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MEMORANDUM

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Date: June 30, 2019

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SUBJECT: 2018 LAKE MERCED WATER QUALITY MONITORING REPORT

1.0 BACKGROUND AND SETTING

Lake Merced is a freshwater lake located approximately 0.25 miles east of the Pacific Ocean in the southwestern portion of San Francisco, California. It is bounded by Lake Merced Boulevard to the north and east, and John Muir Boulevard to the west (Figure 1). Lake Merced is a natural habitat for many species of birds and waterfowl and a regional recreational venue offering fishing, boating, bicycling, and wildlife viewing.

Prior to the beginning of Hetch-Hetchy aqueduct water delivery in 1935, Lake Merced was used as a municipal water supply. When San Francisco began receiving Hetch-Hetchy water, Lake Merced became an emergency and irrigation water supply source. In the late 1930s, the City of San Francisco (City) acquired Lake Merced and gave jurisdiction of the Lake to the SFPUC. In 1950, the San Francisco Recreation and Park District was given jurisdiction to develop beneficial recreational uses at the Lake while maintaining its status as an emergency non-potable water supply with the SFPUC managing the water aspects of the lake.

Beginning in the late 1980s, Lake Merced's water levels began declining. By the early 1990s, water levels had dropped ten feet below the historic averages of the 1950s to 1980s. Declining water levels generated significant concern

over the long-term health of Lake Merced for recreational, ecological, and emergency water supply uses. These decreases were the result of a reduction in stormwater runoff from the historical watershed into the lake as a result of urbanization, groundwater pumping and below average precipitation.

Lake level increases from 2002 to 2006 were a result of a combination of factors, including above-average precipitation, reductions in groundwater pumping by the surrounding golf course due to introduction of recycled water, SFPUC system water additions in 2002 and 2003, and limited addition of treated stormwater from 2004 to 2006 as part of the Lake Merced Pilot Stormwater Enhancement Project. By 2006, Lake Merced water levels had increased and reached 6.8 feet City Datum, a level not reached for 20 years.

The urbanization of the watershed has also resulted in the diversion of an increasing amount of storm water away from Lake Merced and into the ocean or wastewater treatment plant. These diversions began with the construction of the Vista Grande Canal and Tunnel by the Spring Valley Water Works in 1897 and have continued with successive urban development in San Francisco and northern San Mateo County. These diversions have resulted in short-term lake levels being more sensitive to fluctuations in precipitation, because direct precipitation and shallow groundwater inflow are the two primary lake replenishment mechanisms.

1.1 Lake Merced Climatic Setting

The proximity of Lake Merced to the Pacific Ocean results in a distinct maritime Mediterranean climate primarily influenced by wind, fog, and precipitation. This climate is characterized by cool, foggy summers and mild, rainy winters. In summer and fall, locations adjacent to the ocean, such as Lake Merced, are often enclosed in fog with cool temperatures in the 50s and 60s ^{o}F. The Lake Merced area often experiences its warmest weather in late September and early October as a result of less fog and the occasional off-shore breezes.

Based on historical precipitation data from the Lake Merced Pump Station rain gauge, the majority of annual rainfall occurs from late October through March. Precipitation typically declines during the late spring and becomes minimal during the summer. Average annual rainfall (based on a water year of October through September) at the Lake Merced rain gauge[1] is approximately 20.4 inches, with a record high of 47.6 inches in 1998 and a record low of 9.5 inches in 1976.

The Lake Merced rain gauge was out of service for a large portion of the year, consequently cumulative rainfall totals were collected from the Downtown San

[1] The Lake Merced Pump Station rain gauge data was not available in 2015.

Francisco rain gauge. Precipitation at the San Francisco Downtown gauge was 17.2 inches during water year 2018 (October 2017 through September 2018) and 19.9 inches for the 2018 calendar year. The average annual precipitation at this station for the preceding 30 years (1988-2017) was 22.7 inches, the minimum annual rainfall was 8.16 inches in water-year 1976, and the maximum annual rainfall was 46.56 inches in 1998 (NOAA, 2018).

2.0 HISTORICAL LAKE WATER QUALITY MONITORING

Detailed quarterly water quality monitoring has occurred at Lake Merced since 1997. Lake Merced is considered a shallow eutrophic lake; meaning that it is rich in minerals and organic nutrients that promote proliferation of plant life including algae which can lead to depressed dissolved oxygen levels. The lake is on the State of California Clean Water Act (CWA) Section 303 [d] list for pH and dissolved oxygen.

In January 2010, Kennedy/Jenks Consultants finalized the Lake Merced Water Quality Data Organization, Review and Analysis (Kennedy/Jenks Consultants 2010), which provided a review of the water quality data gathered from 1997 to 2008, evaluated the overall health of Lake Merced, and provided recommendations for the monitoring program. Based on the review of the data, seven water quality parameters were chosen to represent lake health. Brief descriptions of these parameters are as follows:

- Dissolved oxygen (DO): Sufficient DO is required for fish habitat and healthy biological processes.

- Secchi depth: Secchi depth is a measurement of lake clarity, but can be impacted by algae production and suspended solids.

- Algae, total bioavailable nitrogen, and nitrogen to phosphorus ratio (N:P): These parameters are indicators of algal production and the limiting macro-nutrient, which impact long-term lake health. A limiting nutrient in a lake is a nutrient necessary for plant/algae growth which is available in smaller quantities than needed for said plant or algae population to increase their abundance. Once this limiting nutrient is exhausted, the population of algae stops growing. If more of the limiting nutrient is added, larger algal populations will result until their growth is again limited by nutrients or by other environmental factors.

- Total coliform and Esherichia coli (E. coli): Total coliform and E. coli are indicators of pathogenic microorganisms and fecal contamination.

Results of the 2010 report indicated that based mainly on the parameters listed above, the health of Lake Merced remained relatively constant from 1997 to 2008 with a slight improvement in lake clarity (Secchi depth). From 2001 to 2005, the Lake appeared to be phosphorous-limited or nitrogen and phosphorous co-limited. In 2005, the lake shifted to being nitrogen-limited.

Also, during the 1997-2008 sampling period, there were no significant changes in algal biomass levels, with periodic increases in concentration due to algae blooms. Dissolved oxygen (DO) levels remained above the warm (5 mg/L) and cold (7 mg/L) water habitat criteria for the majority of the data set, however there remained episodes of DO concentrations lower than 5 mg/L during the summer within the deeper portions of the lake.

Additionally, while swimming is prohibited in Lake Merced, the bacteria levels (e.g., total coliform and E. coli levels) typically met State guidelines for the protection of public health in recreational waters (Kennedy/Jenks 2010).

