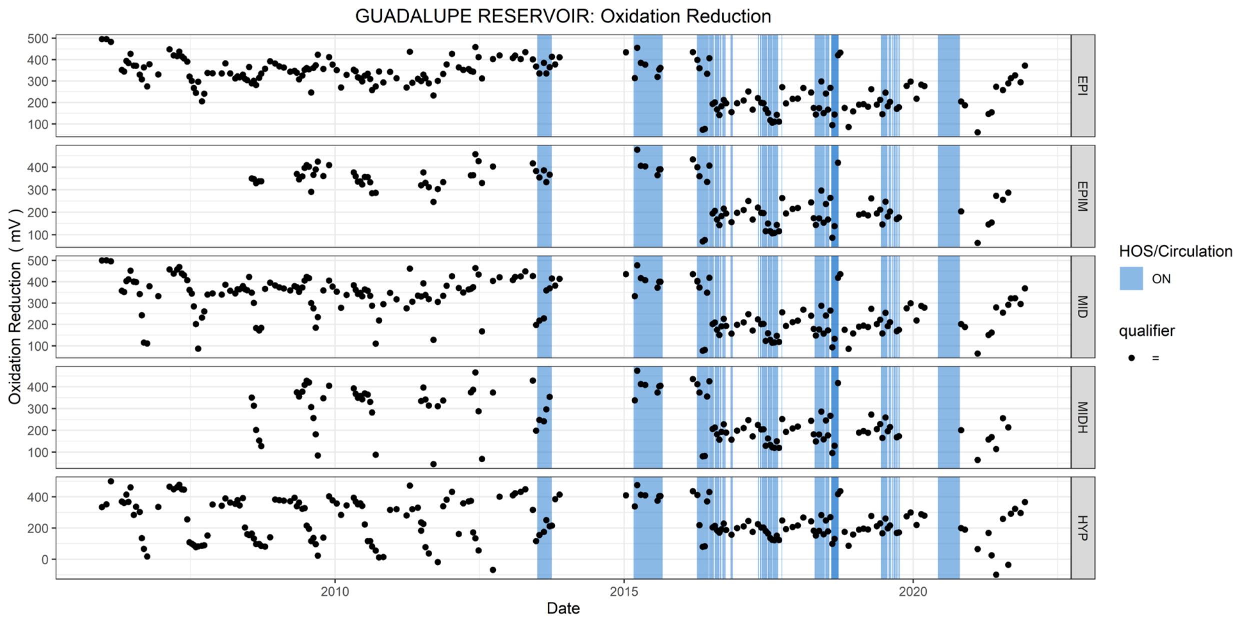
CALERO RESERVOIR: Water Temperature
Water Temperature (C)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=



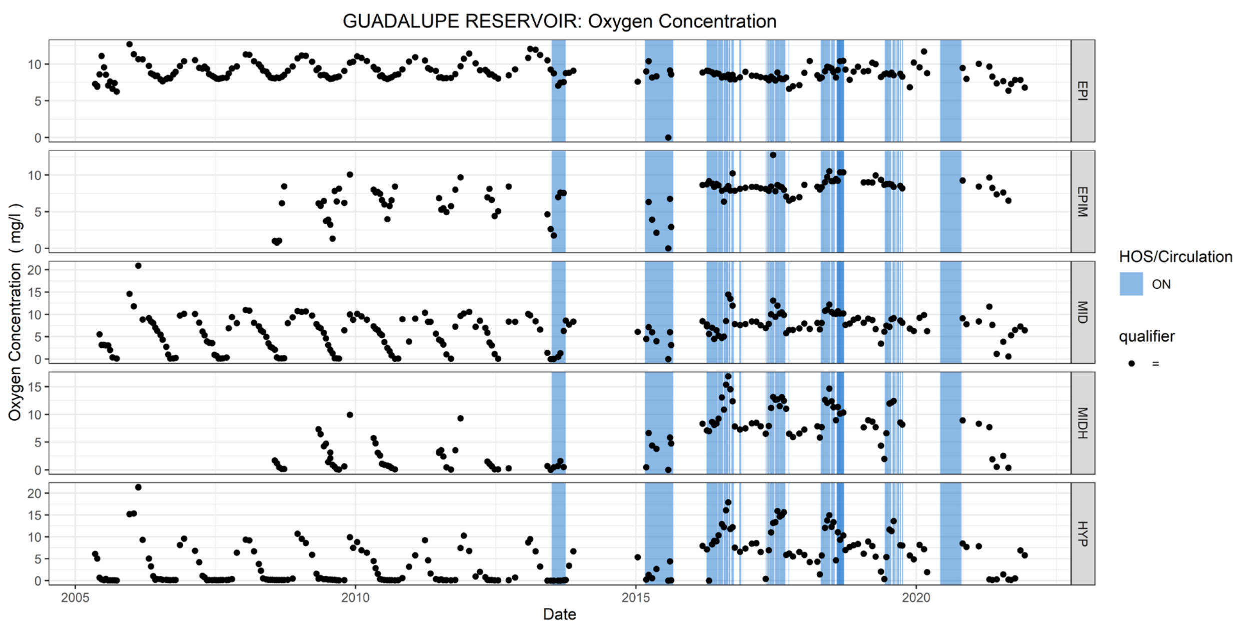
GUADALUPE RESERVOIR: Ammonia
Ammonia (mg/L)
Date
EPI
HYP
HOS/Circulation
ON
qualifier
=
<



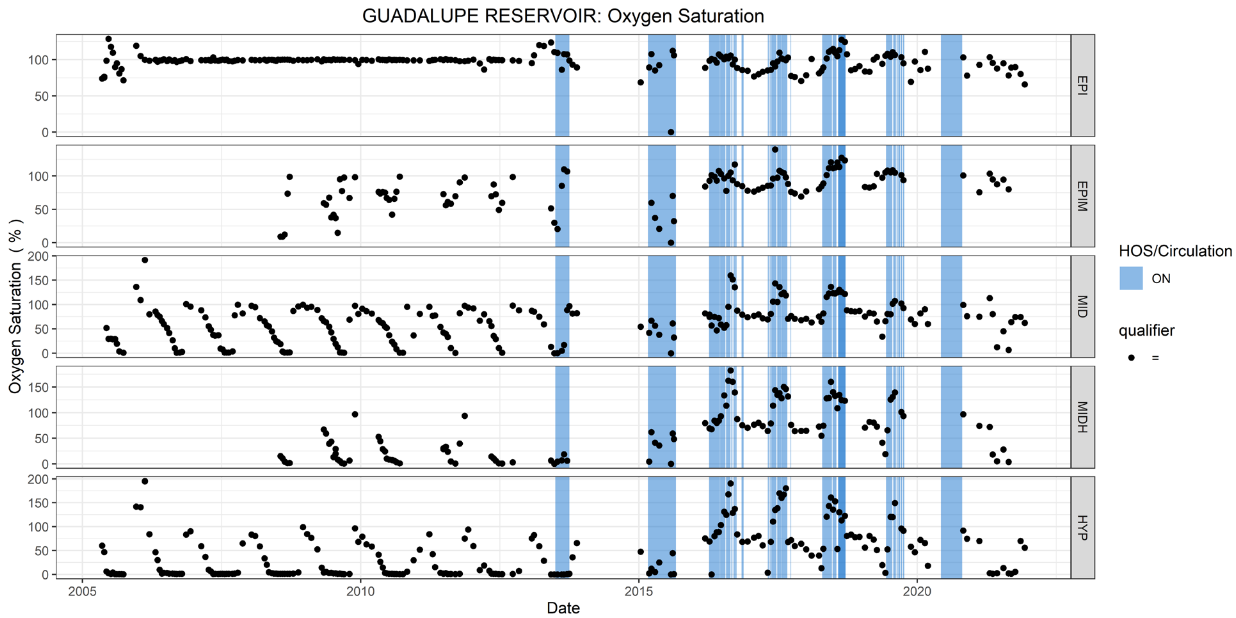
GUADALUPE RESERVOIR: Chlorophyll
Chlorophyll (ug/l)
Date
EPI
EPIM
MID
MIDH
HYP
HOS/Circulation
ON
qualifier
=

