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MEMORANDUM

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Date: May 30, 2020

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SUBJECT: 2019 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) and is designated as a non-potable emergency water supply for the City of San Francisco. Lake Merced is a natural habitat for many species of birds and waterfowl and a regional recreational venue offering fishing, boating, bicycling, walking paths, and wildlife viewing.

Prior to the 1870's Lake Merced was a coastal estuary which would fill up with water and overflow during large rain events, creating a stream which connected the lake to the ocean[1]. The lake drained an area of 6,320 acres in size, approximately 10 square miles which included Daly City, Westlake, and the Stonestown area of San Francisco.

The stream flowed to the ocean through the present-day location of the San Francisco Zoo and Sloat Boulevard. The springs were primarily along the eastern side and beneath the southern portion of the lake, resulting in primarily south-to-north flow through the lake.

[1]Over a period of hundreds of years, this outlet was closed off by the natural transport of beach and dune sands, and intermittently reopened during extraordinary events, such as high lake levels in unusually wet years or during earthquakes."

In 1895, the Spring Valley Water Company (SVWC) built a dam at Lake Merced, disconnecting the lake from the ocean. This allowed the company to use the lake as a source of drinking water. As the city grew in the late 1800's, so did its need to protect its water sources for drinking. The sewer system was built to divert the creeks that drained into Lake Merced, protecting the lake from debris and pollution that might otherwise flow into the lake.

After the SVWC was purchased by San Francisco, and Hetch Hetchy water replaced Lake Merced water in 1934, the lake was no longer used as a drinking water source but has since been designated as an emergency non-potable supply for the City of San Francisco. 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.

1.1 Current Lake Conditions

Today, Lake Merced remains a terminal lake which consists of four lakes (North, East, South, and Impound lakes) and has no channelized inflow or outflow. A narrow channel connects North Lake and East Lake and equalizes their water surface elevations. A conduit between North Lake and South Lake allows water to flow between the lakes when the elevation in either lake is at least approximately 3.35 feet San Francisco City datum (14.72 feet NAVD88). When lake levels are below that elevation, these two lakes are separated and typically exhibit different water surface elevations. South Lake and Impound Lake are separated below an elevation of approximately 4.26 feet San Francisco City datum (15.63 feet NAVD88), by a levee that contains the Ingleside combined sewer pipeline and the foundation of a pedestrian walkway. Water flows freely beneath the pedestrian walkway and connects both lakes when the level of either lake is above this levee. The flow through the four lakes is generally north to south.

1.2 Lake Water Levels

Beginning in the late 1980s, Lake Merced's water levels began declining. By the early 1990s, water levels had dropped ten feet below the previous historic averages of the 1950s to 1980s. Declining water levels generated significant concern among stakeholders and SFPUC watershed managers over the long-term health of Lake Merced for recreational, ecological, and emergency water supply uses. Conclusions of various investigations and evaluations commissioned by SFPUC, indicated that these declines were the result of a reduction in stormwater runoff from the historical watershed into the lake due to urbanization, increased groundwater pumping and below average precipitation.

In order to address these significant decreases in lake levels, the SFPUC working with local stakeholders and regulatory agencies implemented a multi-pronged approach including in the short-term addition of regional system water to stabilize declining lake levels. In 2002 the SFPUC in coordination with the

City of Daly City implemented a test program to evaluate the effectiveness of potentially diverting treated stormwater from the historical watershed back into the lake. Limited addition of stormwater was added to the lake from 2004 to 2006 as part of the Lake Merced Pilot Stormwater Enhancement Project. Hydrogeological studies completed to enhance understanding of how the lake system operated in relation to the regional groundwater aquifers determined that additional impacts to lake levels where the result of groundwater pumping by three golf courses in the near vicinity of the lake. This pumping for golf course irrigation resulted in net outflow from the lake to underlying shallow aquifers further impacting lake levels. To this end, the SFPUC once again in coordination with the City of Daly City, developed a recycled water project to deliver water to the surrounding golf courses, allowing significant reduction in the amount of groundwater pumped for irrigation.