In 2013, SFPUC prepared a technical report which summarized and evaluated Lake Merced water quality data for 2010 to 2012, based on the previously listed representative parameters. Water quality samples were collected quarterly in 2010, 2011, and 2012. Results of this evaluation indicated that overall, Lake Merced water quality had remained relatively constant from 1997 through 2012. While dissolved oxygen levels in the Lake were affected by periods of weak stratification measured levels in the upper 5 feet of the lake remained above the cold and warm water quality objectives (SFPUC 2013).

3.0 LAKE MERCED WATER QUALITY MONITORING 2018

The purpose of this memorandum is to provide a summary of the 2018 Lake Merced water quality data and determine if there has been a significant change in water quality at Lake Merced based on the representative water quality parameters. The SFPUC's Limnology Division conducted quarterly water quality monitoring at Lake Merced. The statistical analyses for each parameter is updated and summarized in Table 1. Figure 1 shows the field sampling locations while, Figures 2 through 8 show representative lake health parameters.

3.1 Statistical Analysis

Table 1 lists the parameters that were measured in Lake Merced from May 1997 to December 2018 and a statistical analysis for each parameter. The number of sampling events is listed for each constituent.

The average values from 1997 to 2009 and the average values from 1997 to 2018 were compared. Results indicate slight increases in the average values of algal biomass, ammonia-nitrogen (NH3), conductivity, dissolved oxygen, hardness, orthophosphate, oxygen reduction potential (ORP), total dissolved solids (TDS), temperature, total coliform, total organic carbon (TOC) and turbidity. There were decreases in the average values of E. coli, iron (Fe) nitrate (NO3) and plankton. There were relative no changes in the average values of chlorophyll, pH, manganese (Mn), secchi depth and total phosphorus. A summary of findings is presented below as well as in Table 1 attached.

3.2 Dissolved Oxygen (DO)

Dissolved oxygen concentrations in Lake Merced are affected by temperature, algal photosynthetic activity, and diffusion from the atmosphere. DO is an indicator of stratification and is a key constituent to monitor fish health. Lake Merced is a weakly and intermittently stratified lake, but long-term hypolimnetic anoxia (extended periods of very low DO which typically lead to acute adverse effects on fish) has not been observed at the lake. Additionally, summer stratification is a common phenomenon in natural lakes and ponds. Lake Merced is on the State of California CWA Section 303 [d] list of impaired water bodies for DO and pH. Dissolved oxygen concentrations measured to date in Lake Merced at the surface, 5, 10 and 15ft below the surface are presented in Figure 2a. Figures 2b presents measured DO concentrations at the lake's surface, 5ft and 10ft below the surface. These show that dissolved oxygen measured at the surface and at 5 foot depths continue to exceed 5 mg/L, which is the water quality objective for warm water habitat. For 2018 dissolved oxygen levels measured at 15 feet below surface in south Lake Merced improved during the summer and fall compared to 2017 due to the demonstration aeration mixing system installed in mid 2017. Consistently low DO was typically measured at the sediment water interface during summer months due to weak stratification. However during the late summer months of 2018, measured DO levels increased over previous results likely due to better mixing as a result of the aeration mixing demonstration system.

3.3 Secchi Depth

Secchi depth is a measure of lake clarity or lake health and decreases are usually due to increases in algae and/or mineral particles. Secchi depth data, as shown on Figure 3, had previously demonstrated a slightly increasing trend at Lake Merced. For 2018 measured secchi depth averaged 1.9 ft which was the same for 2017.

3.4 Algae and Nitrogen to Phosphorus Ratio (N:P)

Several studies have evaluated the "total nitrogen to total phosphorus ratios" in Lake Merced to determine if the lake is nitrogen-limited. These studies used slightly different approaches to calculating nitrogen to phosphorous ratios. However, in general, all of the studies found nitrogen to be the limiting nutrient in the lake.

Total phosphorous, total nitrogen and total algal biomass are plotted on Figure 4a. As demonstrated on Figure 4a, algae blooms typically spike in the fall and the bioavailable nitrogen typically peaks in the winter or spring. As shown on Table 1, there has been an increase in algal biomass and no discernable increase in TKN or total phosphorus. The ratio of total inorganic nitrogen (NH3-N + NO3-N) to the bioavailable phosphorus (80% of total phosphorus) is plotted on Figure 4b. Since Lake Merced has high levels of organic nitrogen, it is more appropriate to analyze the bioavailable nitrogen to bioavailable phosphorus ratio. This is because algae can uptake the inorganic forms of nitrogen more easily. Bioavailable nitrogen is the sum of nitrate and ammonia, which is referred to as total inorganic nitrogen (TIN). Bioavailable phosphorus

is approximately 80% of total phosphorus (Professor A. Horne, personal communication, November 9, 2010).

This report uses the ratio of bioavailable total nitrogen to bioavailable total phosphorous as described above to calculate nitrogen to phosphorous ratios. Based on this approach Lake Merced is nitrogen limited. However, due to very shallow secchi depth readings, the lake biomass production is arguably light-limited physically, as well as the nutrient limitation.

The average ratio of TIN to Total Inorganic phosphorous (80% of Total P), for Lake Merced in 2018 is 0.1.13 (well below 10), indicating the Lake is strongly nitrogen limited and has been since 2000. A ratio between 10 and 15 indicates growth ratio is balanced between nitrogen and phosphorus, while a ratio above 15 would indicate that phosphorus is the limiting nutrient.

For 2018, average TIN was 2,766 ug/l which is a slight increase compared to the 2,278 ug/l average concentration from 2017. Although slightly higher than the 2017 average, TIN concentrations remains well within historical ranges while average algal biomass concentrations increased slightly during this monitoring period (Figure 4A and 4B).

3.5 Total Coliform and Escherichia coli (E. coli)

Results indicate that average total coliform and E. coli concentrations decreased slightly compared to the previous monitoring periods and remain within historical ranges. As shown on Figure 5, coliform levels remain well below the California Department of Public Health threshold guidelines for recreational waters, which are 10,000 per 100 mL total coliform and 235 per 100 mL for E. coli (Table 1 and Figure 5).

3.6 Trophic Status Index (TSI)

Trophic Status Index (TSI) is a measurement that uses Secchi depth (a measure of the clarity of a water body) and chlorophyll-a concentrations to calculate a numeric value of a water body's algal productivity level. Changes in nutrient levels can cause changes in algal biomass, which can change lake clarity and Secchi depth readings. The index ranges from 0 to 100, where a value less than 40 is an unproductive lake, a value between 40 and 50 is moderately productive, and a value greater than 50 is highly productive. As demonstrated on Figure 6, over the past 15 years, TSI has historically ranged from about 50 to 75. During the 2018 monitoring period, average TSI was essentially the same at 68.9 compared to 68.2 for 2017. Between 2010 and 2017, TSI has remained well above 50 indicating that the Lake Merced remains moderately to highly productive. Figure 6 shows Secchi depths, Chlorophyll a and TSI for Lake Merced[i].