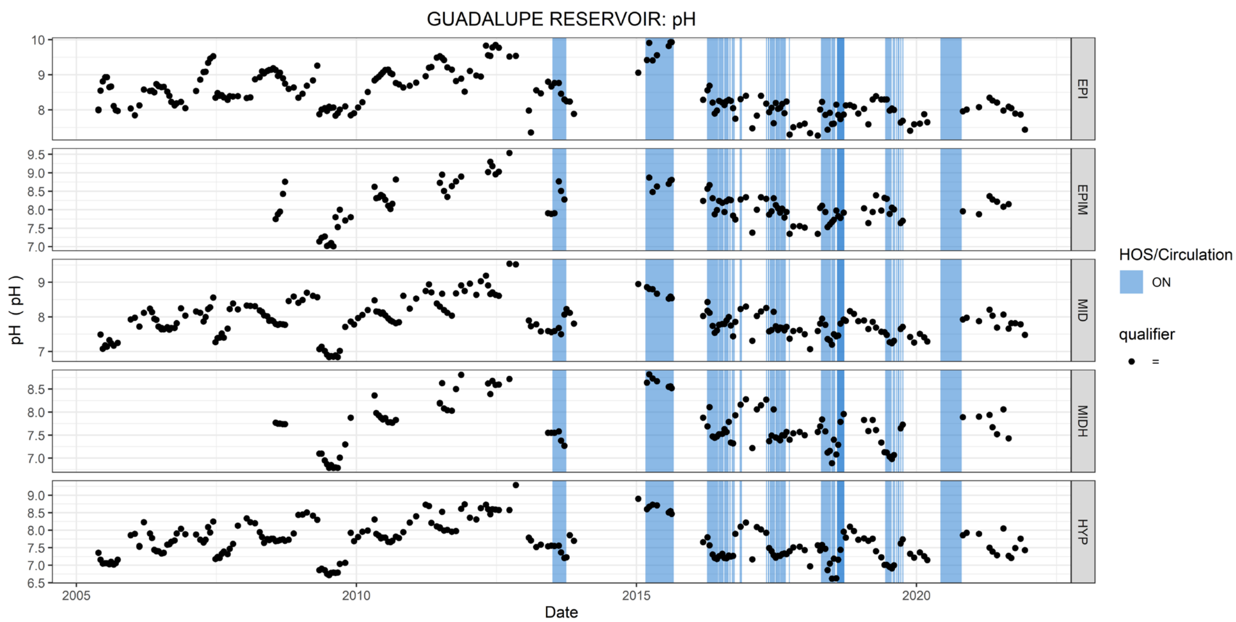


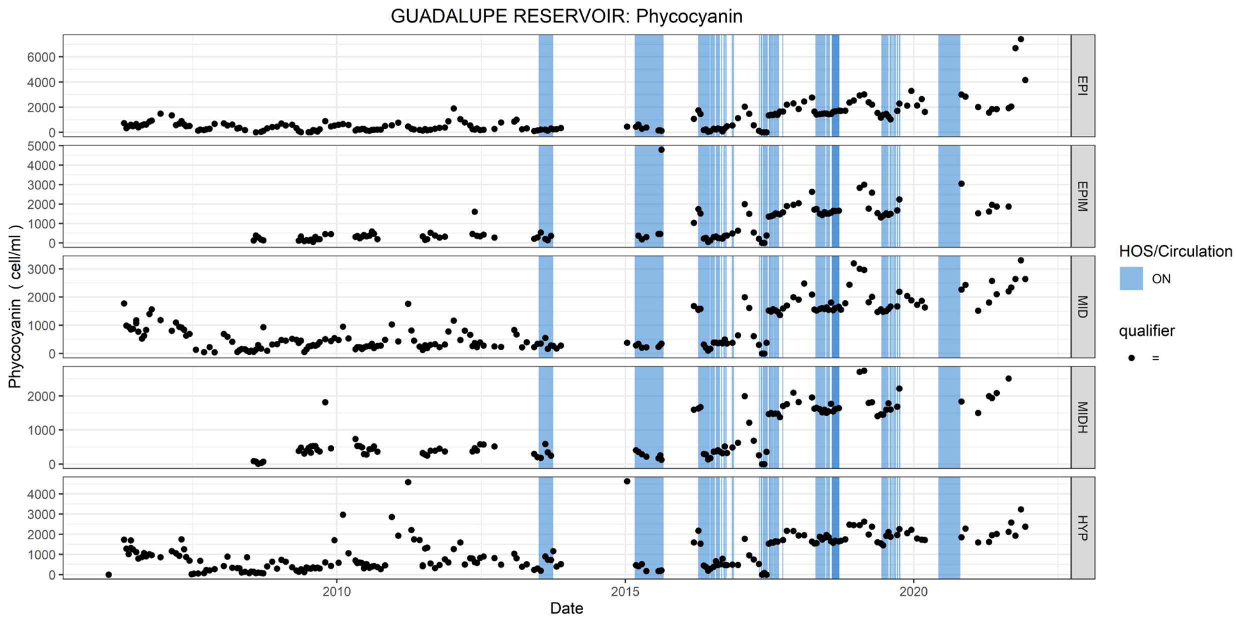
GUADALUPE RESERVOIR: Oxidation Reduction
Oxidation Reduction (mV)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=

