Sweetwater Reservoir Water Quality Improvement Analysis

Performed for
Sweetwater Authority
Chula Vista, California
(on behalf of Gillingham Water Planning and Engineering, Inc.)

By

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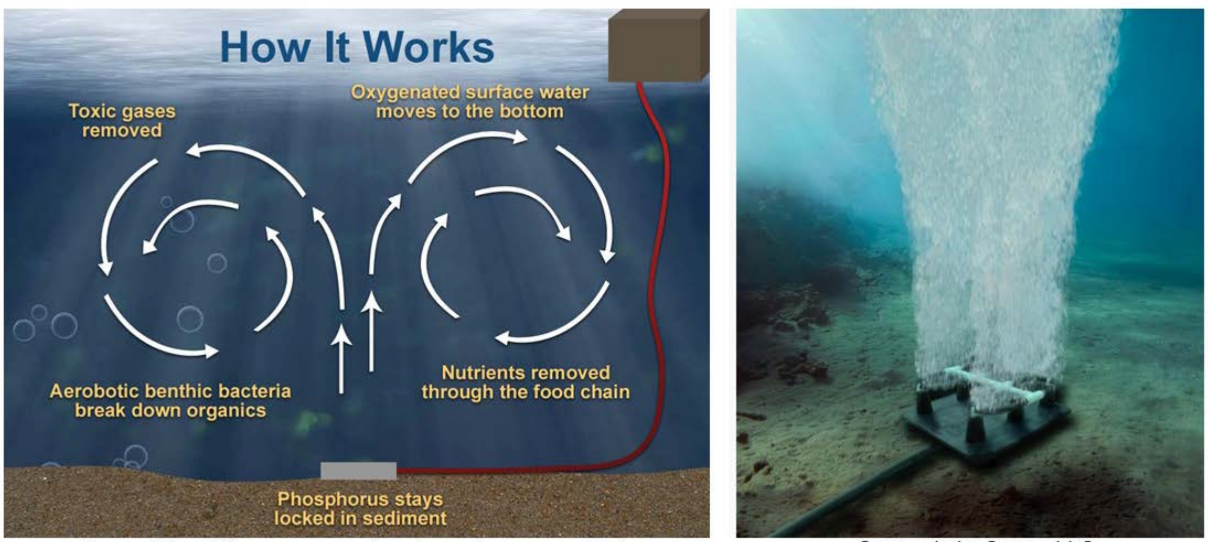
SECTION A: Vertical Mixing

A.1 Destratification and Vigorous Mixing

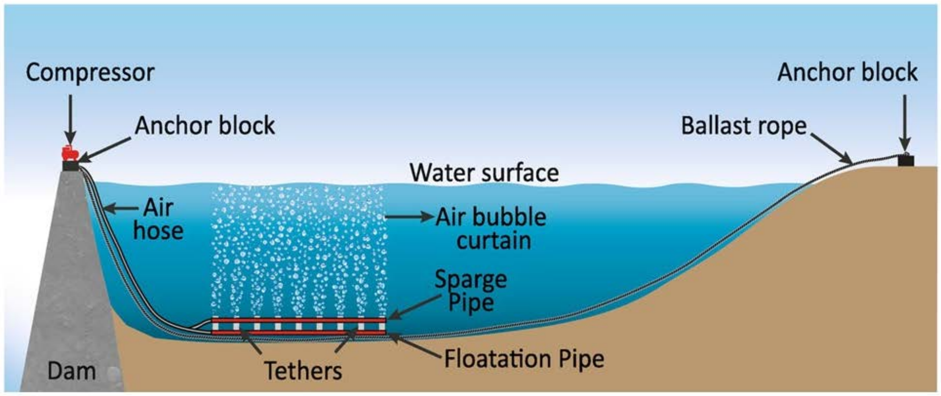
A destratification system destratifies a reservoir through entraining water with an upward stream of bubbles. This brings deep, anoxic water to the surface that is replaced by downwelling of oxygenated surface water (**Figure A.1**). This leads to oxygenated water with uniform water quality throughout the reservoir, which decreases hydrogen sulfide (H_2S) and manganese levels and decreases internal nutrient cycling. However, by providing uniform water quality, vertical mixing reduces benefits of selective withdrawal. Reservoir water quality may be adversely affected during the start-up period. Quagga mussel growth may also increase. Destratification could be achieved in Sweetwater Reservoir through use of a line diffuser near the deepest part of the reservoir (**Figures A.2** and **A.3**)



Source: https://lake-savers.com/how-inversion-oxygenation/ Source: Lake Source LLC

Figure A.1: Diagram showing effects of vertical mixing (left); example of air diffuser (right).

In addition to destratification, a more extensive line diffuser could also be used for vigorous mixing. Vigorous mixing is a subset of vertical mixing that retains the benefits of destratification while adding suppression of blue-green algae. Blue-green algae live in the upper photic zone of reservoirs and contain gas vesicles to remain buoyant. While blue-green algae can overcome weak mixing to remain buoyant, vigorous mixing will move them out of the photic zone, decreasing their energy source and therefore their population. To achieve vigorous mixing, mixing velocity and turbulent diffusion must be greater than buoyancy of blue-green algae throughout the reservoir, requiring a powerful compressor and horizontal distribution of mixing devices throughout the reservoir.



Source: Physical Processes for In-Lake Restoration: Destratification and Mixing, Gibbs and Howard-Williams, 2019

Figure A.2: Schematic of air bubble curtain for vertical mixing.

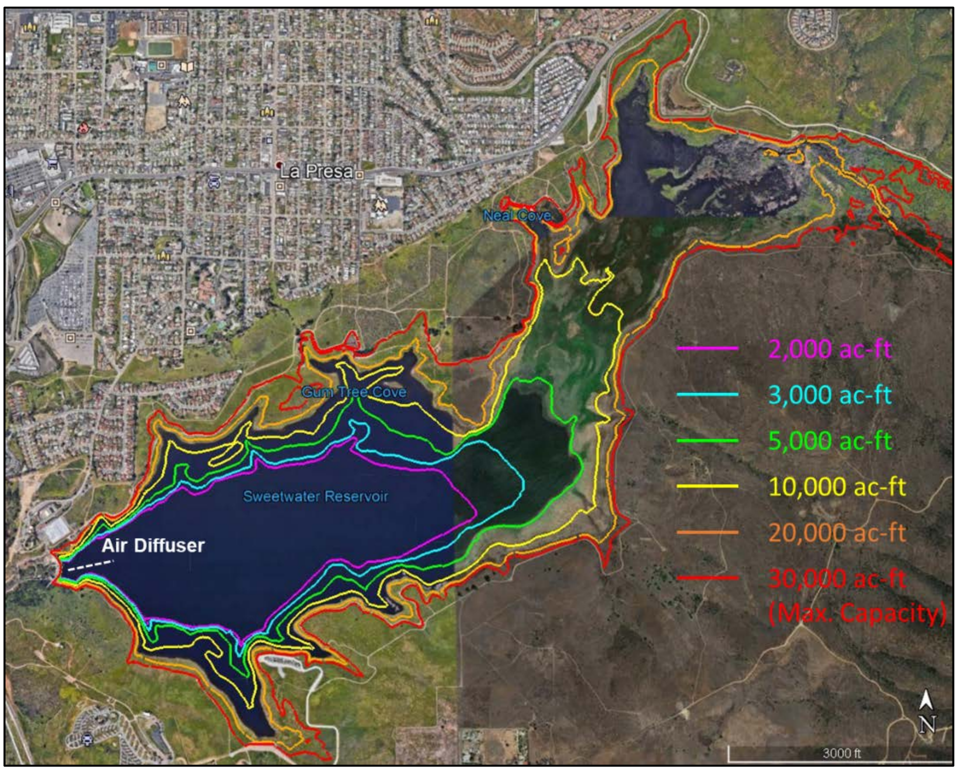


Figure A.3: Potential diffuser layout in Sweetwater Reservoir.

A.2 Modeling of Vertical/Vigorous Mixing

To determine the amount of mixing needed to destratify Sweetwater Reservoir, one-dimensional hydrodynamic modeling was conducted with the Dynamic Reservoir Simulation Model program (DYRESM) under several simulated conditions. DYRESM is a one-dimensional hydrodynamics model developed at the former Centre for Water Resources at the University of Western Australia that treats a lake as a horizontally homogeneous water body and computes the vertical variations in temperature, salinity, and other variables. The model for Sweetwater

Reservoir was calibrated using data from the period January 1, 2016 to January 1, 2020. This calibration involved changing some model parameters to obtain the best agreement with water surface elevation and temperature field data.

In the first simulation, the period 2016-2019 was simulated with the existing 25 horsepower (hp) compressor (**Figure A.4**). We found that a 25 hp compressor is sufficient to destratify the reservoir under the actual flow and storage conditions during this period. In the second simulation, the reservoir was simulated at 25,000 acre-feet with a 25 hp compressor (**Figure A.5**). Bubbler operation was started on July 1, after thermal stratification had begun. The 25 hp compressor was sufficient to destratify the reservoir over the course of approximately two months. In the third simulation, the reservoir was simulated at 5,000 acre-feet with various compressor powers (**Figure A.6**). We found that a compressor with more than 10 hp would be needed to destroy the thermal stratification under this condition.

These simulations assume the reservoir remains horizontally mixed at all times and do not include allowances for frictional pressure losses in the air tubing. Furthermore, these simulations assume constant full power operation. We estimate that 100 hp of compressor power would be necessary to provide destratification and oxygenation under all conditions.

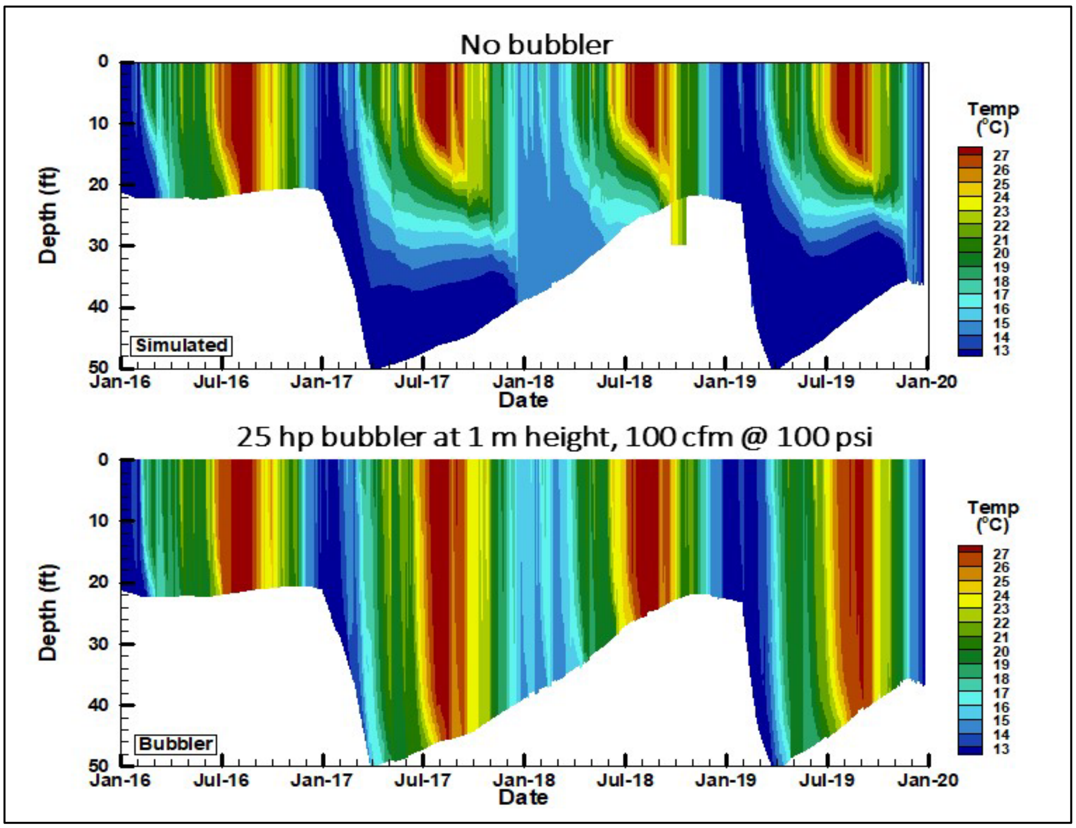


Figure A.4: Comparison of simulation for period 2016-2020 with no bubbler (top) and 25 hp bubbler (bottom)