Ultimately following implementation of these various measures and projects, as well as above average precipitation, lake level increased from 2002 to 2006 and have generally remained above the historical drought and groundwater pumping induced lows observed in the early 2000s.

As part of the ongoing monitoring program, Lake Merced levels are measured daily using pressure transducers located at the Lake Merced Pump Station and connected remotely to the SFPUC's SCADA reporting system. For 2019, lake levels ranged from a low of 5.27 ft City datum or 16.64ft NAVD88 on January 5th, 2019 to 7.04ft City datum or 18.41ft NAVD88 in April, 9th 2019. This was compared to 2018, lake levels ranging from 4.85ft to 6.2ft City datum. Measured lake levels for 2019 showed significant increases compared to 2018 values, primarily due to increased precipitation when compared to the near drought conditions of 2018.

1.3 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[2] 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 remains out of service, consequently cumulative rainfall totals were collected from the Downtown San Francisco rain gauge. Precipitation at the San Francisco Downtown gauge was 25.8 inches during water year 2019 (October 2018 through September 2019) and 26.3 inches for the 2019 calendar year. Compared to 2018 water year and calendar year precipitation of 17.2 inches and 19.9 inches respectively. The average annual precipitation for the preceding 30 years (1989-2018) at this station is 22.60 inches (NOAA, 2019)

2.0 HISTORICAL LAKE WATER QUALITY MONITORING

Quarterly water quality monitoring, testing and reporting has occurred at Lake Merced since 1997. Lake Merced is considered a terminal, stratified, 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 within lower portions of the lake. The lake is on the State of California Clean Water Act (CWA) Section 303 [d] list for pH and dissolved oxygen (DO) with occasional pH levels above 9 and DO levels below 5mg/l specifically in the lower portions of the lake (hyperlimnion). DO levels in the upper portion of the lake (epilimnion) remain fairly high and well above the 5mg/l threshold for the entire year.

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 the lake between 1997 and 2008, evaluated the overall health markers of Lake Merced, and provided recommendations for the monitoring program. Based on the review of the data, seven water quality parameters were chosen to generally 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 the limiting macro-nutrients within the lake system and indicators of algal production, 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 between 1997 and 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 and has generally remained that way to date. Also, during the 1997-2008 sampling period, there were no significant changes in algal biomass levels The lake continues to exhibit periodic fluctuations in algal biomass concentration due to algae blooms. Dissolved oxygen (DO) levels remained in general 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 (hyperlimnion) of the lake as a results of weak stratification which is typical of eutrophic lakes.

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

4.0 LAKE MERCED WATER QUALITY MONITORING 2019

The SFPUC's Limnology Division conducted quarterly water quality monitoring at Lake Merced in 2019, collecting samples in March, June, September and December. The historic 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, with data results presented in Appendix A.

4.1 Statistical Analysis

Table 1 lists the parameters that were measured in Lake Merced from May 1997 to December 2019 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 2019 were compared. Results indicate increases in the average values of algal biomass, ammonia-nitrogen (NH3-N), chlorophyll, conductivity, dissolved oxygen, hardness, lead (Pb), orthophosphate (PSO4), , total dissolved solids (TDS), , total coliform, total organic carbon (TOC), total phosphorous and turbidity. There were decreases in the average values of E. coli, , oxygen reduction potential (ORP) and plankton. There were relative no changes in the average values of iron (Fe), , pH, manganese (Mn), nitrate (NO3), secchi depth and total phosphorus. A summary of findings is presented below as well as in Table 1 attached.

4.2 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 2019 dissolved oxygen levels measured at 15 feet below surface in south Lake Merced where lower during the summer and fall compared to 2018 due to the Demonstration Aeration Mixing system installed in July 2017. The demonstration project operated between July 2017 and September 2018 and consisted of twelve (12) 3/4 HP super-duty, Brookwood twin cylinder HighFlow air compressors installed to provide sufficient airflow to the diffusers for aeration of this portion of the lake. The air compressors were housed in three (3) rustproof aluminum outdoor cabinets for protection and to minimize noise. The system was operated continuously (24hrs/day) during the demonstration period. During operation of the demonstration project, DO levels measured at 15 feet below surface remained above 5mg/l and also remained above 7mg/l for the entire year. In 2020 the SFPUC restarted the aeration mixing system on a 6hr per day operational schedule to determine whether similar benefits to lake DO will be observed in the lower levels of the lake without continuous daily operation. During this period, Lake Merced continued to exhibit consistently low DO levels measured at the sediment water interface during summer months due to weak stratification.