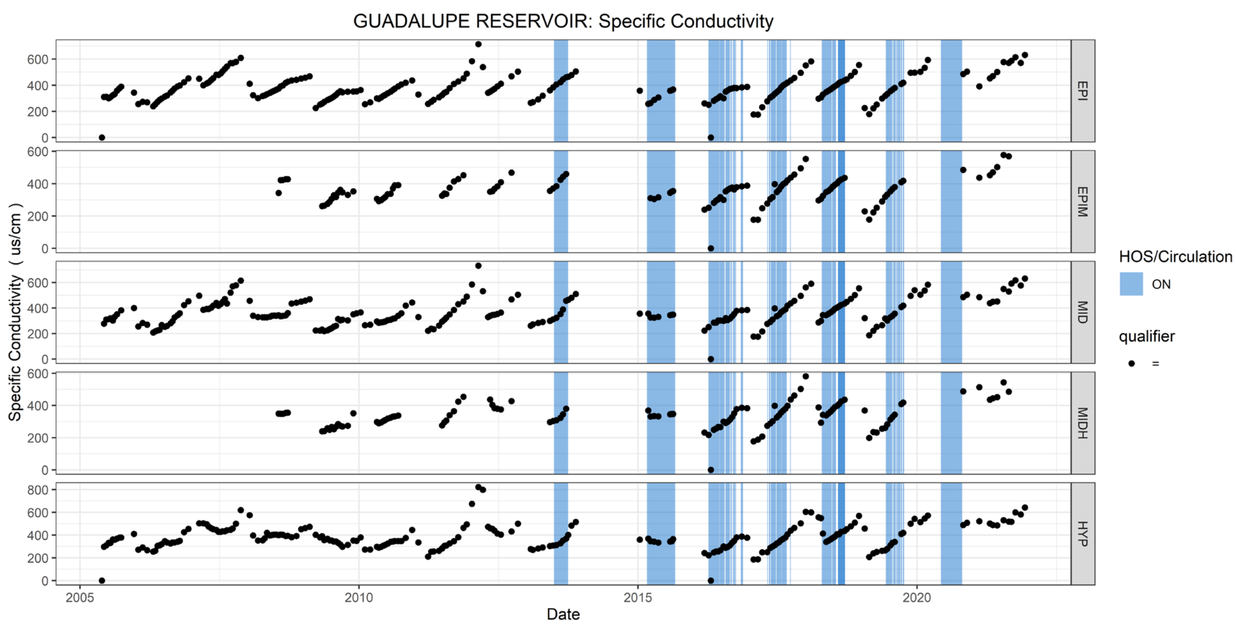


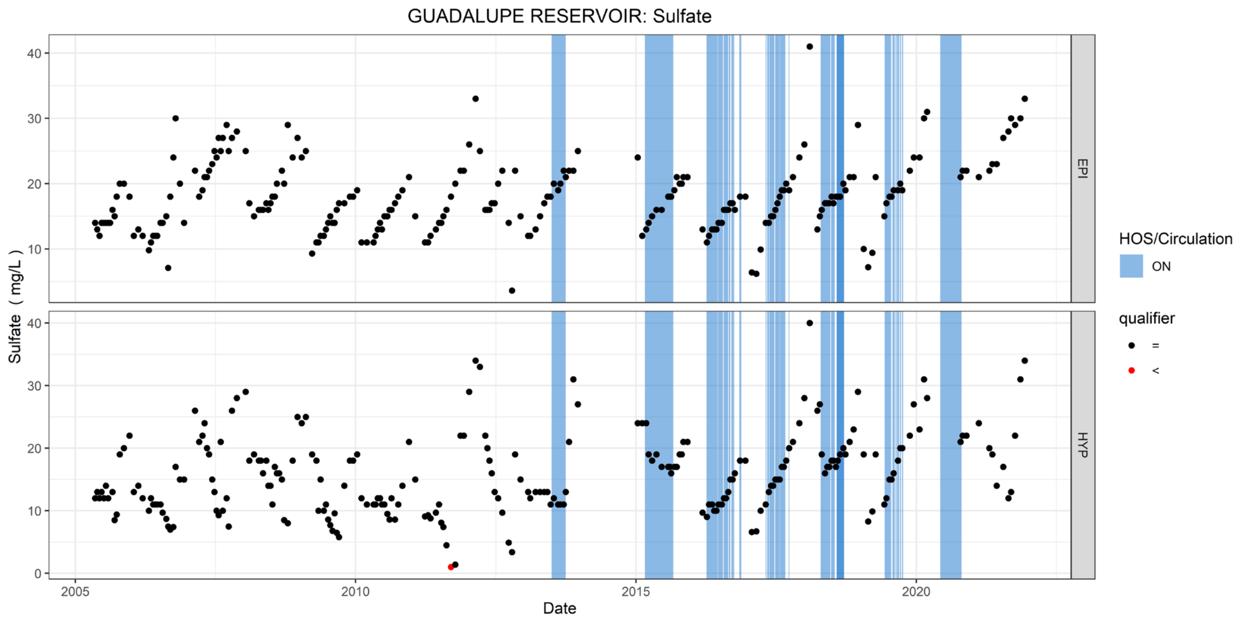
GUADALUPE RESERVOIR: Oxygen Concentration
Oxygen Concentration (mg/l)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=

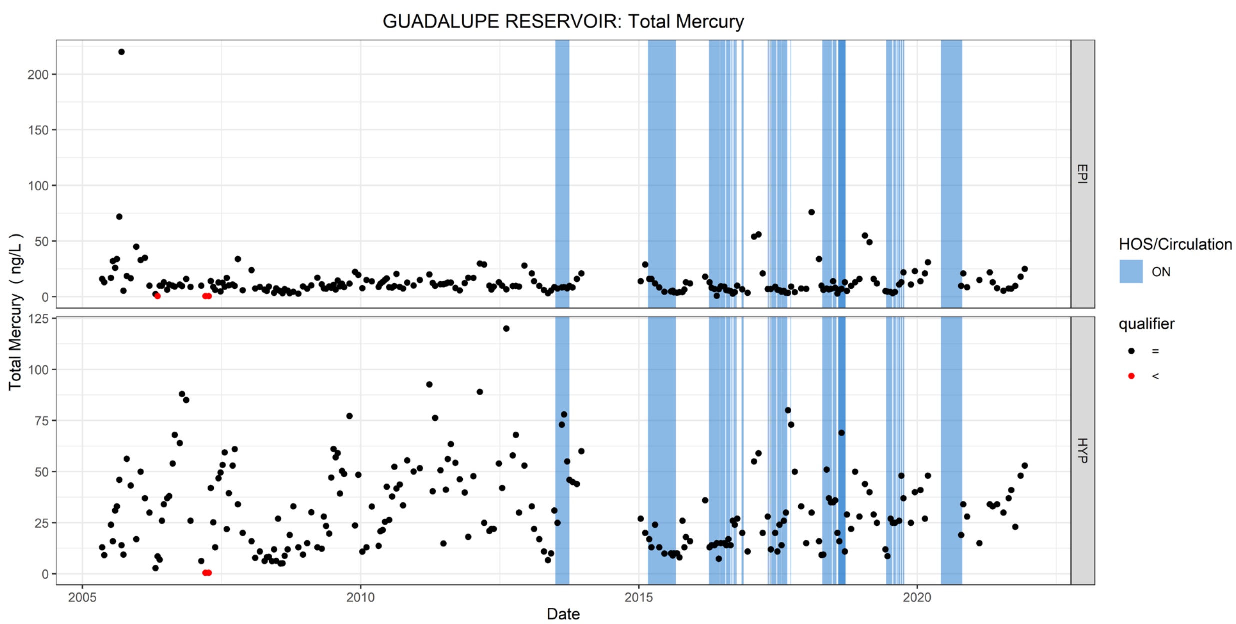

GUADALUPE RESERVOIR: Oxygen Saturation
Oxygen Saturation (%)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=