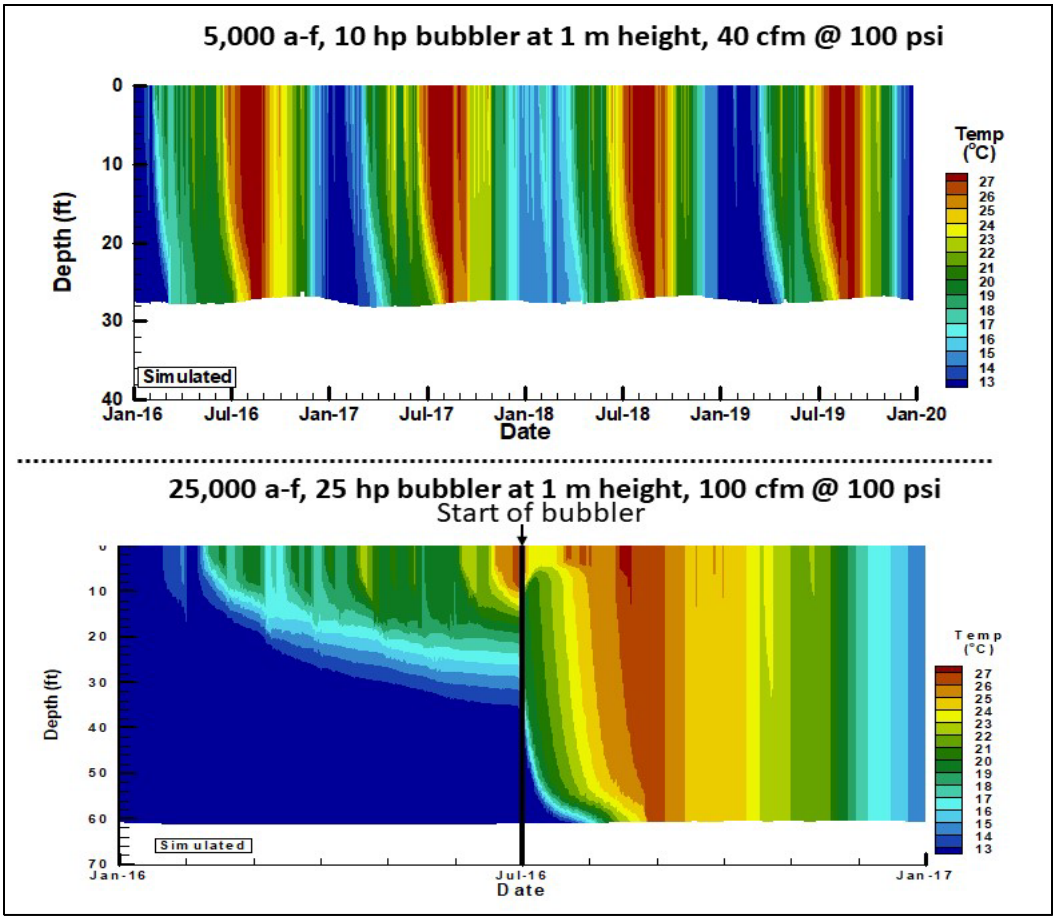


Figure A.5: (top) At a low volume of 5,000 acre-feet (a-f), a 10 hp compressor with a flow rate of 40 cfm at 100 pounds per square inch (psi) can achieve destratification throughout a four-year simulation. (bottom) At a higher volume of 25,000 acre-feet, a more powerful 25 hp compressor with a flow rate of 100 cfm at 100 psi is sufficient to destratify the reservoir over two months based on a one-year simulation.

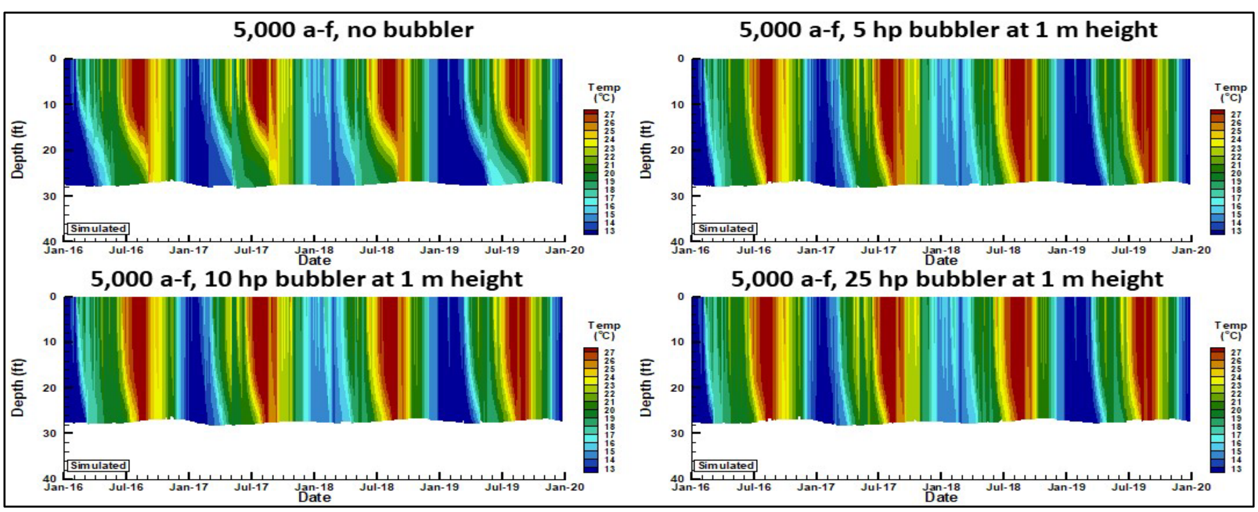


Figure A.6: Comparison of various compressor powers at 5,000 acre-feet volume.

Preliminary estimates of vigorous mixing needed to suppress blue-green algae are based on literature reports (Visser 2016). Decreases in blue-green algae populations were observed in many cases with greater than 1.3 cubic feet per minute (cfm) bubbler per acre of reservoir surface area. While a 100 hp compressor and single diffuser line can achieve destratification at all volumes (see above), a more powerful 200 hp compressor and extensive diffuser system would be required to provide vigorous mixing for reservoir volumes of 10,000 acre-feet.

A preliminary diffuser layout is shown in **Figure A.7**, incorporating six lines from one or two shore locations for a total of 12,000 ft of diffuser. This diffuser arrangement would provide good horizontal reach with vigorous mixing at storage volumes up to 10,000 acre-feet, providing reservoir turnover on the order of once per day. Due to the highly variable water surface elevation (WSEL) and surface area of Sweetwater Reservoir, a vigorous mixing diffuser layout design for storage volumes greater than 10,000 acre-feet would require diffuser lines that are frequently exposed above the reservoir surface. This would lead to damage by ultraviolet light and other weather, and is not considered a viable option.

Above 10,000 acre-feet, the system would provide effective destratification and some blue-green algae suppression but the vigorous mixing decreases as the reservoir volume increases, resulting in the effectiveness decreasing. Vigorous mixing provides effective suppression of blue-green algal blooms, but other algal growth may still be significant.

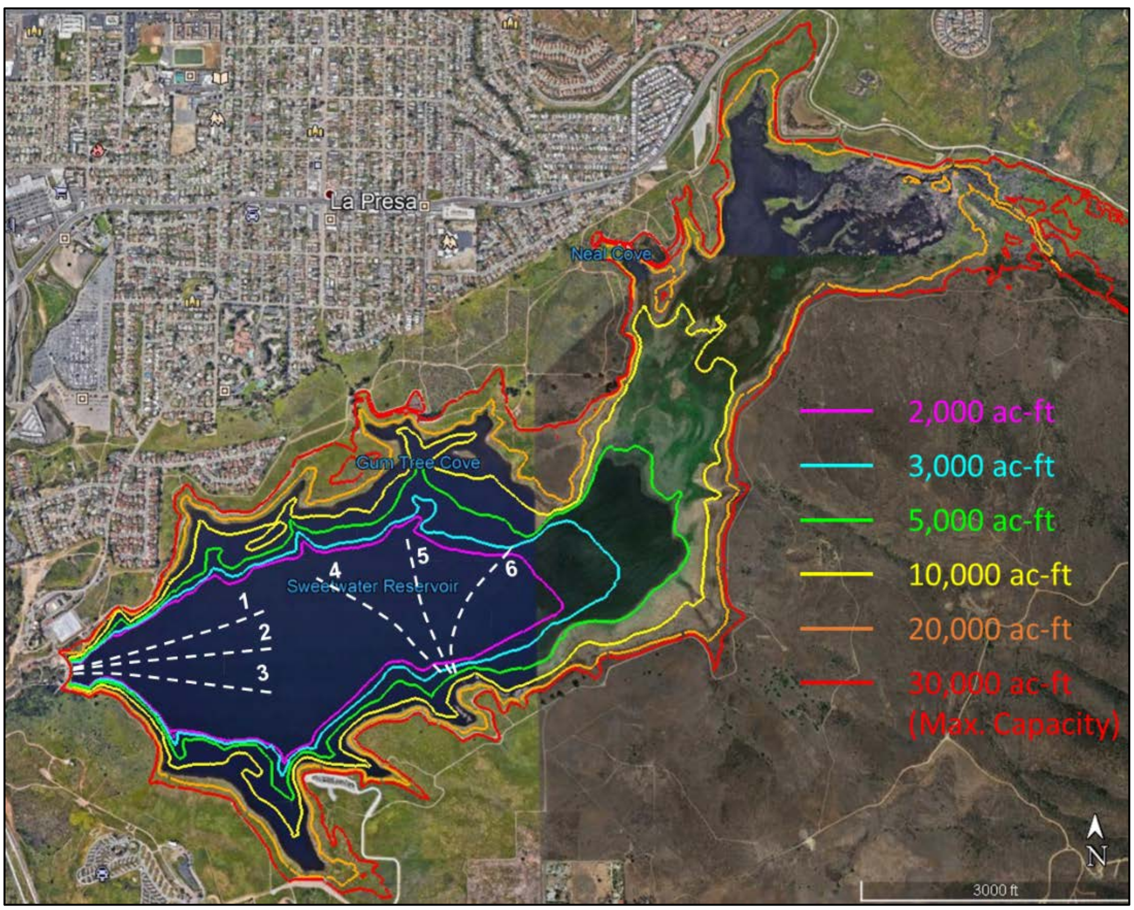


Figure A.7: Potential diffuser layout for vigorous mixing.

A.3 Vertical Mixing Cost Estimates

Cost estimates for three vertical mixing scenarios are provided in **Table A.1**. For destratification, cost would depend on the condition of current equipment and whether a backup compressor is desired. A vigorous mixing installation would require a more powerful 200 hp compressor and a larger, more horizontally extensive diffuser system.

For estimation purposes, total costs include an allowance for building improvements, 20% allowance for undefined design elements, 10% for construction contingency, 25% design allowance, 3% markup for escalation, and an allowance for environmental permitting. Annual costs include 4% of construction cost for maintenance, 3% of construction cost for a sinking fund for replacement, an allowance for additional Quagga Mussel control, and electricity costs. Electricity costs are calculated at $0.14/kWh, and assume a destratification system will run at 52% power on average while a vigorous mixing will run at 83% power on average. These estimates account for the variable WSEL of Sweetwater Reservoir as well as the lower power demand to maintain destratification during the winter months.

Table A.1: Cost Estimates for destratification and vigorous mixing.

Scenario	Compressor	Other Component Costs	Electricity/year	Total***	
				Initial	Annual
Destratification	$160,000	$392,500*	$48,000	$1,200,000	$100,000
Vigorous Mixing	$300,000	$1,825,000*	$52,500	$3,900,000	$300,000

*Includes air lines, installation labor, and diffusers.

**Initial cost includes allowances for building improvements, undefined design elements, contingency, design, environmental permitting, and escalation. Annual cost includes maintenance, replacement costs, and quagga mussel control.

A.4 References

Visser, P. M.; Ibelings, B.W.; Bormans, M.; Huisman, J. (2016). “Artificial Mixing to Control Cyanobacteria Blooms: A Review,” Aquatic Ecology, 50, 423-441.

SECTION B: Hypolimnetic Oxygenation Systems (HOS)

There are several hypolimnetic oxygenation systems that have been historically used. They typically consist of 1) hardware to spread the oxygen in the hypolimnion and 2) an on-land oxygen source. Systems for spreading oxygen into the hypolimnion include the Speece Cone, SDOX® system, and diffused oxygenation system (DOS). Oxygen sources consist of either on-site oxygen generation or liquid oxygen (LOX) delivery and storage at the site. Due to the variable water surface elevation (WSEL) of Sweetwater Reservoir, a DOS system would be most suitable to efficiently oxygenate multiple strata.