3.7 pH

Results of water quality monitoring at Lake Merced from 1997 to 2009 indicated statistically similar values for pH compared to current values. Average pH of the lake was 8.1. Lake Merced is on the State of California CWA Section 303

[d] list of impaired water bodies for pH exceeding 7. For 2018, average pH was 8.17 and remains well within historical ranges.

3.8 Lake Levels

Lake Merced water levels have fluctuated significantly since 1997 as shown on Figure 8. Since 2006, Lake levels had remained more consistently between 5 and 7 feet (City Datum). Lake Merced levels peaked in 2011 at an elevation of about 7 feet city datum. Lake levels which decreased in 2012 and 2013, continued to decrease through 2015 due to drought conditions and resulting below average precipitation. Lake levels rebounded in 2016 and 2017 due to increased precipitation. For 2018, lake levels also increased with water levels ranging from 4.85 to 6.2 feet city datum compared to a range of 3.96 to 6.01 feet city datum for 2017.

4.0 CONCLUSIONS

Overall, Lake Merced water quality has remained relatively constant from 1997 through 2017. Lake levels have been severely impacted by recent drought conditions which in turn resulted in an increase in algal biomass and a decrease in the measured secchi depth (clarity) in the lake. Increased precipitation for 2016 and 2017 has resulted in a significant increase in lake levels compared to drought induced lows. For 2017 Secchi depth increased slightly (average 1.9 ft) compared to 2016 average values (1.6 ft). Dissolved oxygen (DO) levels are affected by periods of weak stratification, however DO levels in the upper 5 feet of the lake continue to remain above the cold and warm water quality objectives. The Lake continues to be strongly nitrogen-limited, coliform levels remained below the regulatory guidelines and the TSI continued to indicate a moderately to highly productive Lake. Average pH levels remained below the fresh water criteria and did not exceed 9.0 during this period.

Lake Merced Aeration Mixing Project

The SFPUC completed implementation of the Demonstration Aeration Mixing Project in the southern portion of Lake Merced's South Lake. The project entailed installation of up to 1500 ft of pvc tubing, connected to 3 air compressors located at the Lake Merced Pump Station. Compressed air is pumped through these pipes which are connected to diffusers located along the bottom of the lake. The compressed air released at the bottom of the lake assists in mixing various lake layers, potentially minimizing periods of hypoxia/anoxia that fall below the warm and cold-water quality objectives at lower depths in the lake during the warm summer months. This was expected to result in higher dissolved oxygen levels within the lower layers of the lake and general lake quality improvement. The system was installed and activated in July 2017 and operated continuously through September 2018. The demonstration project was originally scheduled to operate through February

2018. However due to malfunction of sondes deployed in the deeper portion of the lake, the demonstration project was extended through September 2018.

The Lake Merced aeration demonstration appeared to be successful in raising DO levels in the water column. Overall, measured DO levels during aeration were above the 5 mg/L target 99% of time during the aeration demonstration compared to 85% of the time prior to the demonstration project. With or without aeration, Lake Merced is relatively well-mixed in the winter months (December to March) and DO levels below 5 mg/L were rarely observed during this time. During aeration, near-bottom DO levels during non-winter months were observed to be above the target DO level 97% of the time as opposed to baseline data where DO levels were above 5 mg/L only 40% of the time.

During aeration, pH values stabilized between the surface and near-bottom as mixing of the water column resulted in a more consistent pH. The pH in Lake Merced is on the high side of the target range of 6.5 to 8.5 with approximately half of collected data during aeration being within this range and approximately half above 8.5. During aeration, the maximum pH measured was 8.9.

The SFPUC will determine whether improvement in DO concentrations justifies implementation of a larger scale aeration mixing project.

The Lake Merced monitoring program will continue to be implemented and the Lake Merced water quality summary report will be updated annually.

Attachments

Table 1

Figures 1-8

References

EDAW, 2004, Initiative to Raise and Maintain Lake Level and Improve Water Quality, Task 3 Technical Memorandum, FINAL, September 2004.

Kennedy/Jenks Consultants, 2010, Lake Merced Water Quality Data Organization, Review and Analysis. Prepared for San Francisco Public Utilities Commission, January 2010.

RMC, 2007, John Muir Wetland Conceptual Design Update. Prepared for SFPUC Water Resources Planning, September 17, 2007.

SFPUC, 2017, Lake Merced Water Quality Summary Report, December 2, 2016.

SFPUC, 2018 Annual Groundwater Monitoring Report Westside Basin

Kennedy Jenks Consultants, 2019, Lake Merced Aeration Demonstration Results. Prepared for San Francisco Public Utilities Commission, June 2019

TABLES

Table 1
Water Quality Summary Data - Lake Merced Water Quality Monitoring
South Lake 0-5 Feet

Number of Sampling Dates	Parameter	Units	Average 1997-2009	Change	Average 1997-2018	1997-2018 Median	1997-2018 Minimum	1997-2018 Maximum
92	Algal Biomass	ug/L	1879	13	1892	1623	442	6705
171	Ammonium (NH_4^+)	mg/L	0.05	0.02	0.07	0.05	ND	0.48
100	Chlorophyll	ug/L	27.0	1	27.5	24.3	5	100
185	Conductivity	mmho/cm	580	91	671	623	431	1244
181	Dissolved oxygen (DO)	mg/L	7.1	2	9.1	9.1	5.0	12.7
140	E.Coli	MPN/100 mL	36.9	-10	27.2	18.0	0.50	100
175	Hardness	mg/L	180	24	204	200	145	276
71	Iron (Fe)	mg/L	0.03	0.00	0.025	0.01	ND	0.14
42	Lead (Pb)*	ug/L	0.44	0.10	0.54	0.50	ND	2.0
80	Manganese (Mn)	mg/L	0.06	0.0	0.07	0.04	ND	1.7
177	Nitrate ($NO3^-$)	mg/L	0.03	-0.01	0.02	0.01	ND	0.62
181	Orthophosphate	mg/L	0.06	0.02	0.08	0.07	ND	0.26
181	Oxidation-reduction potential (ORP)	mV	319.0	1	320.5	314.0	76.8	543
185	pH	-	8.1	0.2	8.3	8.3	7.5	8.8
87	Plankton	NU/mL	822.0	-178	644.2	600.4	6.48	2511
94	Secchi depth	Feet	1.8	0	1.8	1.8	0.50	3.0
185	Temperature	°C	15.8	0.3	16.1	16.3	9.80	22.6
70	Total Coliform	MPN/100 mL	925.0	75	1000.3	866.0	109.0	2420
179	Total dissolved solids (TDS)	mg/L	372	56	427.6	399.0	276.0	809
142	Total Kjeldahl nitrogren (TKN)	mg/L	3.76	0.1	3.86	3.10	ND	28.2
76	Total organic carbon (TOC)	mg/L	6.7	0.8	7.52	7.30	ND	15.18
172	Total phosphorus	mg/L	0.14	0.03	0.17	0.16	ND	0.48
174	Turbidity	NTU	13.2	0.5	13.70	12.0	2.46	34