4.3 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 2019 measured secchi depth averaged 1.9 ft which was the same for 2018.

4.4 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.

For 2019, average TIN was 46.3 ug/l which is a decrease compared to the 211 ug/l average concentration from 2018. Algal biomass concentrations also increased slightly during this monitoring period (Figure 4A and 4B).

The average ratio of TIN to Total Inorganic phosphorous (80% of Total P), for Lake Merced in 2019 is 0.36 (well below 10) compared to an average TIN to TIP ratio of 1.9 in 2018, indicating the Lake continues to be 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.

4.5 Total Coliform and Escherichia coli (E. coli)

Results indicate that average total coliform and E. coli concentrations increased slightly compared to the previous monitoring periods however 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).

4.6 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. This report utilizes the formula TSI= 60-14.41ln(Secchi depth (m)) to calculate the Trophic Status Index. 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 2019 monitoring period, average TSI decreased slightly 68.2 compared to 70 for 2018. Between 2010

and 2019, TSI has remained well above 50 indicating that Lake Merced remains moderately to highly productive. Figure 6 shows Secchi depths, Chlorophyll a and TSI for Lake Merced[i].

4.7 pH

Lake Merced is currently on the State of California CWA Section 303 [d] list of impaired water bodies for pH exceeding 7. Lake Merced continues to display high alkalinity with a historical surface pH range of approximately 7.5 to 8.8. The average pH across all depths sampled over time was 8.1, within the range of Basin Plan WQOs of 6.5 to 8.5 and near the level of 8.3 which would result from equilibrium with carbon dioxide in the atmosphere. The pH levels appear to be the result of photosynthesis from algal activity, combined with the elevated alkalinity within the Lake due to it being a terminal lake, with no regularly occurring outflow since it lost connection to the ocean. Results of water quality monitoring at Lake Merced from 1997 to 2009 indicated statistically similar values for pH compared to current values. Average surface pH of the lake for 2019 was 8.4, while average pH for the entire lake depths sampled was 8.1 which remains well within historical ranges.

4.8 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 decreased in 2012 and 2013, and 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 2019, lake levels also increased with water levels ranging from 5.3 to 7 feet city datum compared to a range of 4.85 to 6.2 feet city datum for 2018.

Of note for 2020 is increased pumping of groundwater by the surrounding golf courses (Olympic Club, San Francisco Golf Course and the Lake Merced Country Club), which had previously been meeting close to 80% of their irrigation demand by using recycled water produced at the Daly City Treatment Plant. Due to operational issues, the plant has not produced recycled water since mid 2019, forcing the golf courses to revert to pumping groundwater. SFPUC will continue to observe measured lake levels in order to determine what if any impact the additional pumping may have on the lake.

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.

5.0 CONCLUSIONS

Overall, Lake Merced water quality has remained relatively constant from 1997 through 2019. Lake levels had 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. Precipitation increased in 2019 compared to 2018 resulting in rebounding and stable lake levels for this period. For 2019 Secchi depth remained the same at an average of 1.9ft. Dissolved oxygen (DO) levels across the lake 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. Following conclusion of the Aeration Mixing Demonstration, there was a slight decrease in DO levels in the lower portion of South Lake compared to the 2018 periods during which the system was operational. Based on these observations, SFPUC restarted the aeration system running on a 6hr per day schedule. Results of subsequent monitoring will assist SFPUC staff further fine tune operation while maintaining higher DO concentrations in the hyperlimnion. 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.

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

Appendix A – Analytical Results (SFPUC Millbrae Lab)

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.

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