B.1 Diffused Oxygen System (DOS)

A DOS consists of "soaker-hose" lines that are placed in the hypolimnion and deliver small oxygen bubbles to the water. Typically, several hundred feet (ft) or more of soaker hose are used in an installation. A schematic of a DOS is shown in **Figure B.1**. A DOS does not require any water pumping. As shown, there is an oxygen delivery line that is connected to the soaker hose at various junctures. A "buoyancy" pipe is also connected in parallel to the oxygen supply line. The buoyancy pipe serves to float or sink the diffusers. If the buoyancy pipe is full of water, the diffusers are designed to sink. To retrieve the system to the surface, air is pumped into the buoyancy line to displace the water. The pipelines are typically secured to the bottom using stainless steel cable and anchors. **Figure B.2** presents a typical installation of the diffused oxygen pipelines (Lake Casitas). Typically, the diffusers are laid on the water surface and then lowered to the bottom by operating the buoyancy pipeline. To oxygenate Sweetwater up to 20,000 acre-feet of storage, a diffuser system of approximately 2,500 feet would be necessary (**Figure B.3**).

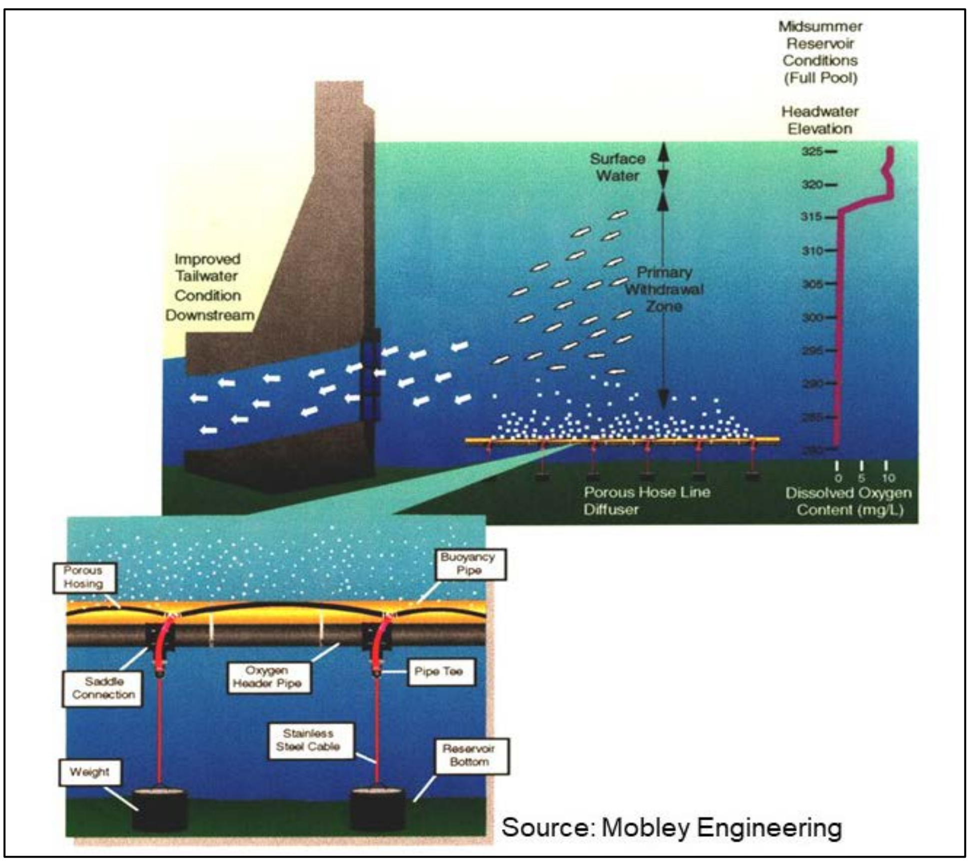


Figure B.1: DOS schematic with inset showing details of diffuser hose.

Source: Initial Results for a Hypolimnetic Oxygenation System Lake Casitas, California, presented at NALMS 2016

Figure B.2: Installation of diffused oxygen pipelines at Lake Casitas.

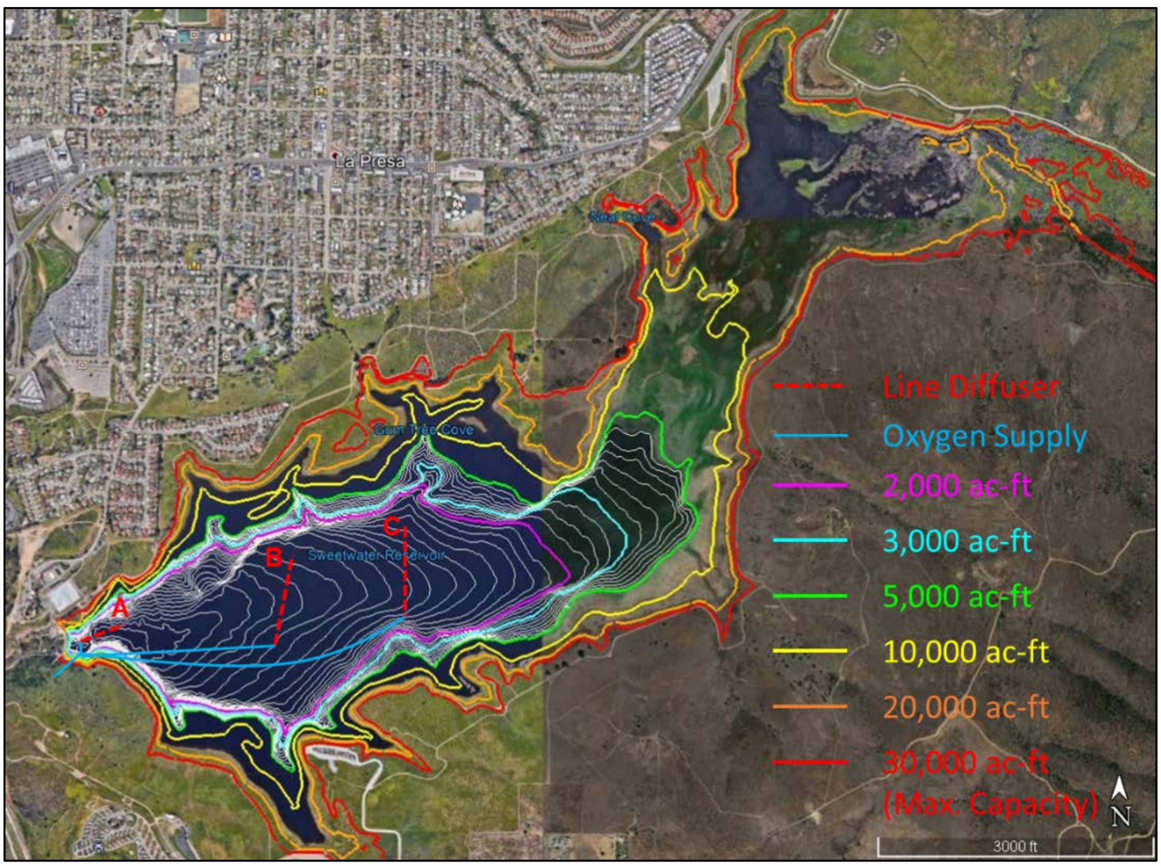


Figure B.3: Potential layout of HOS diffusers (red) and oxygen supply lines (blue) in Sweetwater Reservoir.

B.2 Oxygen Supply

An oxygen source is required to supply a hypolimnetic oxygenation system. Typically, gaseous oxygen can be generated on-site or LOX can be trucked in and stored on-site. LOX delivery provides more reliable operation and is the preferred option for Sweetwater Reservoir.

LOX delivery requires road access for a delivery truck, an oxygen storage tank, and vaporizers. A typical LOX storage tank configuration and associated appurtenances are shown in **Figure B.4**. Tanks can be provided with a remote level sensor and a low-pressure alarm. A tank can either be horizontal or vertical, depending on space and visual requirements, and is typically supported on a thick double-reinforced concrete pad. Approximate dimensions of a pad for a 9,000 gallon vertical tank and vaporizers is 25' x 25' x 3' thick. A LOX installation should meet all safety, engineering, and seismic requirements and is typically enclosed in a fenced area. A LOX storage tank is typically sized to hold a full truck delivery (approx. 6,000 gallons) plus a few days of extra supply. Two ambient vaporizers are desirable: one in operation and one in defrost mode. It is noted that an ambient vaporizer does not require electricity.

Source: Mobley Engineering

Figure B.4: LOX storage tank configuration (left) and associated appurtenances (right).

B.3 DOS Cost Estimates

B.3.1 Sizing of DOS

The sizing of a hypolimnetic oxygenation system depends on two main factors: the peak hypolimnetic oxygen demand (HOD) and the hypolimnetic volume. In particular:

- Total Oxygen Demand (Tons/day) = Peak HOD (mg/L/day) * Hypolimnetic Volume (Eq. B.1)
- Peak HOD has units of mg/L/day (milligrams per liter per day). Peak HOD is computed as:
- Peak HOD (mg/L/day) = Observed HOD (mg/L/day) * Stir Factor * Safety Factor (Eq. B.2)

The observed HOD is calculated from historical field data. A "stir factor" is needed because it has been observed that induced water movement by a hypolimnetic oxygenation system may lead to increased oxygen demand by the sediments. Typically, stir factors range from about 2.5 to 3.4. In this investigation, we use a stir factor of 3.0. Additionally, a safety factor is used to account for possible equipment down time and other factors that may lead to higher oxygenation requirements for short periods of time (on the order of a week or so). In this investigation, we use a safety factor of 1.2. Below, hypolimnetic volume and HOD for Sweetwater Reservoir are evaluated.

Table B.1: Expected HOD.

Observed HOD (mg/L/day)	Expected HOD (mg/L/day)	Peak HOD (mg/L/day)
0.148	0.287	0.148 * 3.0 * 1.2 = 0.534
Average 2002-2019	*Used to estimate operational cost*	*Used to size the system*

Table B.2: Hypolimnion volume and total oxygen demand.

Reservoir Storage (acre-feet)	Hypolimnion Extent	Hypolimnion Volume (acre-feet)	Total Oxygen Demand (tons/day)	
			Expected	Peak
3,000	10 ft below surface	955	0.37	0.70
5,000	10 ft below surface	2,229	0.87	1.6
10,000	10 ft below surface	5,706	2.2	4.1
20,000	10 ft below surface	13,054	5.1	9.5

B.3.2 Cost Estimate of DOS

Due to the variable WSEL at Sweetwater Reservoir, a DOS system would be most suitable to efficiently oxygenate multiple strata. Based on input from Mobley Engineering, diffuser lines would ideally be staggered at different elevations as shown in **Figure B.3**. The potential design shown employs a total diffuser length of 2,500 ft (shown in red) in addition to 7,500 ft of oxygen supply lines (shown in blue).

Table B.3: Diffuser and O_2 Cost for HOS.

Number of Diffusers	Elevation (ft)	Length (ft)	Total Length (ft)	Initial Diffuser and O_2 Supply Line Cost	Yearly O_2 Cost
3	175	500	2,500	$1,200,000	$151,200*
	180	1,000			
	185	1,000			

***** Oxygen cost is calculated at average historical storage level from 1992-2019 of 12,000 acre-feet.

B.3.3 Cost Estimate of LOX

In the following, initial and annual operating costs for oxygen supply systems are provided. For LOX systems, an option to lease the tanks is discussed in addition to a purchase option. A LOX leased system's initial costs are significantly reduced as the lessor typically would cover most of the installation costs (lessor typically does not cover tank pad installation, fencing, and permitting). The lessor also typically expects the lessee to enter into a long-term oxygen purchase agreement in return for installing the tank storage facilities. This may not be desirable for Sweetwater Reservoir due to fluctuating oxygen demand from varying WSEL, and a purchased LOX system may be more economical. Cost estimates are provided here for purchased LOX storage; leased LOX storage can be evaluated in final design.

Table B.4 presents the calculation of approximate LOX tank necessary for Sweetwater Reservoir, as well as oxygen supply at expected and peak usage.

Table B.5 present the initial and annual costs for the HOS system using a purchased LOX system. The LOX purchase option provides the higher initial cost. Here, the cost of the tank itself is about 40% of the initial total installation cost, with the remainder covering delivery and installation, vaporizers, appurtenances, and tank pad etc. Initial costs for a leased LOX system are lower since the lessee typically only covers the costs of tank pad installation, fencing, and permitting. Annual costs are lower for the purchased LOX system.

For estimation purposes, total costs include an allowance for building improvements, 20% allowance for undefined design elements, 10% for construction contingency, 25% design allowance, 3% markup for escalation, and an allowance for environmental permitting. Annual costs include 4% of construction cost for maintenance, 3% of construction cost for a sinking fund for replacement, an allowance for additional Quagga Mussel control, and oxygen costs.