Note:

ND* Not detected above laboratory detection limits

FIGURES

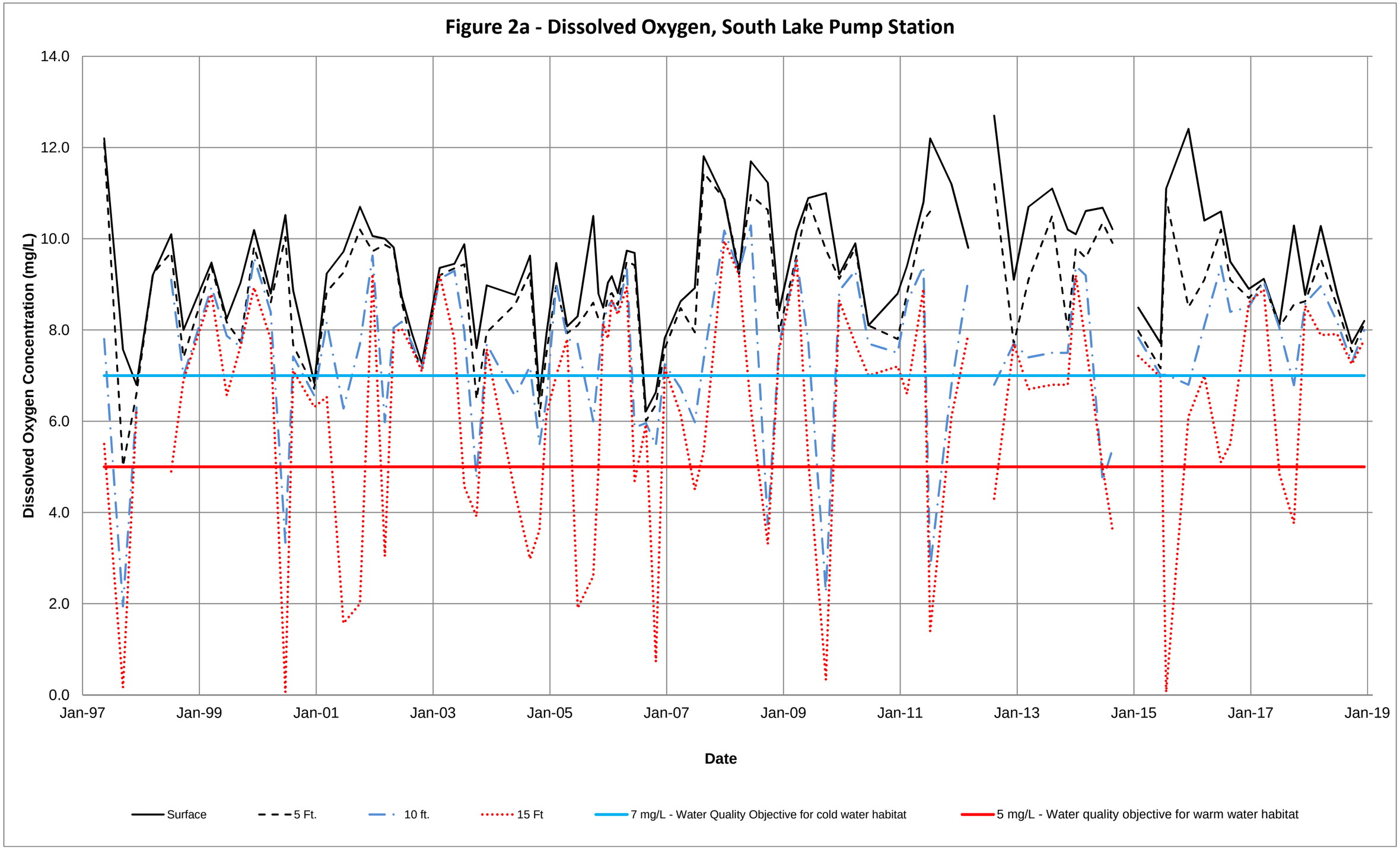
N

0 325 650 1,300 Feet

San Francisco Public Utilities Commission
Lake Merced Water Quality Summary Report
June 2019