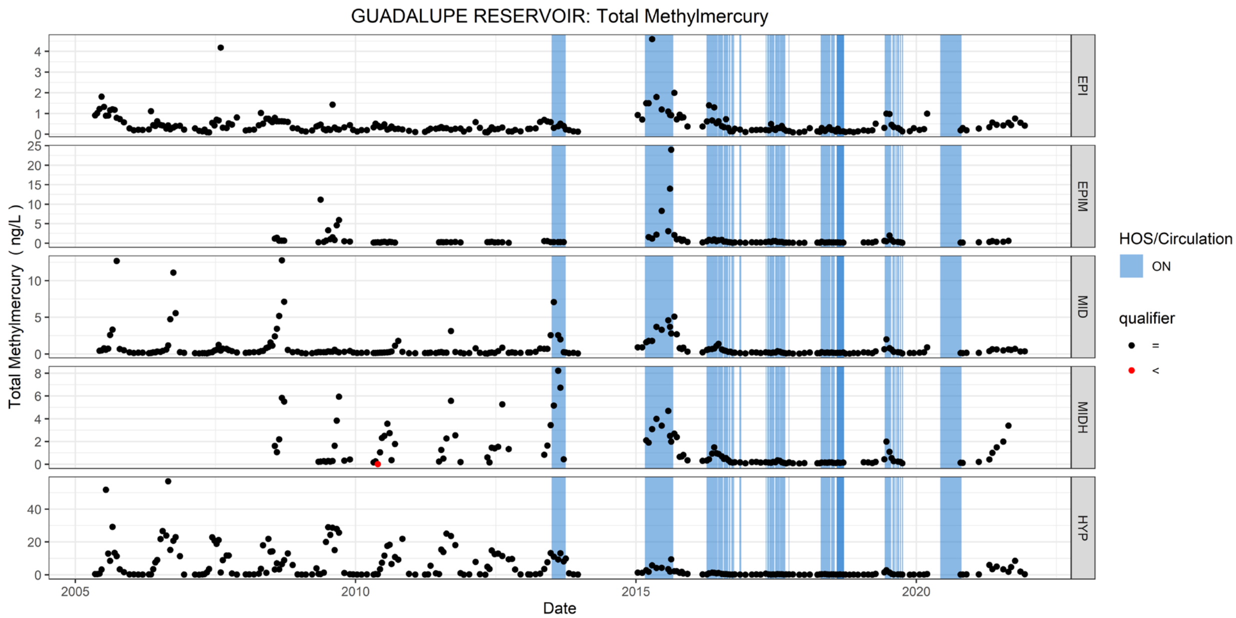

GUADALUPE RESERVOIR: pH
pH (pH)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=

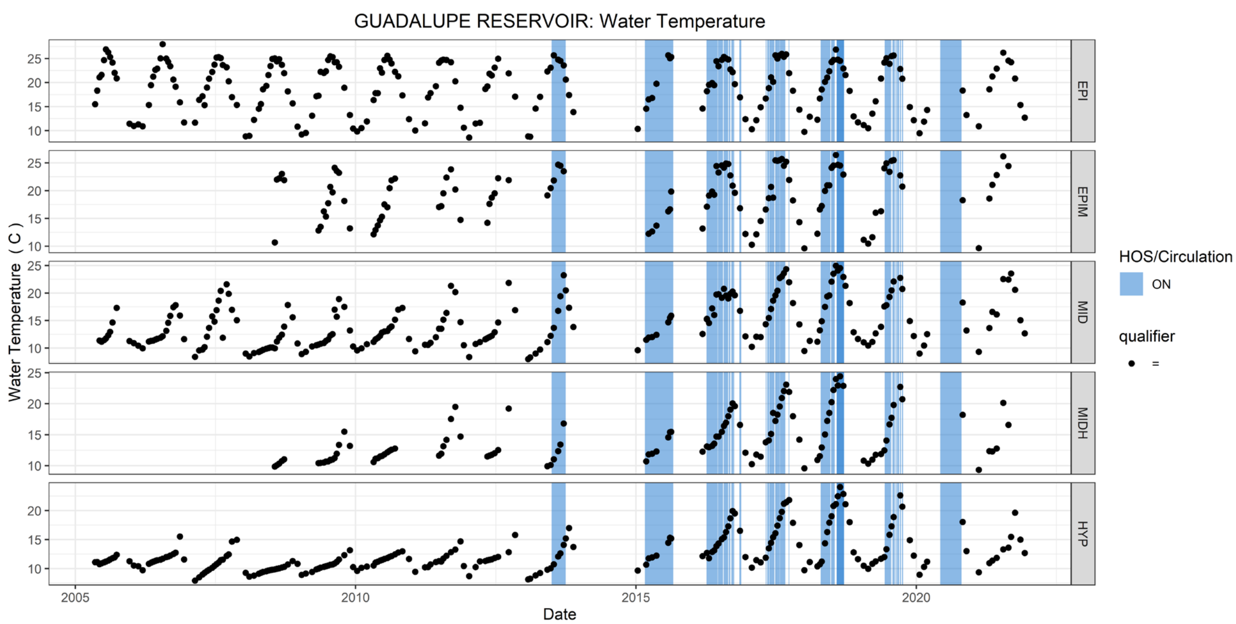

GUADALUPE RESERVOIR: Phycocyanin
Phycocyanin (cell/ml)
Date
EPI
EPIM
MID
MIDH
HYP
HOS/Circulation
ON
qualifier
=

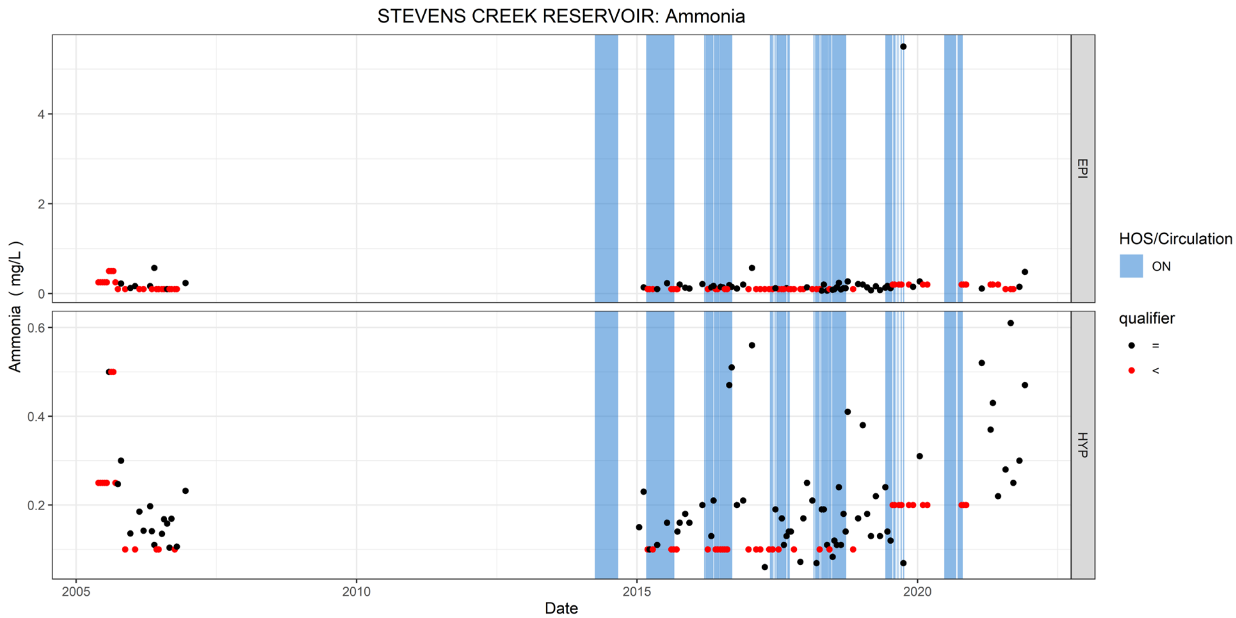

GUADALUPE RESERVOIR: Specific Conductivity
Specific Conductivity (us/cm)
Date
EPI
EPIM
MID
MIDH
HYP
HOS/Circulation
ON
qualifier
=