Table B.4: Recommended size for LOX storage.

Peak Oxygen Demand* (tons/day)	LOX Storage (gallons)	Supply (days)	
		Expected	Peak
5	9,000	14	7

*Peak oxygen demand is calculated at average historical storage level from 1992-2019 of 12,000 acre-feet and augmented by 11% to reflect an oxygen dissolution rate of 90%

Table B.5: Purchased LOX cost estimates.

Initial Diffuser and O_2 Supply Line Cost	Purchased LOX System Cost		Total Cost**	
	Initial	Annual O_2 Cost*	Initial	Annual
$1,200,000	$650,000	$151,200	$3,500,000	$260,000

*Oxygen cost is calculated at average historical storage level from 1992-2019 of 12,000 acre-feet and augmented by 11% to reflect an oxygen dissolution rate of 90%.

**Initial cost includes allowances for building improvements, undefined design elements, contingency, design, environmental permitting, and escalation. Annual cost includes maintenance, replacement costs, and Quagga mussel control.

SECTION C: Water Quality Data Analysis

C.1 Storage and Flows

Sweetwater Reservoir has a maximum storage capacity of 28,079 a-f and maximum WSEL of 239 ft (**Figure C.1**). At maximum capacity, the reservoir has an area of 936 acres (**Figure C.2**).

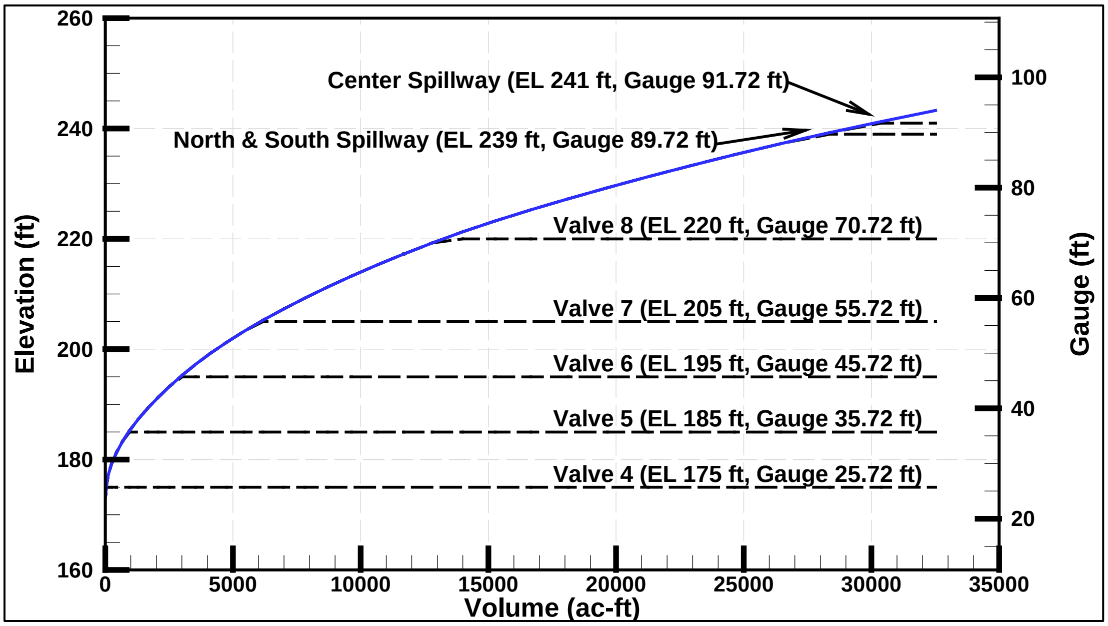


Figure C.1: Capacity and outflow ports of Sweetwater.

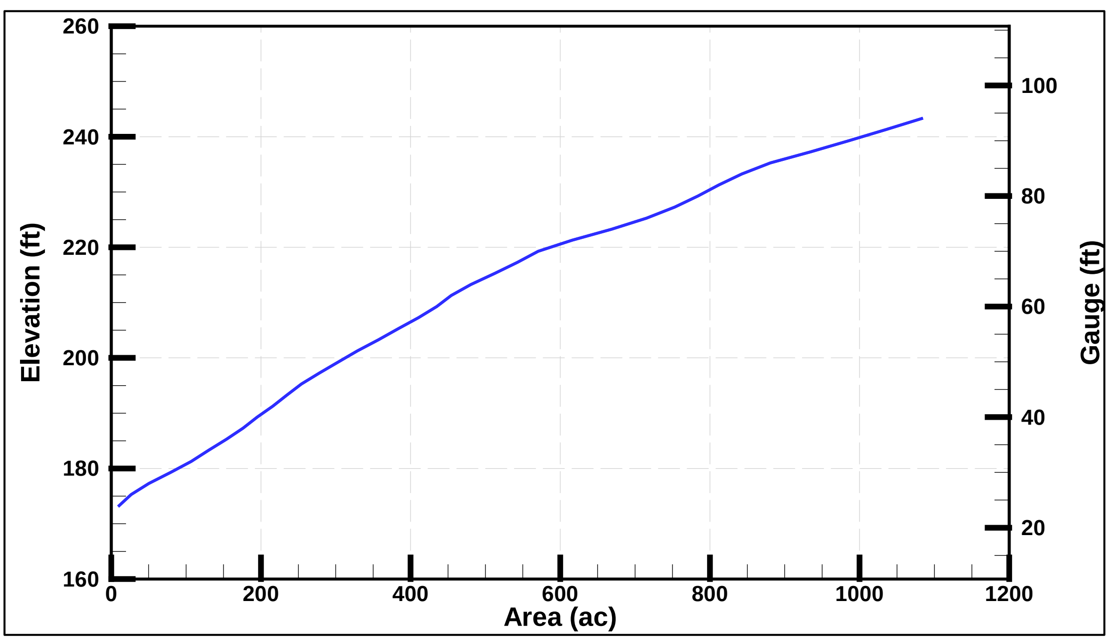


Figure C.2: Surface Area of Sweetwater Reservoir.

Sweetwater Reservoir receives inflows from three sources: runoff, imported water from the San Diego Aqueduct, and water released from Loveland Reservoir (**Figure C.3**). Releases from Loveland Reservoir account for much of the inflow, and generally occur during winter. The quantity of releases depends on storage available in Loveland Reservoir.

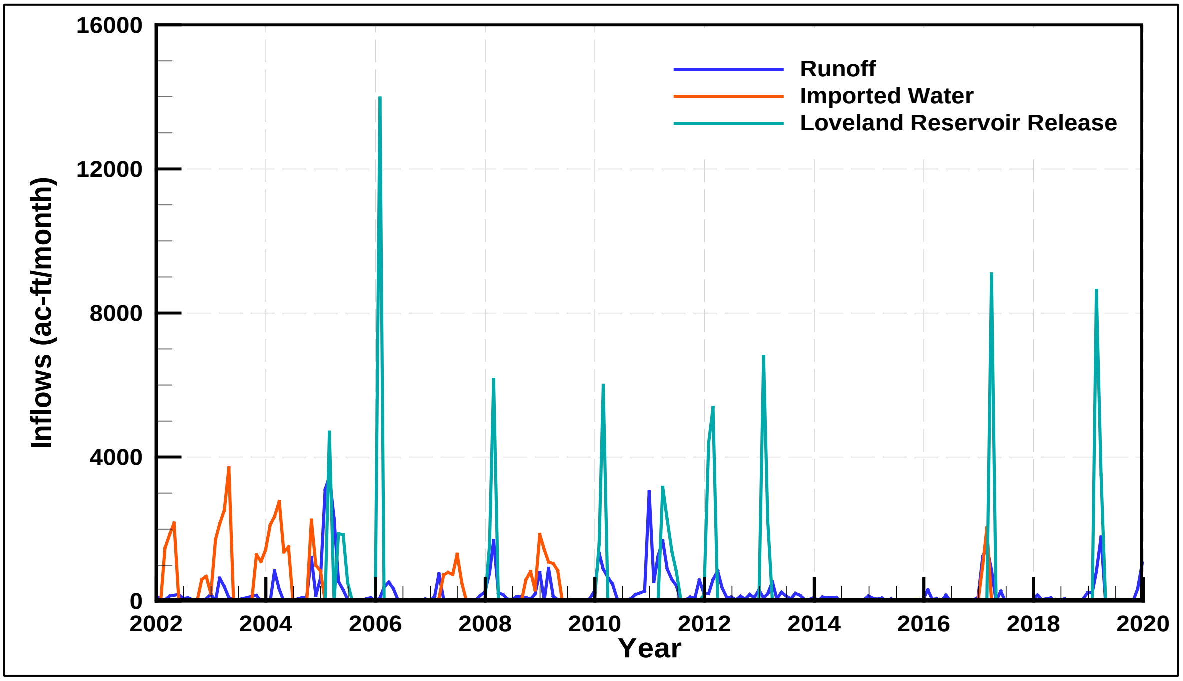


Figure C.3: Inflows into Sweetwater Reservoir.

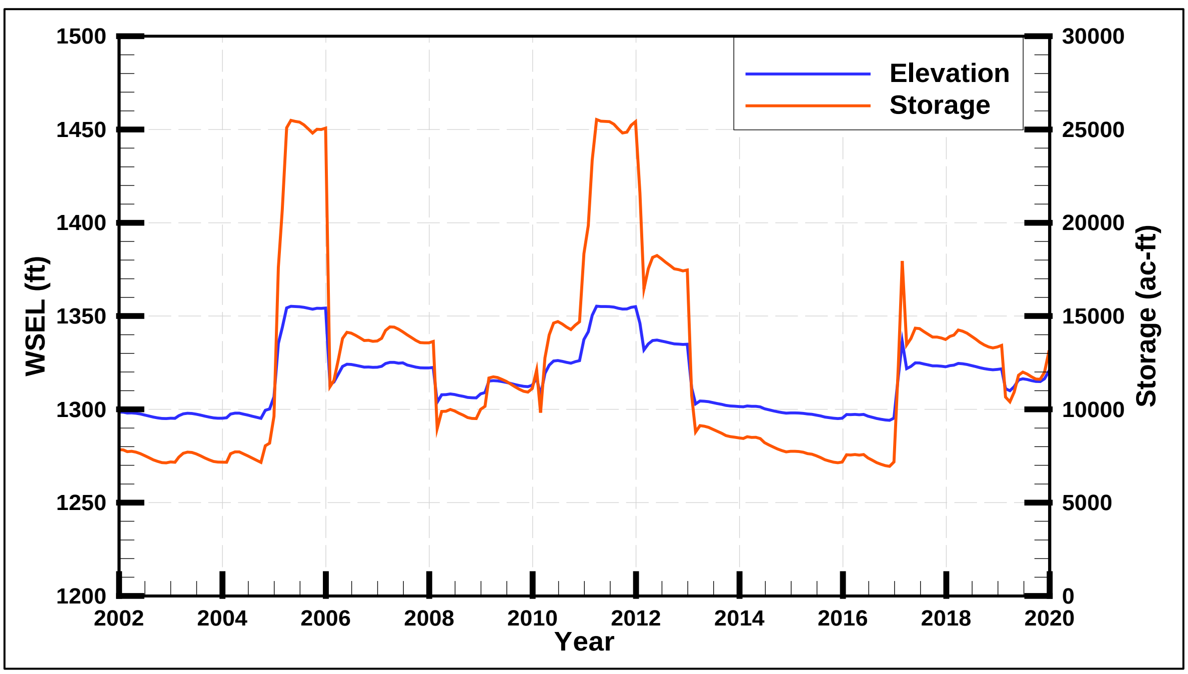


Figure C.4: Storage of Loveland Reservoir.

Releases from Loveland Reservoir have varied from non-existent to 14,000 a-f per month, depending on winter precipitation and the water level in Loveland Reservoir (**Figure C.4**). Loveland Reservoir contains low salt and nutrient levels relative to Sweetwater Reservoir (see below).

The watershed of Sweetwater Reservoir is highly developed, and runoff may be high in nutrients and salts. There are a number of runoff monitoring stations near the reservoir that monitor inflow conductivity (**Figure C.5**), however recent data is not available. From 2002 to 2015, the runoff conductivity has remained near 3000 µS/cm (**Figure C.6**), significantly higher than water released from Loveland Reservoir. The watershed also has an urban runoff diversion system (URDS), which allows for diversion of "first flush" runoff that can be highly contaminated.