Figure 1 – Lake Merced Sampling Points

Figure 2a - Dissolved Oxygen, South Lake Pump Station



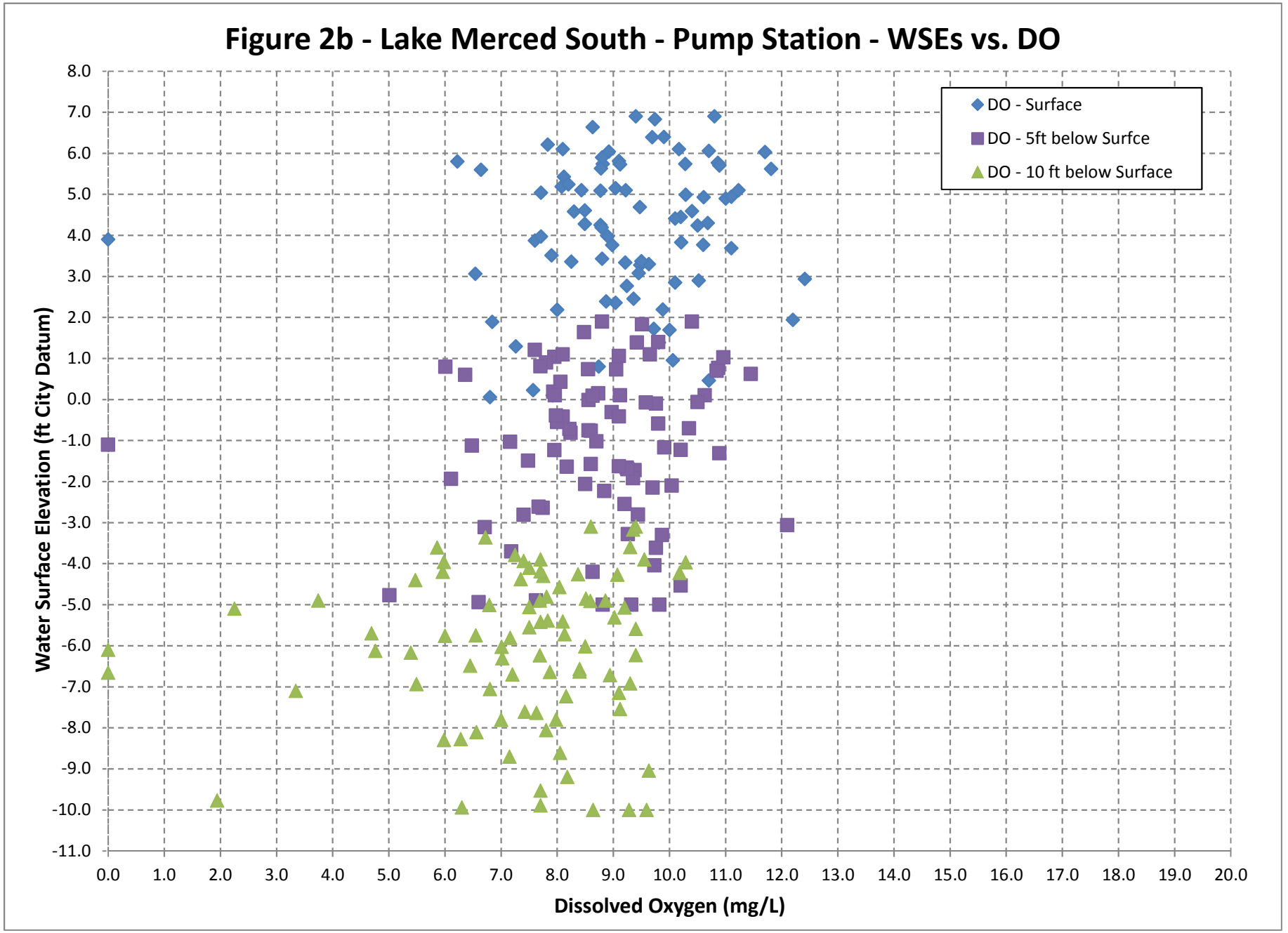


Figure 2b - Lake Merced South - Pump Station - WSEs vs. DO
DO - Surface
DO - 5ft below Surfce
DO - 10 ft below Surface
Water Surface Elevation (ft City Datum)
Dissolved Oxygen (mg/L)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
-11.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0