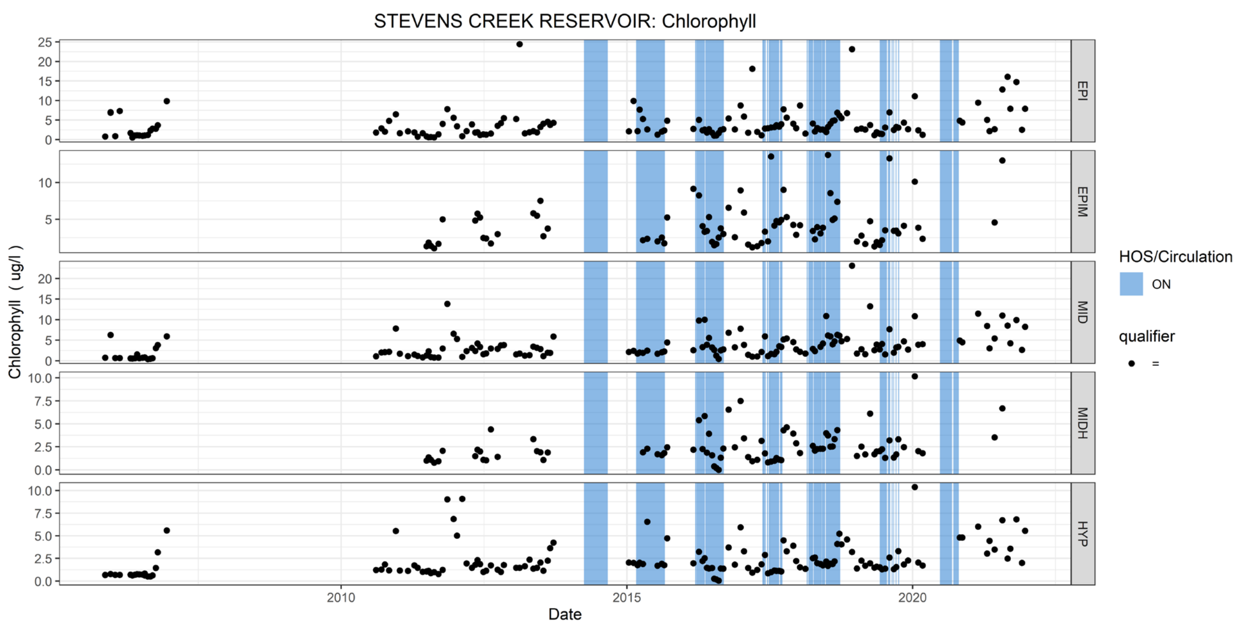

GUADALUPE RESERVOIR: Sulfate
Sulfate (mg/L)
EPI
HYP
Date
2005
2010
2015
2020
0
10
20
30
40
HOS/Circulation
ON
qualifier
=
<


GUADALUPE RESERVOIR: Total Mercury
Total Mercury (ng/L)
EPI
HYP
Date
2005
2010
2015
2020
0
50
100
150
200
25
75
125
HOS/Circulation
ON
qualifier
=
<

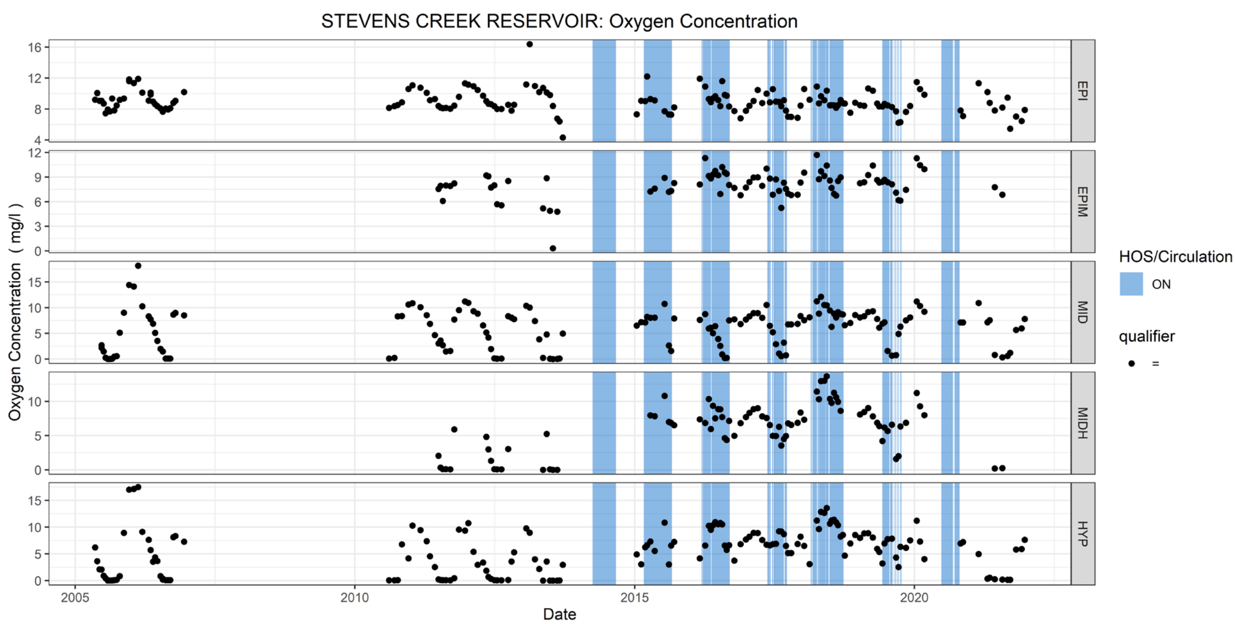

GUADALUPE RESERVOIR: Total Methylmercury
Total Methylmercury (ng/L)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=
<