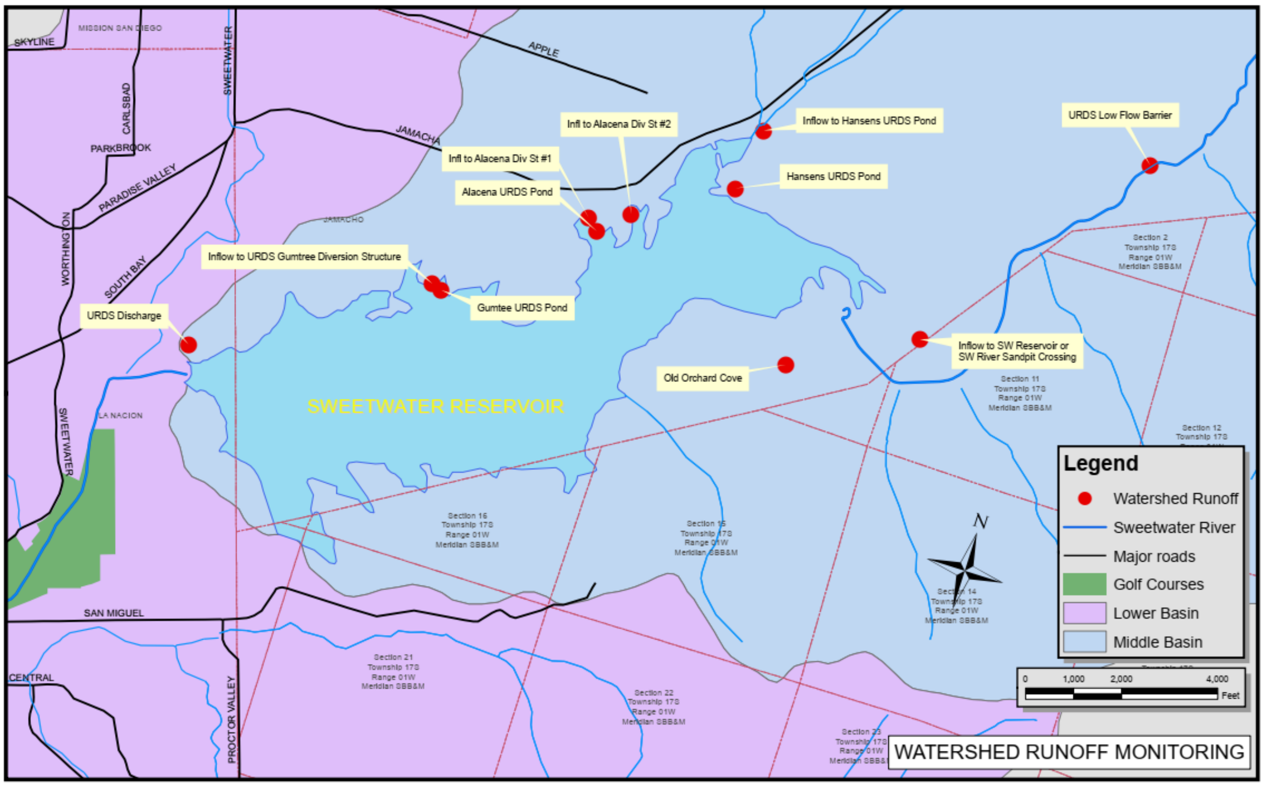


Figure C.5: Map of Sweetwater Reservoir watershed runoff monitoring stations.

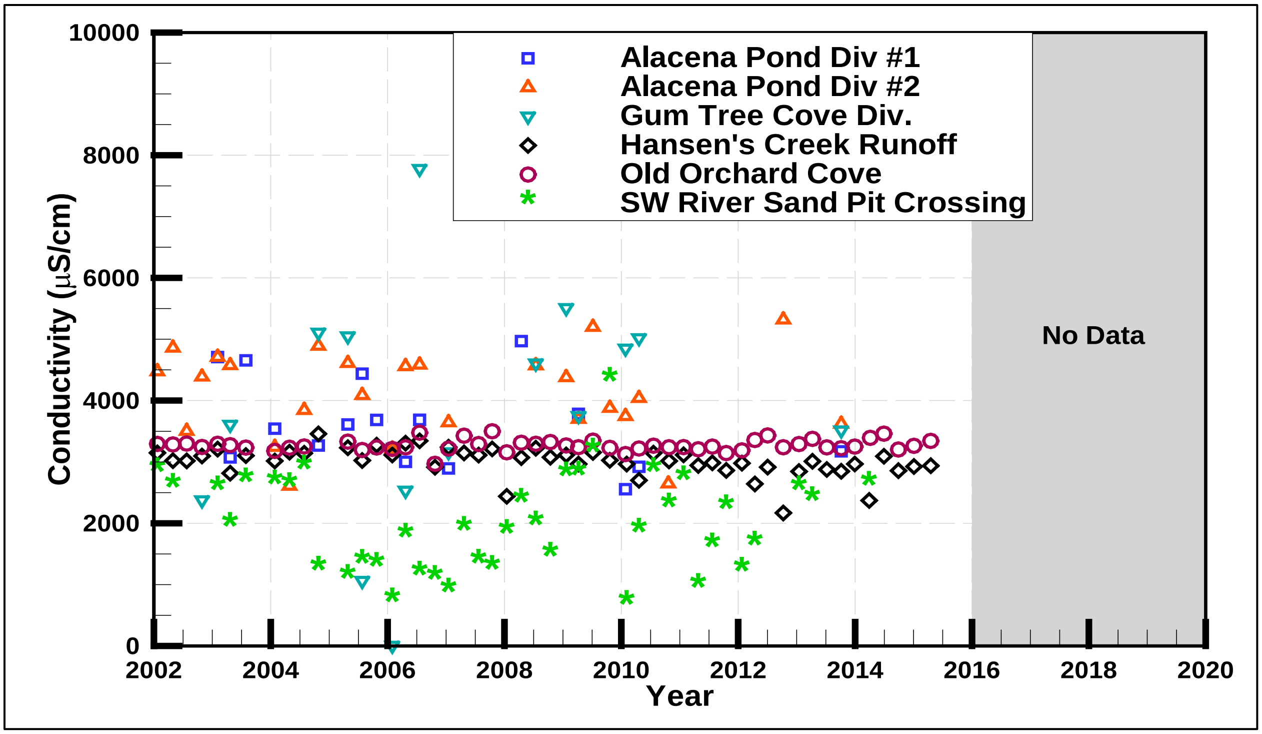


Figure C.6: Conductivity of runoff monitored in the Sweetwater Reservoir watershed.

In addition to releases from Loveland Reservoir and local runoff, Sweetwater receives imported water from the San Diego Aqueduct. This water contains moderately high nutrient levels, with NO_3-N levels varying seasonally from approximately 0.05 mg/L to 0.4 mg/L (**Figure C.7**).

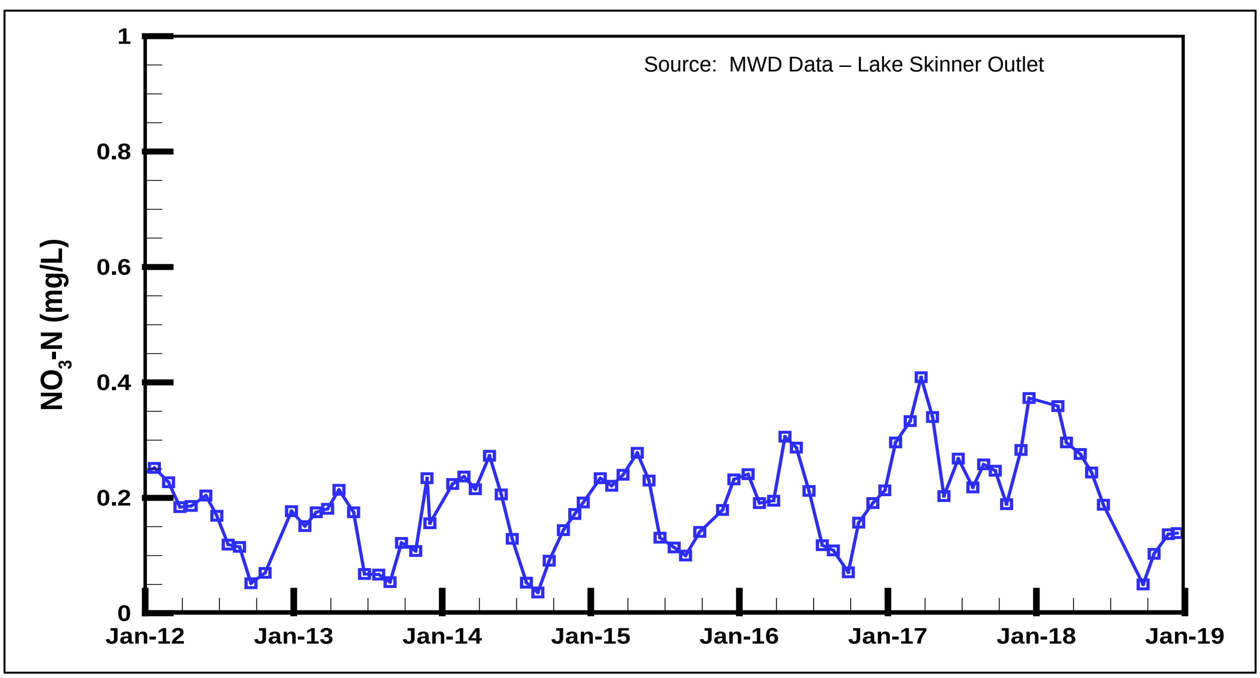


Figure C.7: NO_3-N levels of imported water.

C.2 Water Quality

C.2.1 Data Inventory

From 2002 to 2019, various water quality measurements have been made in Sweetwater Reservoir. These include temperature, dissolved oxygen (DO), Secchi depth, pH, conductivity, nitrate/nitrite levels, total Kjehldahl nitrogen, total nitrogen, total phosphorus, ortho phosphorus, chlorophyll *a*, bromide, and sulfate concentrations (**Table C.1**).

Variable	Sampling Frequency	Depth	Location
Temperature	Weekly, bi-weekly, or monthly	From surface to various depth (10 ft to 40 ft)	Intake Tower; Log Boom
Dissolved Oxygen	Weekly, bi-weekly, or monthly	From surface to various depth (10 ft to 40 ft)	Intake Tower; Log Boom
Secchi	Weekly, bi-weekly, or monthly		Intake Tower; Log Boom
pH	Monthly	Surface only	
Conductivity	Monthly	Surface only	
Nitrate/Nitrite	Monthly or quarterly	Surface only	Lake center
TKN/TN/TP	Quarterly	Surface only	Lake center
Ortho Phosphorus	Monthly or quarterly	Surface only	Lake center
Chlorophyll *a*	Quarterly	Surface	Lake center
Bromide/Sulfate	Monthly or quarterly	Surface	Lake center

Table C.1: Data Availability for Sweetwater Reservoir.

Lakes such as Sweetwater Reservoir generally exhibit thermal stratification that is controlled by meteorological variables such as air temperature, solar radiation, and wind. As air temperature and solar radiation increase in the spring and summer, a thermocline develops as illustrated in **Figure C.8**. In the fall and winter, decreasing air temperature and solar radiation cool the surface water and deepen the thermocline until turnover, the time when a reservoir becomes un-stratified and vertical mixing is uninhibited by stratification (**Figure C.9**). The timing of turnover in a reservoir is affected by meteorological variables as well as reservoir depth.

A by-product of thermal stratification is the inhibition of oxygen transfer from the atmosphere to the hypolimnion. Historically, this generally resulted in anoxic conditions in the hypolimnion of Sweetwater Reservoir. Sweetwater Reservoir experiences anoxia (low DO) at depth during the summer months, a result of oxygen demand by sediments and weak vertical mixing. In general, DO levels are directly dependent on the development of the thermocline, phytoplankton activity, and sediment oxygen demand. Anoxia has increased in recent years, with a significant portion of the reservoir experiencing low DO in 2018 and 2019 (**Figure C.10**). Anoxia can have significant implications for water quality, including high manganese and iron levels (see below).