Figure 3 - Secchi Depth, South Lake Pump Station

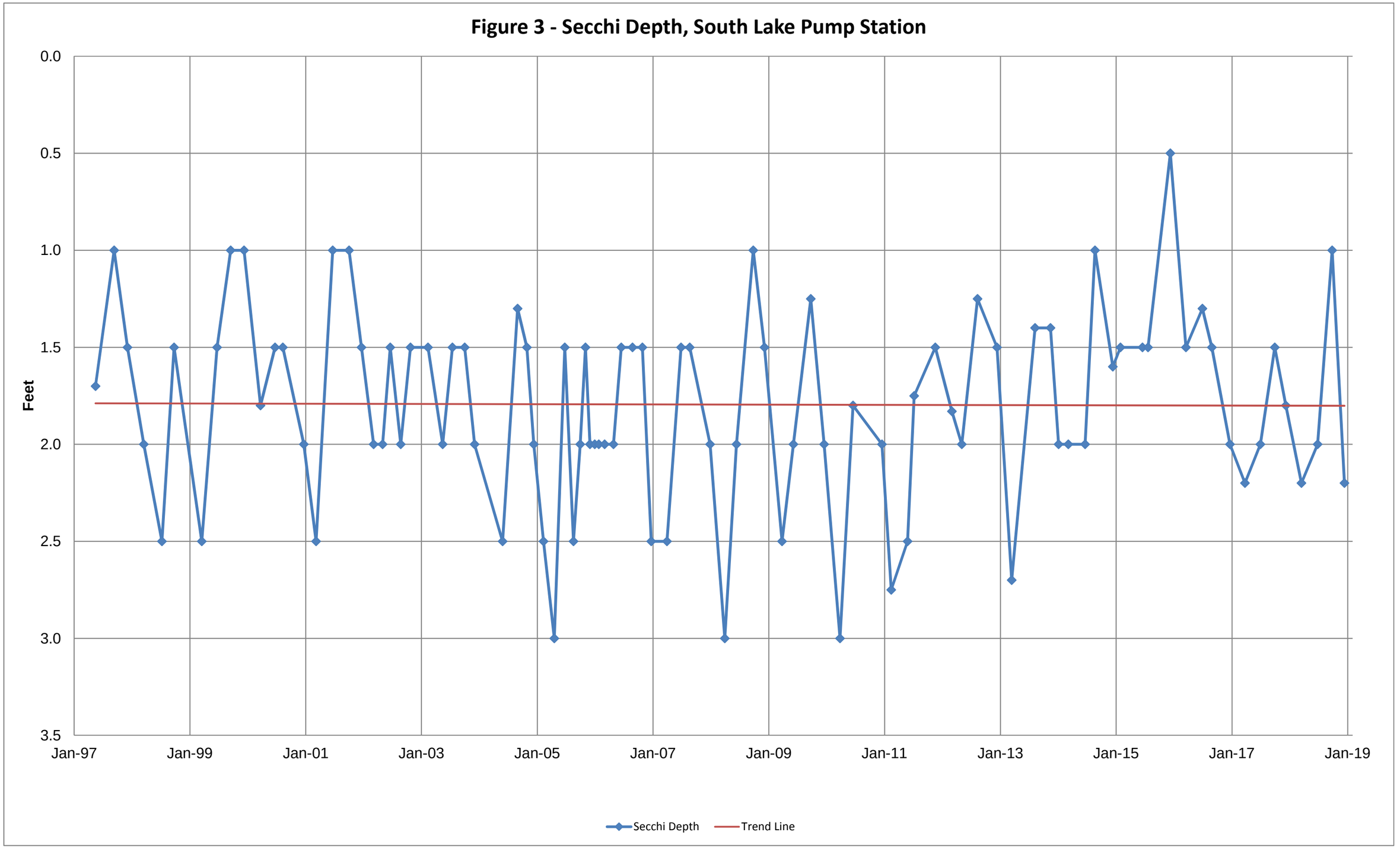


Figure 4(a) - Algal Biomass and Nutrient Information, South Lake Pump Station

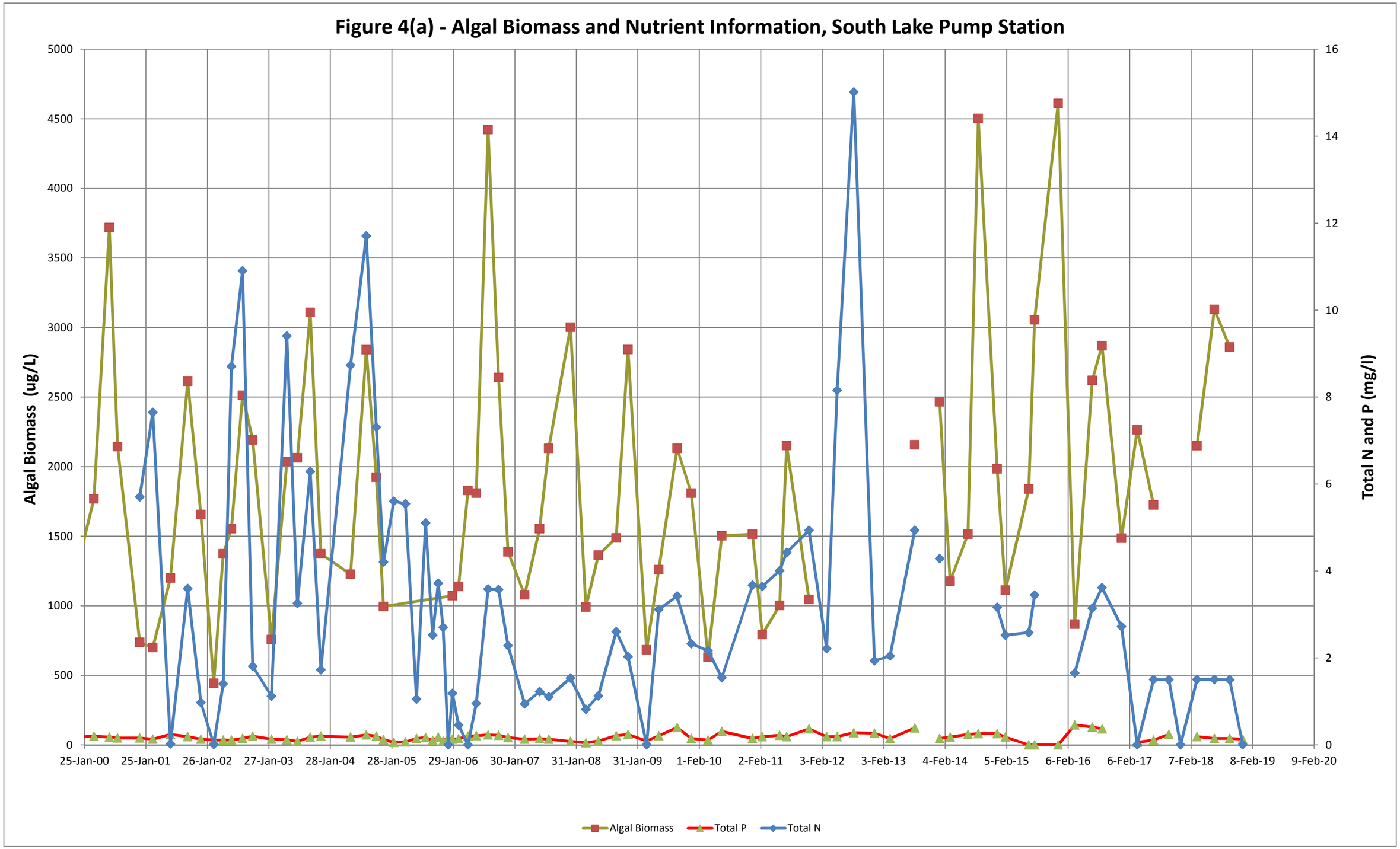


Figure 4(b) - Algal Biomass and Nutrient Information, South Lake Pump Station