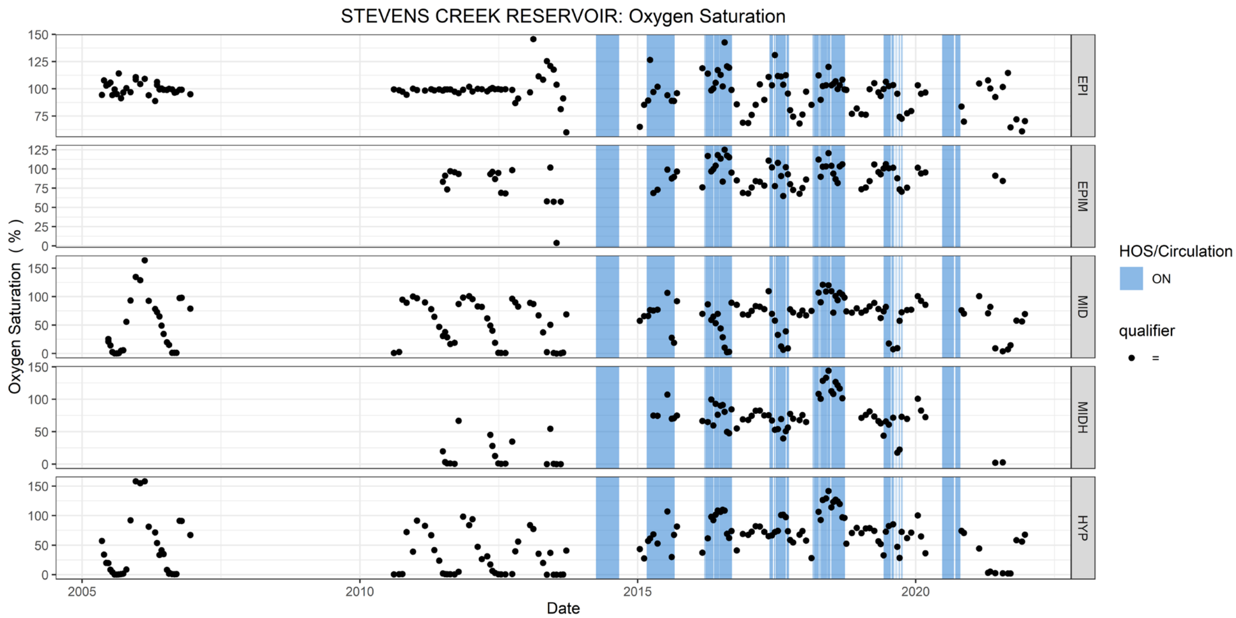

GUADALUPE RESERVOIR: Water Temperature
Water Temperature (C)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=


STEVENS CREEK RESERVOIR: Ammonia
Ammonia (mg/L)
Date
EPI
HYP
HOS/Circulation
ON
qualifier
=
<

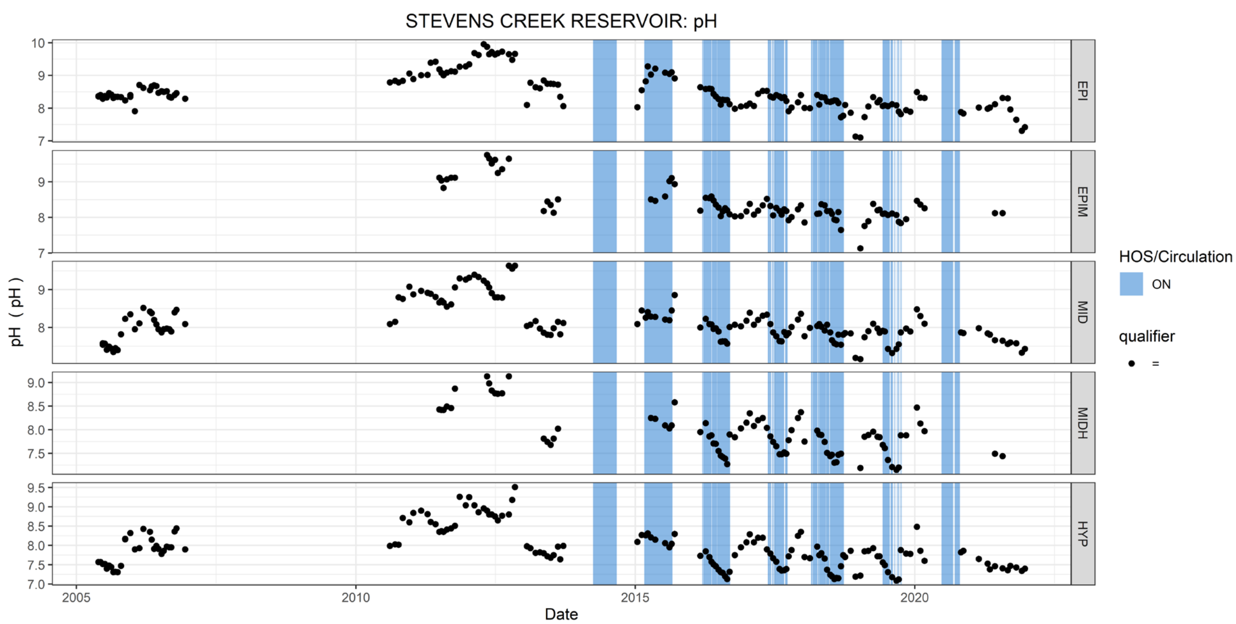

STEVENS CREEK RESERVOIR: Chlorophyll
Chlorophyll (ug/l)
Date
EPI
EPIM
MID
MIDH
HYP
HOS/Circulation
ON
qualifier
=


STEVENS CREEK RESERVOIR: Oxidation Reduction
Oxidation Reduction (mV)
Date
EPI
EPIM
MID
MIDH
HYP
HOS/Circulation
ON
qualifier
=
2010
2015
2020

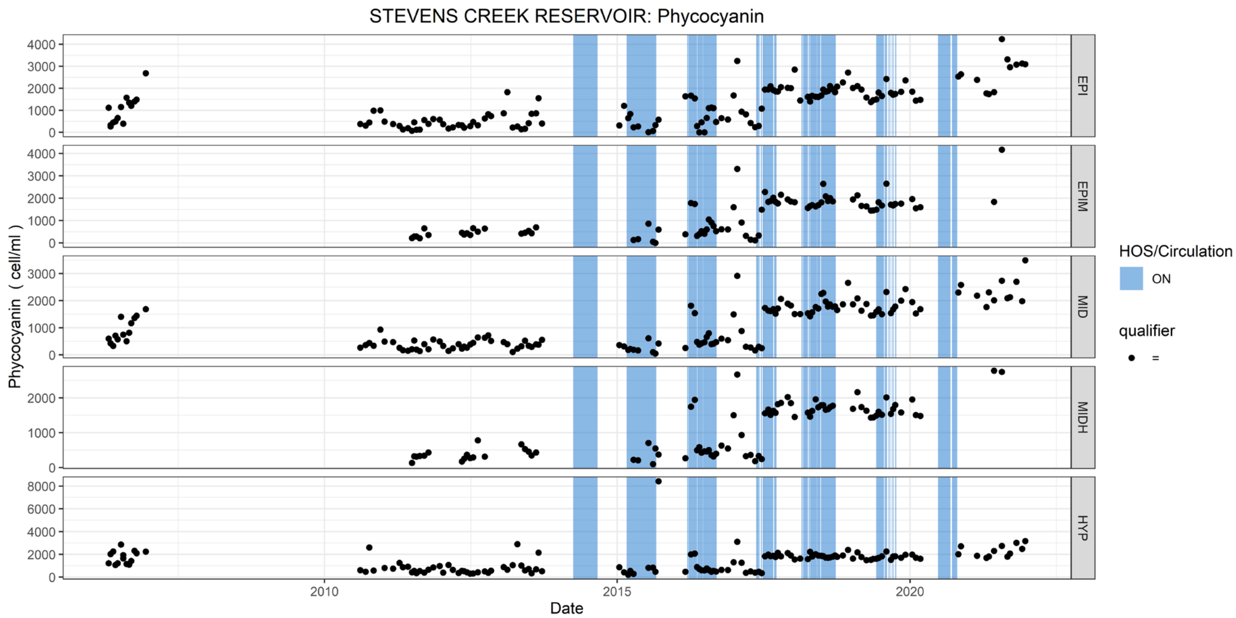

STEVENS CREEK RESERVOIR: Oxygen Concentration
Oxygen Concentration (mg/l)
Date
EPI
EPIM
MID
MIDH
HYP
HOS/Circulation
ON
qualifier
=
2005
2010
2015
2020