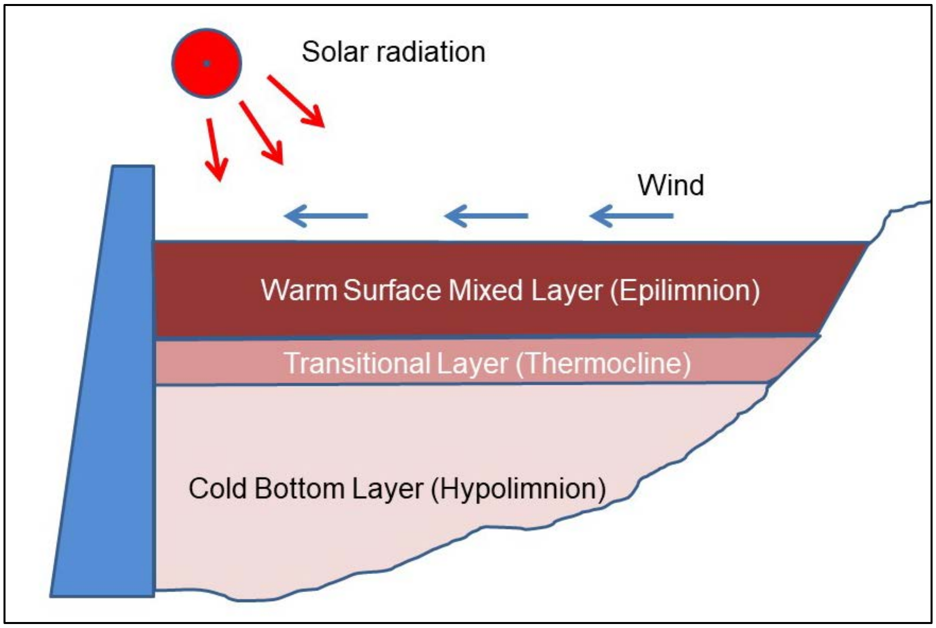


Figure C.8: Illustration of Sweetwater Reservoir thermal structure.

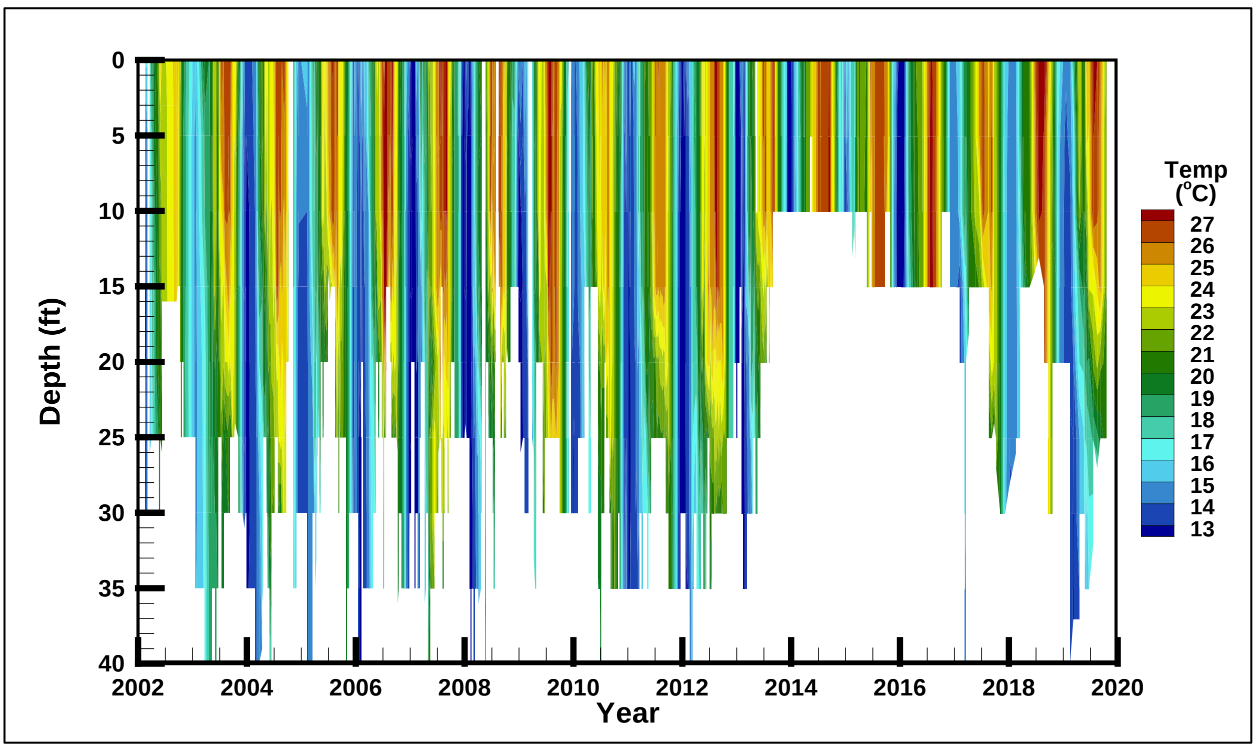


Figure C.9: Temperature profiles for Sweetwater Reservoir.

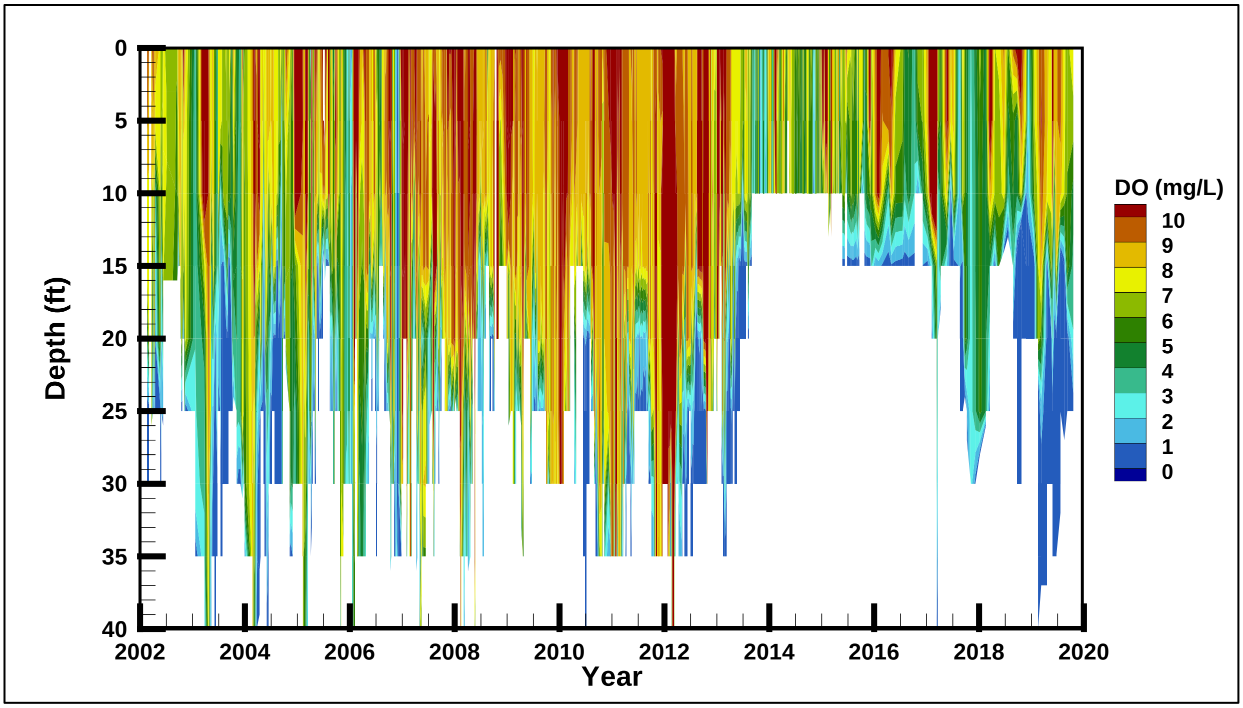


Figure C.10: DO profiles for Sweetwater Reservoir.

Conductivity is generally used as an indirect measure of salinity. From 2002 to 2013, the surface conductivity remained relatively constant near 1000 µS/cm (**Figure C.11**). Between 2013 and 2017, the surface conductivity increased significantly, a result of high-salt runoff and a decrease in Loveland Reservoir release and imported water. Following a significant release from Loveland Reservoir in early 2017, the surface conductivity returned to near 1000 µS/cm.

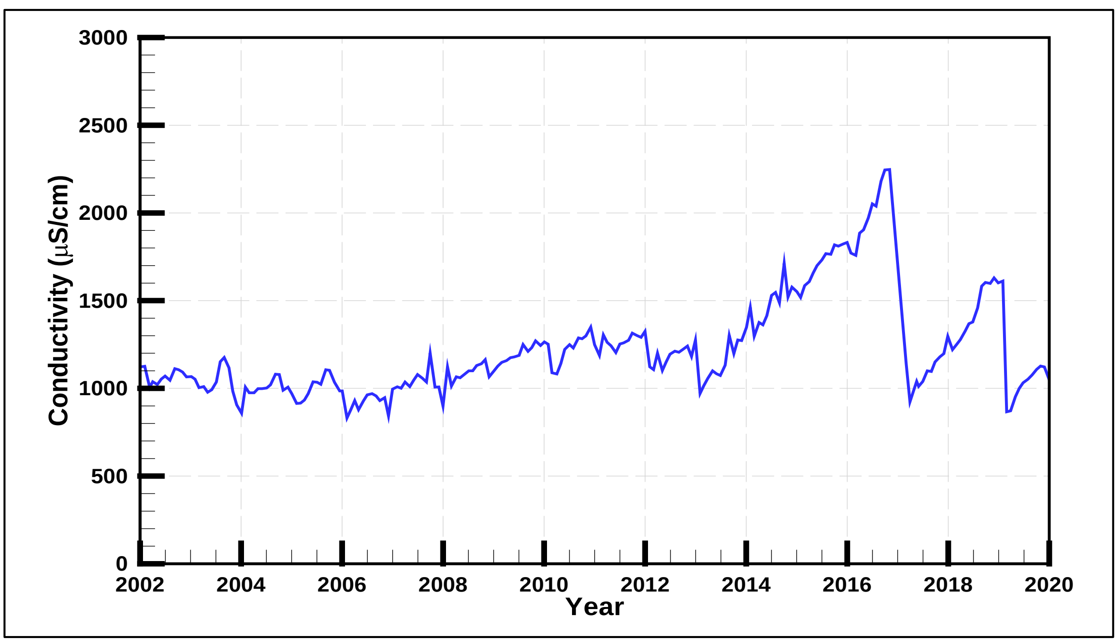


Figure C.11: Sweetwater Reservoir Conductivity.

Loveland Reservoir has a less developed watershed than Sweetwater Reservoir, and is expected to have lower conductivity and nutrient levels. From 2002 to 2019, the conductivity of Loveland Reservoir varied from approximately 400 to 700 µS/cm (**Figure C.12**), and NO_3-N remained below 1.2 mg/L (**Figure C.13**).

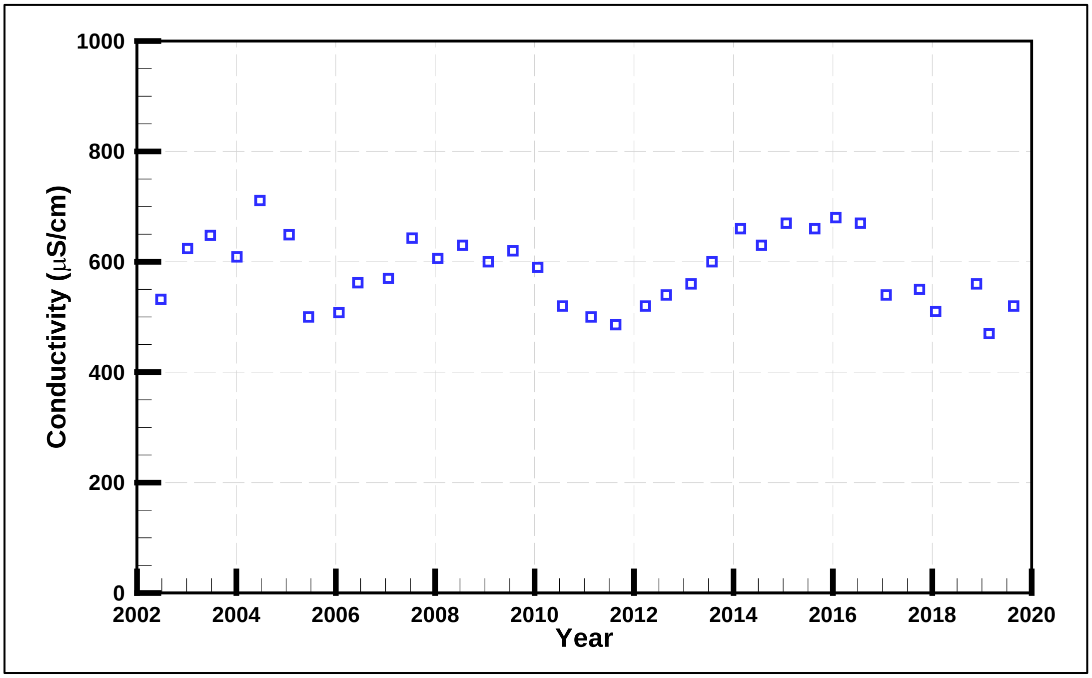


Figure C.12: Conductivity of Loveland Reservoir.