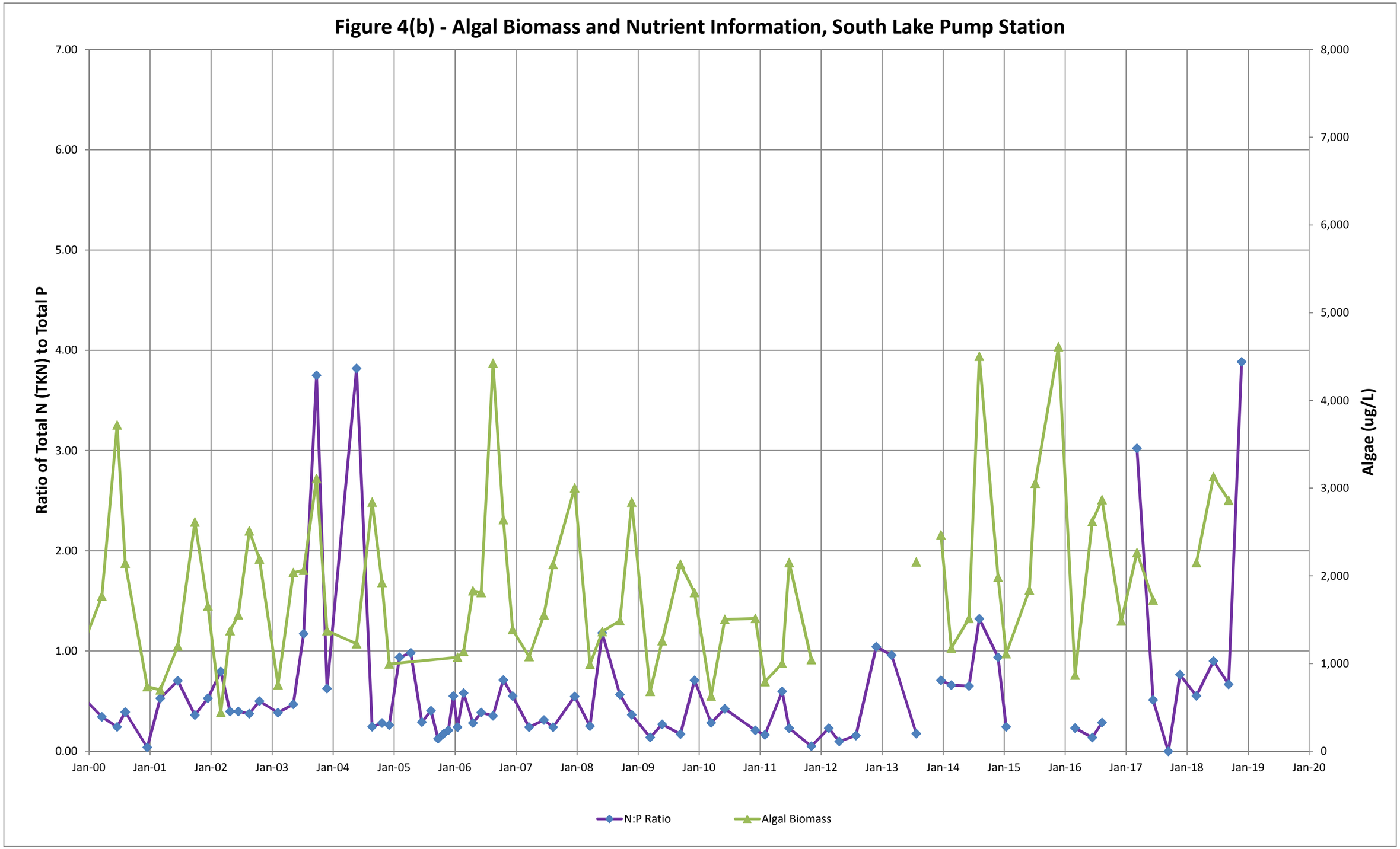


Figure 5 - Coliform, South Lake Pump Station

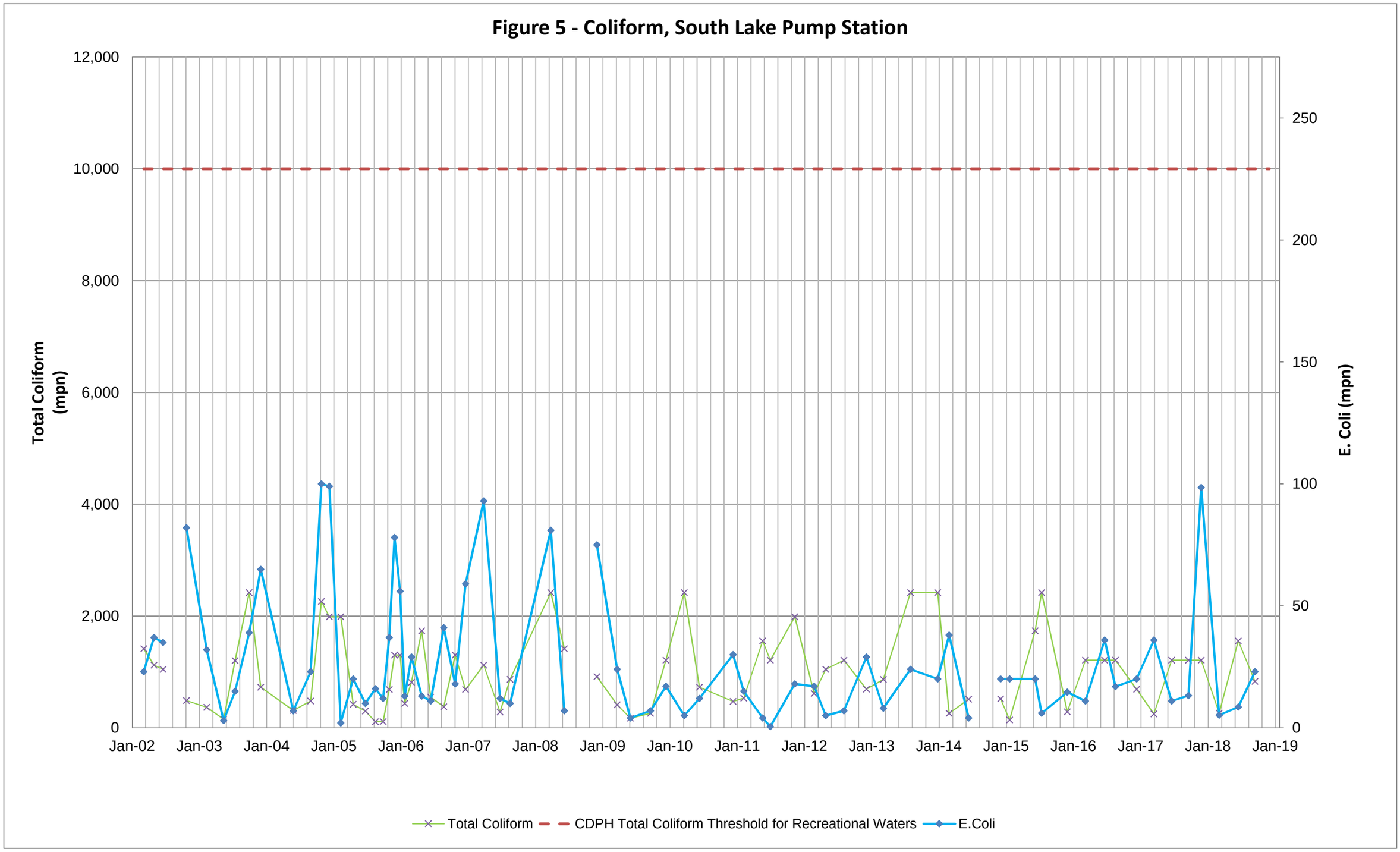


FIgure 6 - Secchi, Chlorophyll-a, and TSI - South Pump Station

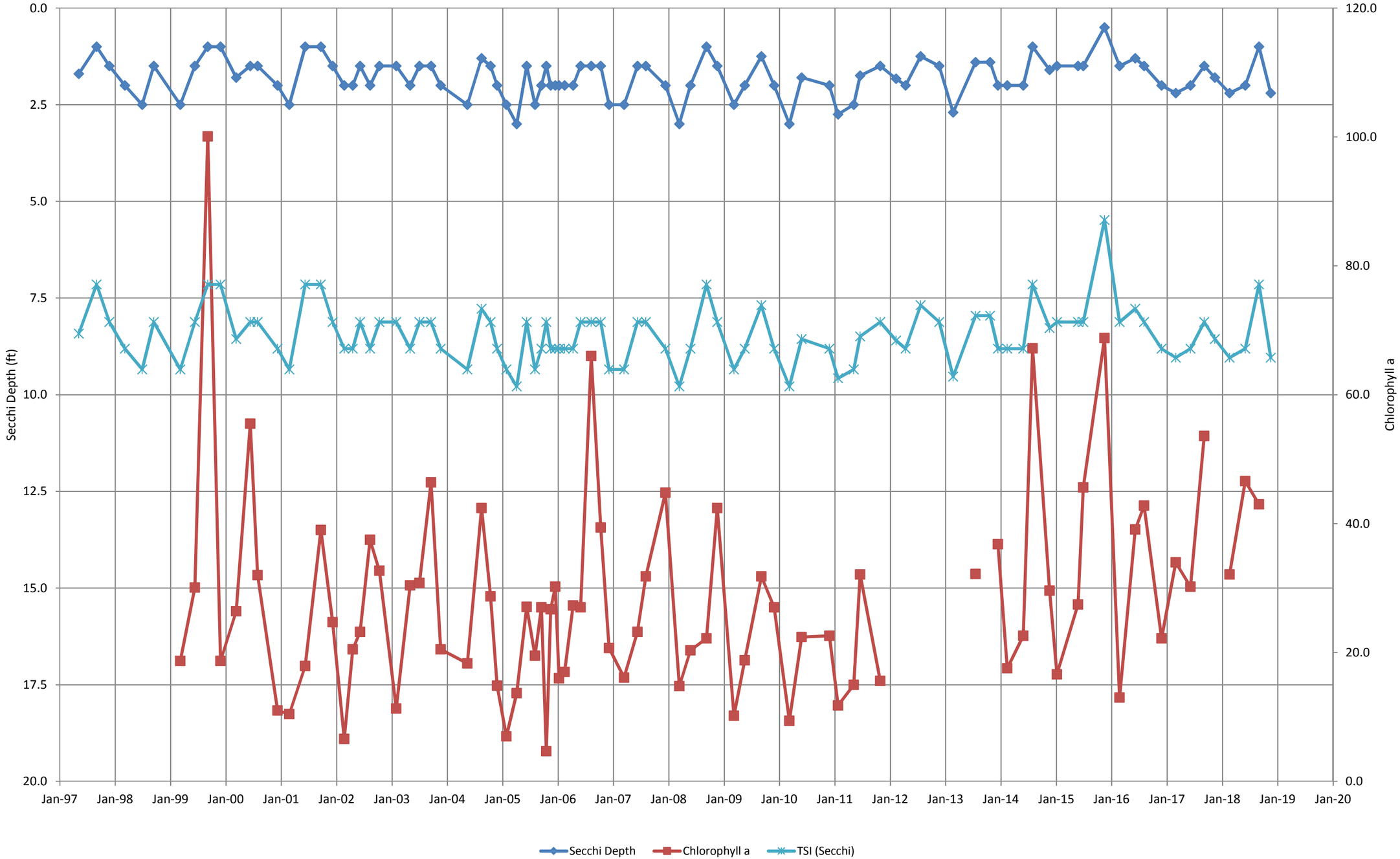