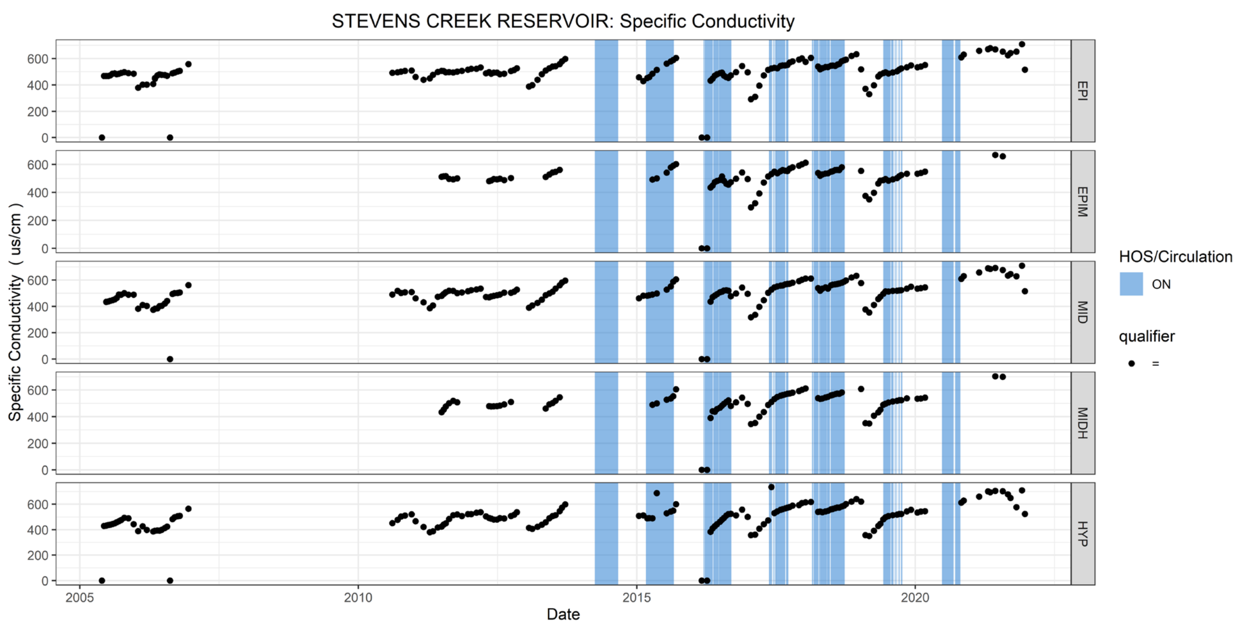
STEVENS CREEK RESERVOIR: Oxygen Saturation
Oxygen Saturation (%)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=



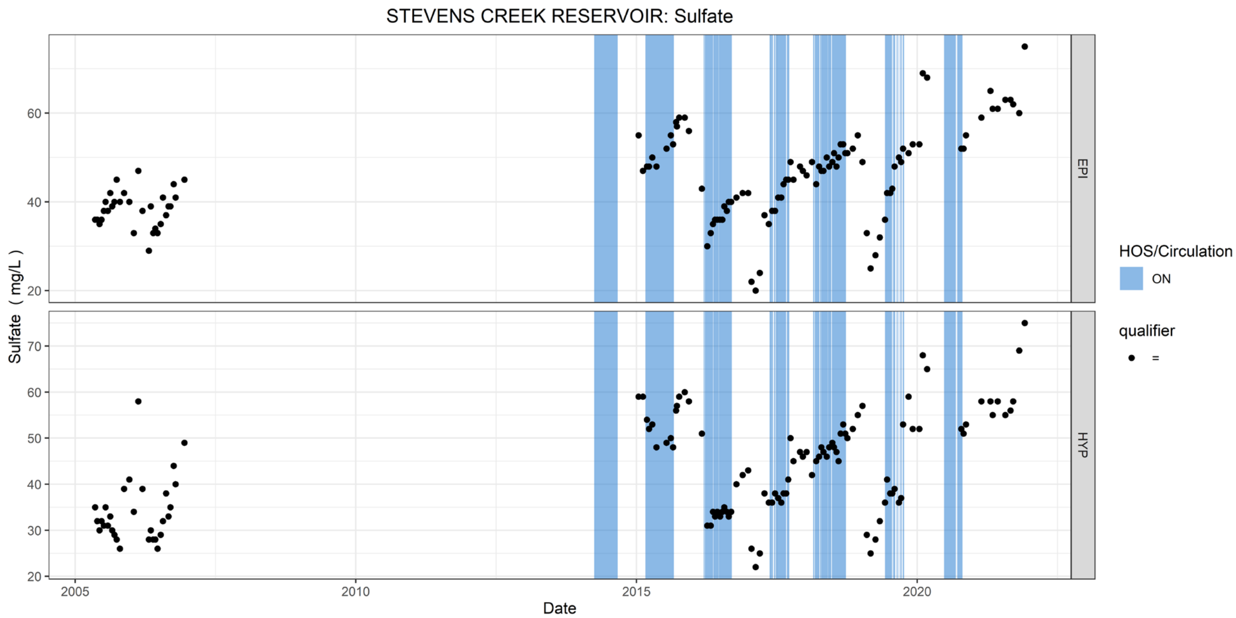
STEVENS CREEK RESERVOIR: pH
pH (pH)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=