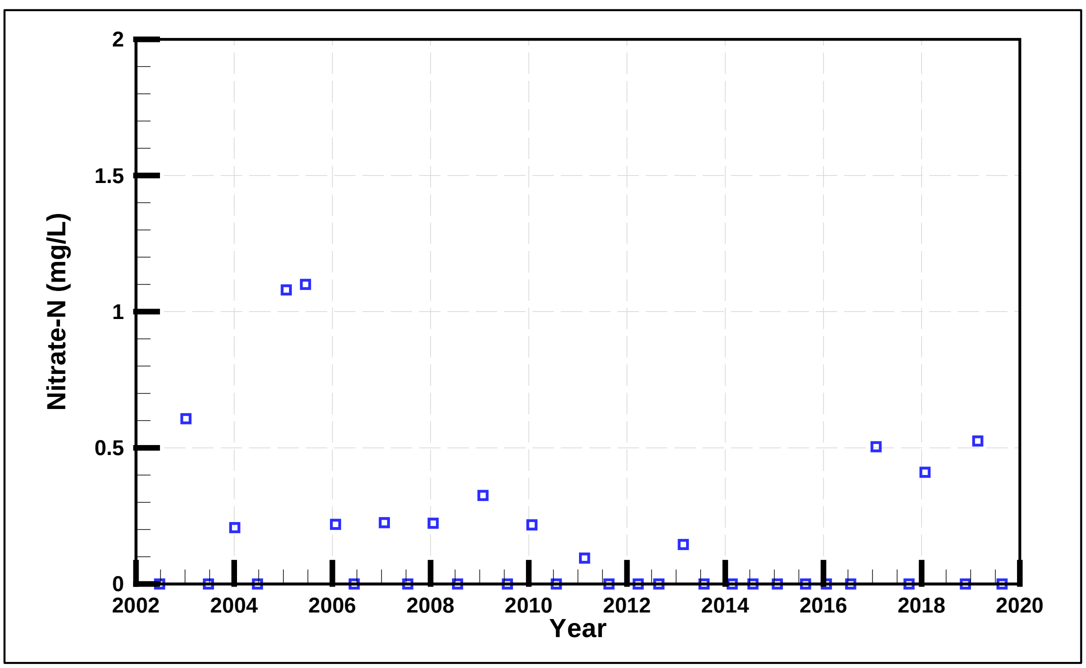


Figure C.14: NO3-N levels in Loveland Reservoir.

C.3 Nutrients and Algae

The presence of nutrients in the water column, coupled with relatively warm water and an abundance of light in the spring and summer, provides conditions that are ideal for the growth of algae. The two primary nutrients required for algal growth are phosphorus and nitrogen. In general, algal growth is hampered by the shortage of any of the nutrients.

Total phosphorus (TP) is a measure of all phosphorus in the water. From 2002 to 2015, TP levels remained relatively low (<0.4 mg/L, **Figure C.15**), but increased to 1.5 mg/L in 2016. This increase in TP may be related to internal nutrient recycling caused by anoxic conditions at depth. No TP measurements are available for 2018-2019.

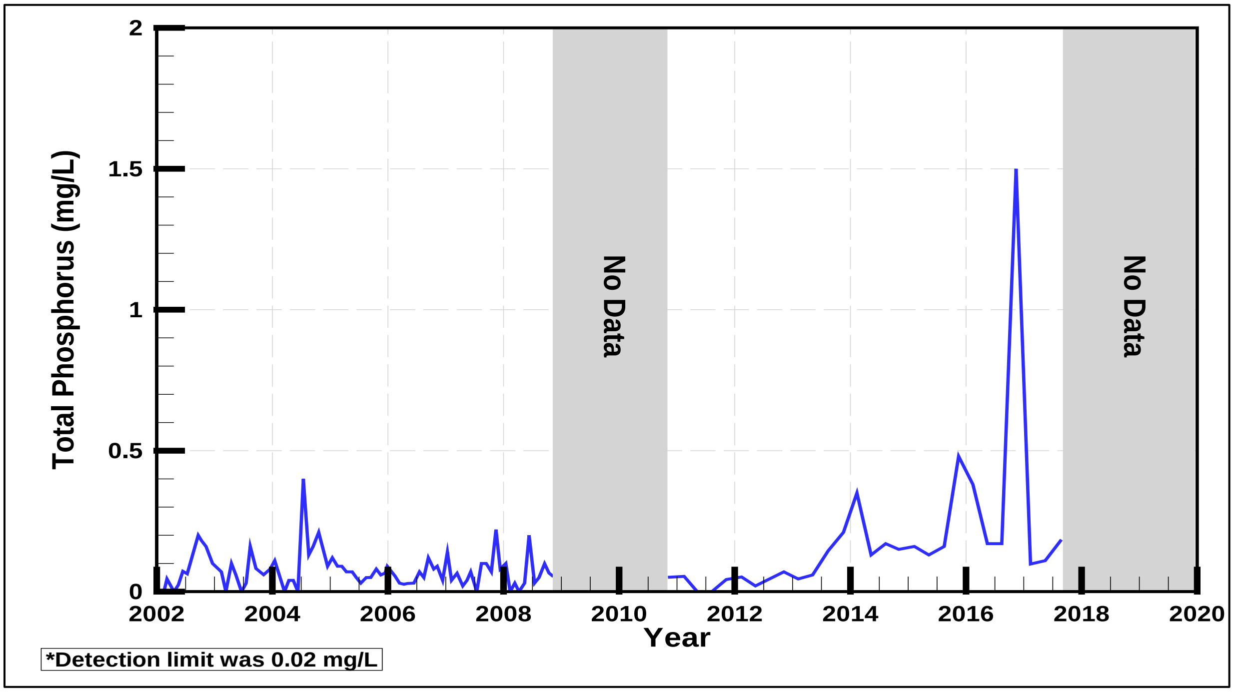


Figure C.15: Total phosphorus levels in Sweetwater Reservoir.

The surface nitrate levels in Sweetwater Reservoir are illustrated in **Figure C.16**. Surface nitrate levels show significant seasonal variation, increasing in winter and decreasing in summer, reaching zero most years. This may be due to nutrient depletion in the epilimnion, nutrient sampling at multiple elevations would give more insight.

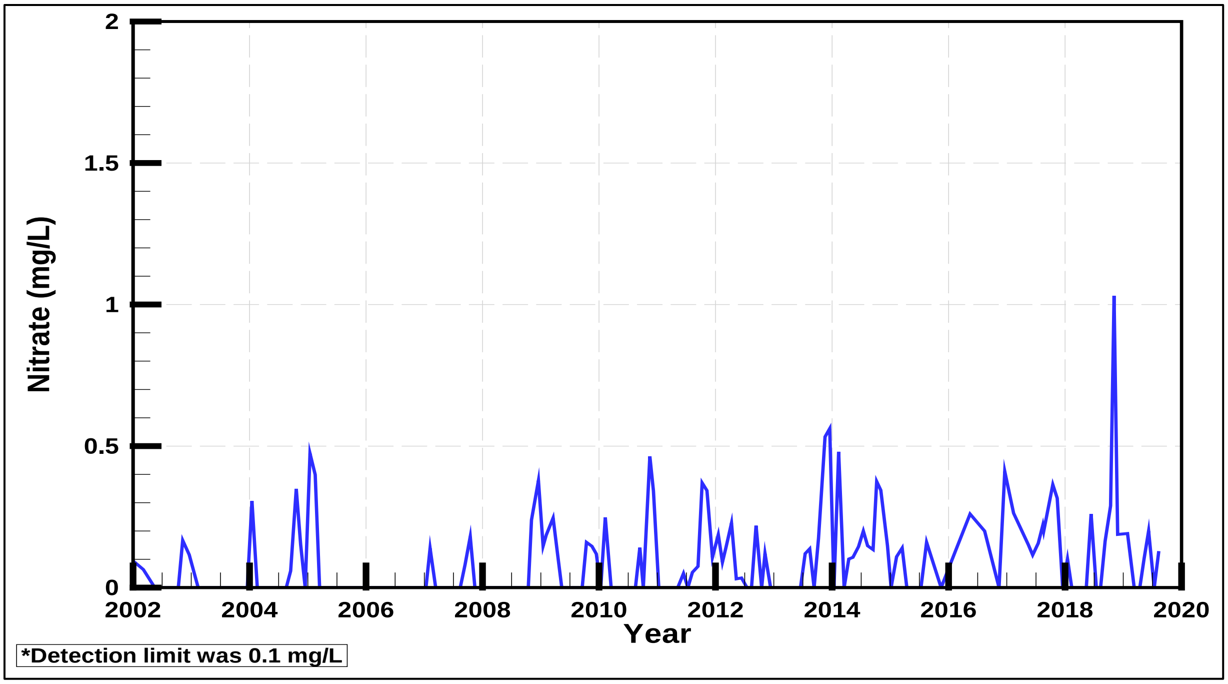


Figure C.16: Surface nitrate levels in Sweetwater Reservoir.

Chlorophyll *a* is an indirect measure of algal growth, and generally increases throughout the summer and decreases in winter months. Surface chlorophyll *a* has varied significantly between years, with very high levels in 2015 and 2016 (**Figure C.17**). This is consistent with high TP levels recorded in 2015 and 2016. No measurements are available for 2018-2019.

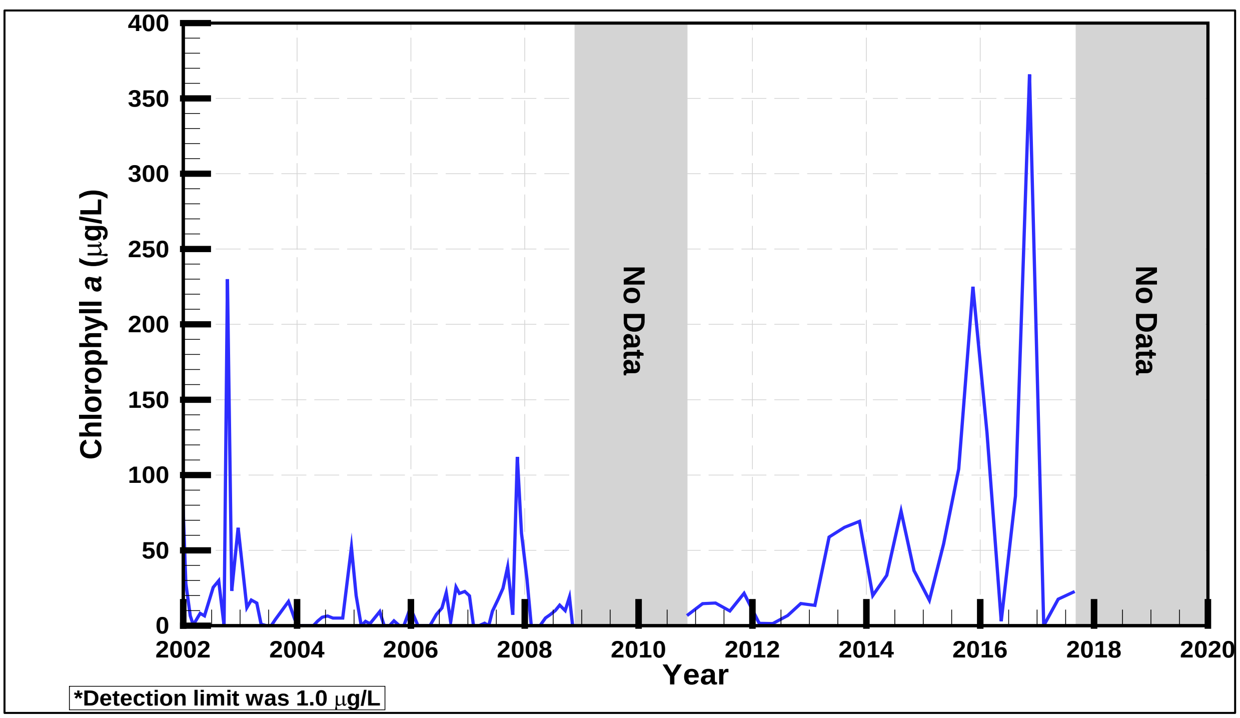


Figure C.17: Chlorophyll a levels in Sweetwater Reservoir.