Figure 7 - pH, South Lake Pump Station

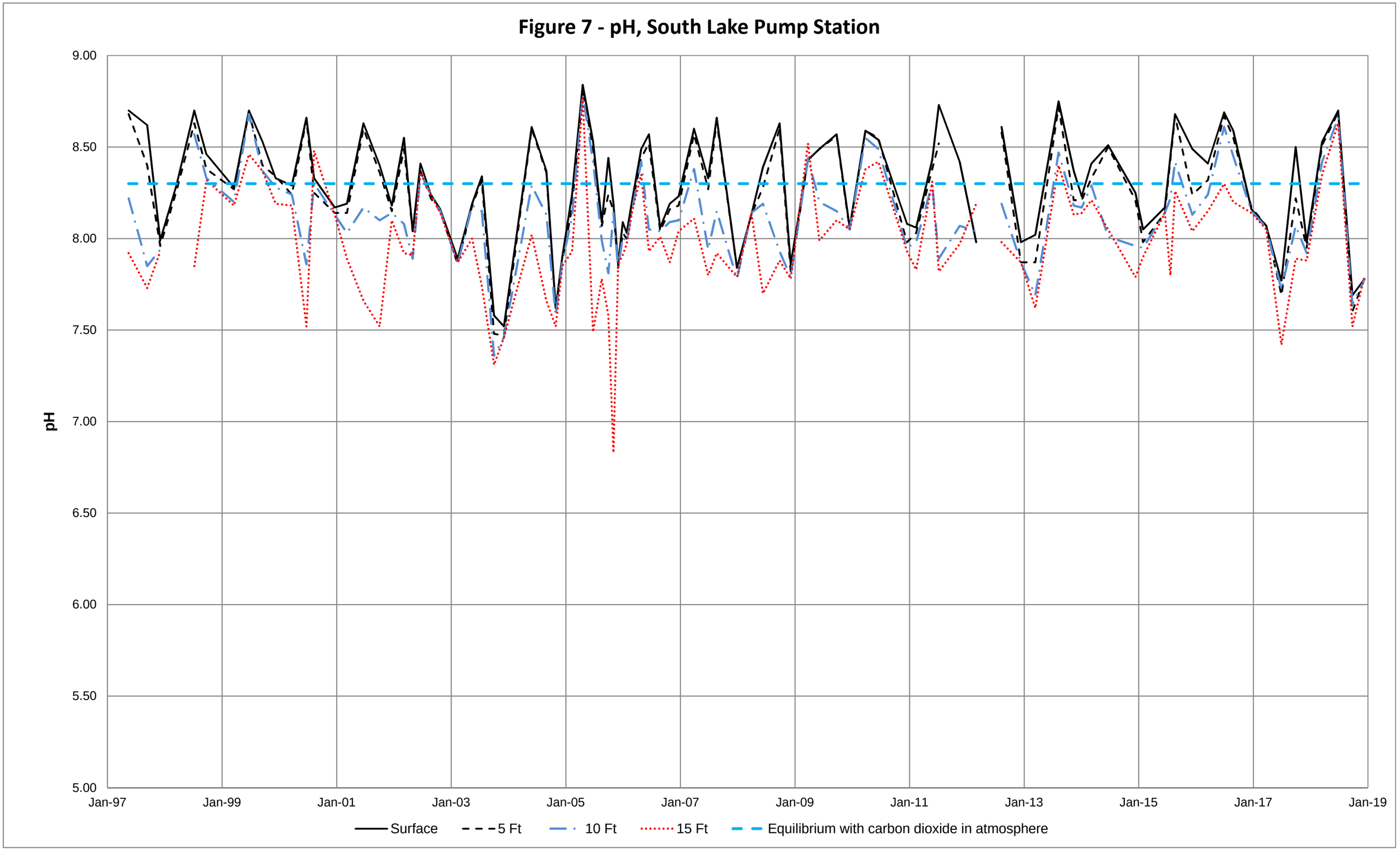


Figure 8 - Water Surface Elevations

Level 1 is equal to Surface Water
Level 2 is equal to North Westside Basin
Level 3 is in list "Lake Merced","Lake Merced (Wet Well)"
Date is between 1/1/1997 and 3/1/2019