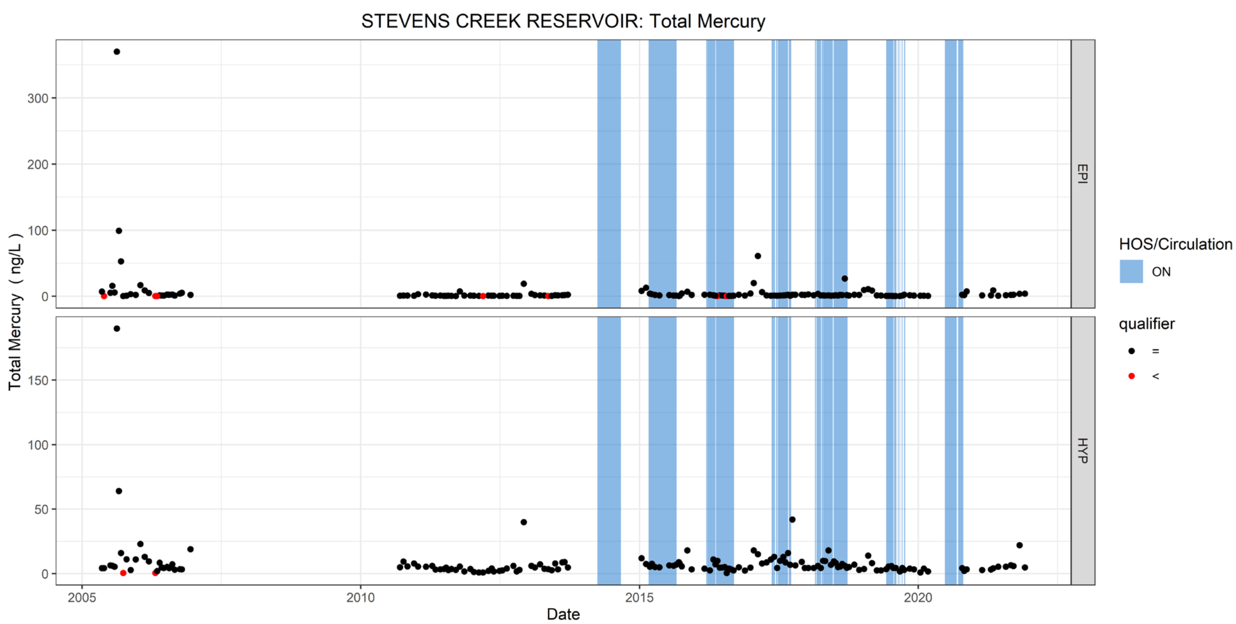


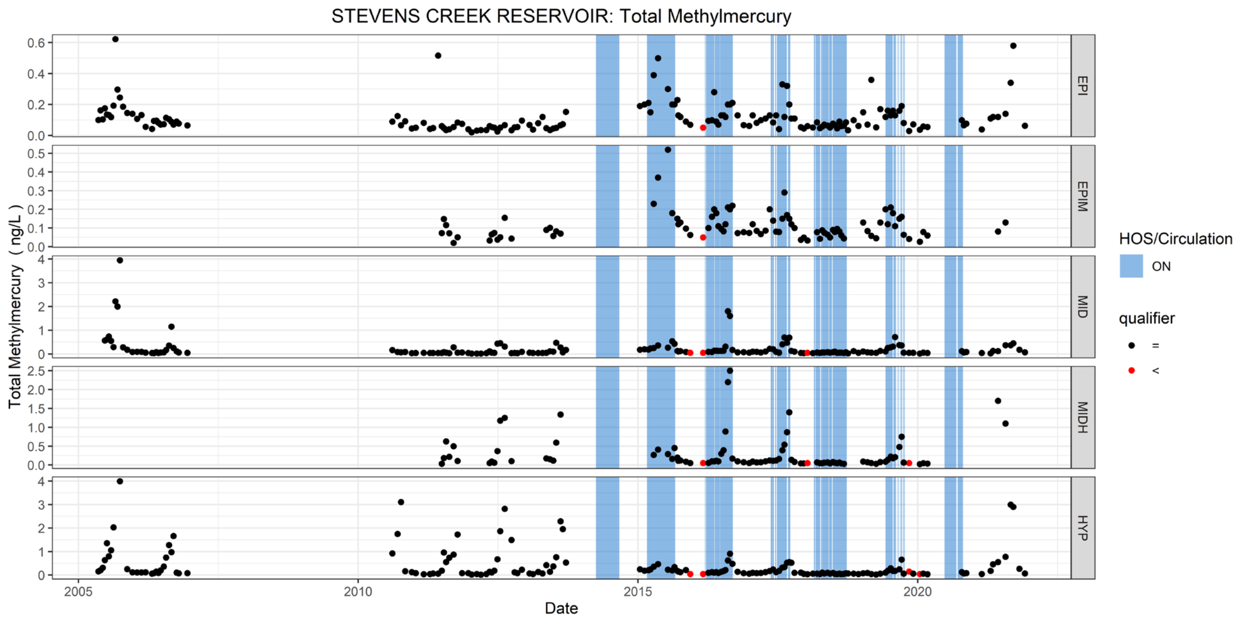
STEVENS CREEK RESERVOIR: Phycocyanin
Phycocyanin (cell/ml)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=



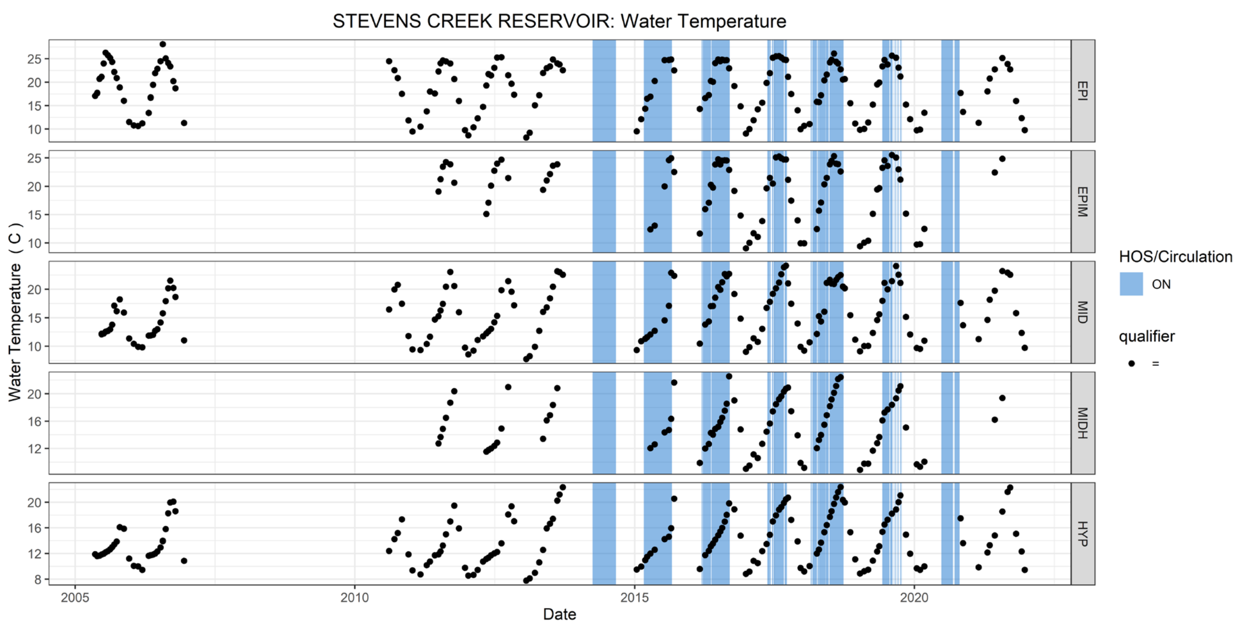
STEVENS CREEK RESERVOIR: Specific Conductivity
Specific Conductivity (us/cm)
EPI
EPIM
MID
MIDH
HYP
Date
HOS/Circulation
ON
qualifier
=


STEVENS CREEK RESERVOIR: Sulfate
Sulfate (mg/L)
Date
EPI
HYP
HOS/Circulation
ON
qualifier
=
2005
2010
2015
2020


STEVENS CREEK RESERVOIR: Total Mercury
Total Mercury (ng/L)
Date
EPI
HYP
HOS/Circulation
ON
qualifier
=
<
2005
2010
2015
2020



STEVENS CREEK RESERVOIR: Total Methylmercury
Total Methylmercury (ng/L)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=
<



STEVENS CREEK RESERVOIR: Water Temperature
Water Temperature (C)
EPI
EPIM
MID
MIDH
HYP
Date
2005
2010
2015
2020
HOS/Circulation
ON
qualifier
=