Secchi depth is a measure of water clarity and an overall indicator of water quality. Secchi depth decreases as water clarity decreases. Generally, Secchi depth will decrease in the summer with algal growth and increase in the winter. Secchi depth in Sweetwater Reservoir has varied from <1 ft to 30 ft, with most measurements since 2013 <5 ft (**Figure C.18**). Secchi depth was lowest in the period 2015-2016, when algal growth was most favorable by other metrics (see above).

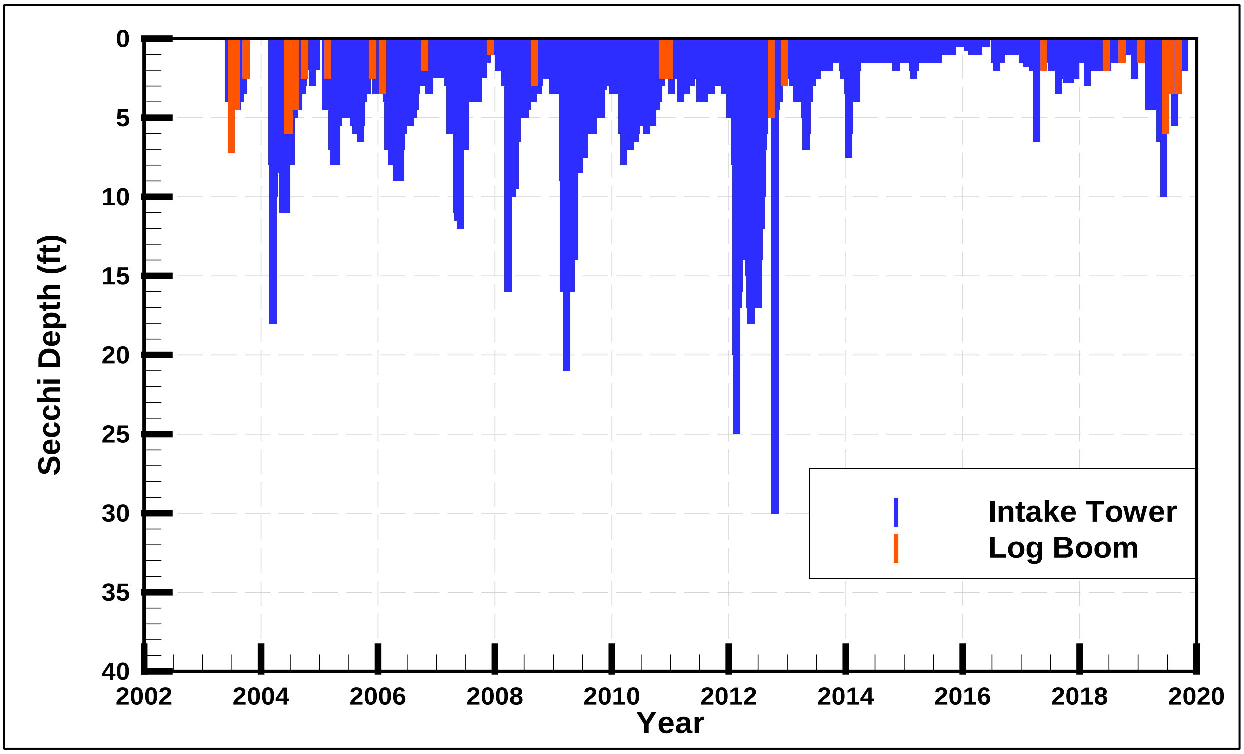


Figure C.18: Secchi depth in Sweetwater Reservoir.

C.4 Water Quality Issues

Manganese and iron are elements, which when present in high concentrations, can complicate water treatment operations and discolor water, potentially leading to customer complaints. These elements reenter the water column when anoxic water comes into contact with sediment. Surface manganese levels in Sweetwater Reservoir have varied from non-detectable to >800 µg/L (**Figure C.19**). This is directly related to low DO at depth (see above; **Figure C.10**). Manganese levels are generally highest at depth, and surface measurements may greatly underestimate concentrations during the stratified summer months. We recommend sampling vertical profiles for manganese concentration.

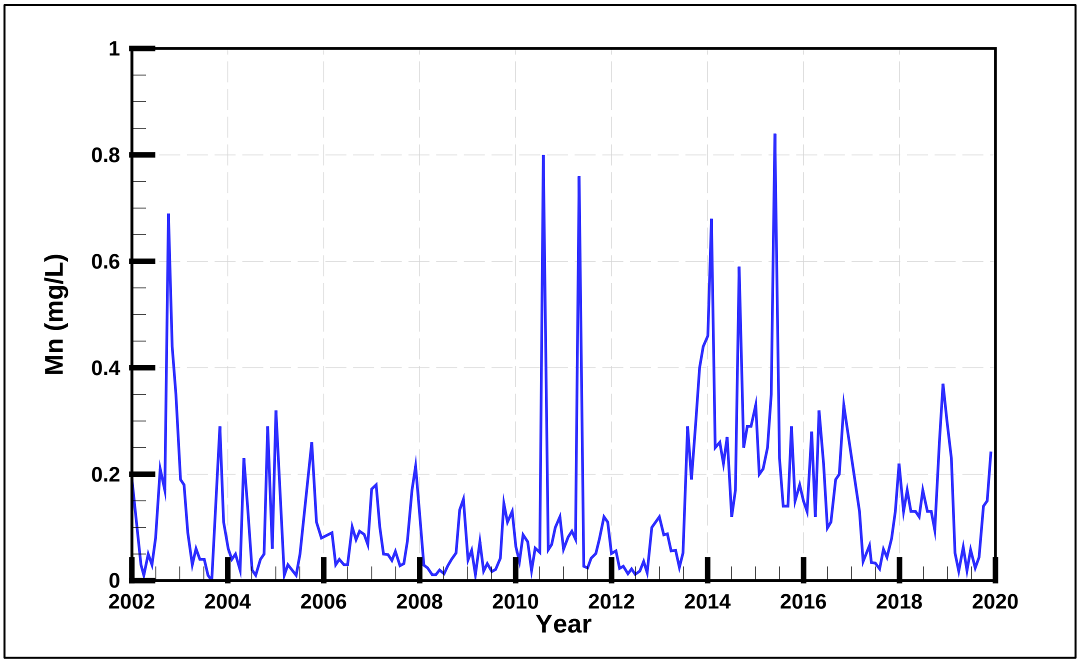


Figure C.19: Manganese concentrations in Sweetwater Reservoir.

Sweetwater Reservoir has experienced significant algal blooms at the reservoir surface, which has resulted in low water clarity (see above; **Figure C.18**). This has resulted in numerous water quality issues, including detection of the odorous compounds methylisoborneol (MIB) and geosmin (**Figures C.20** and **C.21**). MIB and geosmin are produced by some algae, and can complicate water treatment.

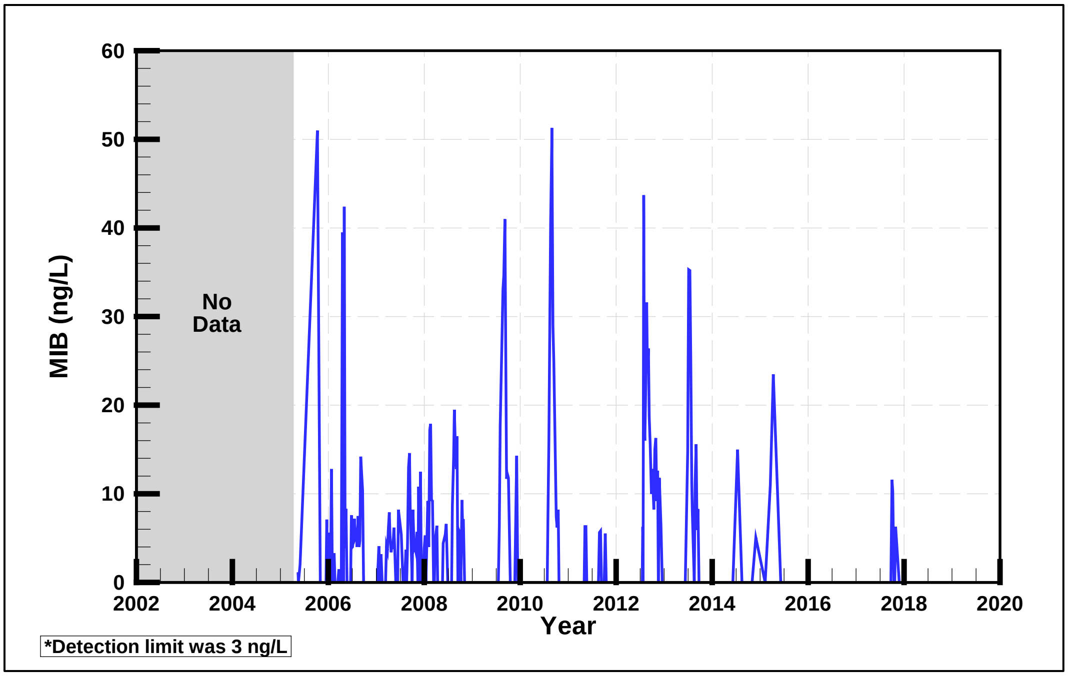


Figure C.20: MIB concentrations in Sweetwater Reservoir.

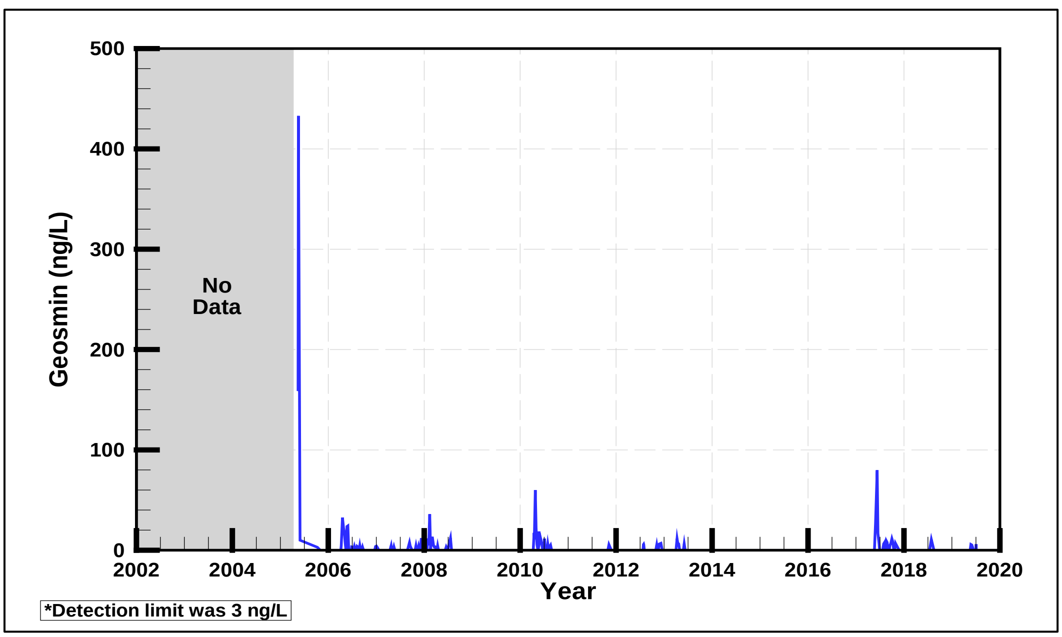


Figure C.21: Geosmin concentrations in Sweetwater Reservoir.

C.5 Summary and Recommendations

Sweetwater Reservoir is a highly eutrophic reservoir with high nutrient input. The water quality data for the period 2002-2019 is highly variable due to large volume fluctuations and wet/dry weather sequences. The low hypolimnetic volume limits the ability to selectively withdraw higher quality water from a single layer. When the reservoir level is low, frequent stratification and destratification may occur.

There is insufficient data to establish an accurate nutrient mass balance for Sweetwater Reservoir, or to characterize sediment characteristics such as oxygen demand or manganese concentration. There is insufficient data to characterize the nutrient levels in inflows to Sweetwater Reservoir. There is also insufficient data to accurately characterize the water quality in Loveland Reservoir.

The following are recommendations for possible enhancement of the water sampling program:

1. Perform more frequent, consistent, and spatial (vertical profiles all the way to bottom) in-reservoir sampling of Sweetwater Reservoir;
2. Perform nutrient mass balance to determine internal vs external loading of Sweetwater Reservoir;
3. Add fluorometer to profiler to measure chlorophyll *a* levels;
4. Measure inflow nutrient levels to establish an accurate nutrient mass calculation for Sweetwater Reservoir, including the effect of the retention ponds;
5. Measure vertical water quality and nutrient profiles in Loveland Reservoir;
6. Measure chlorophyll *a* levels in Loveland Reservoir;
7. Sample releases from Loveland Reservoir.