MEMORANDUM

To: Greg Bartow, P.G., C.HG.

From: Obi Nzewi, P.G.

Date: May 17, 2013

cc: Jason Bielski

SUBJECT: 2010-2012 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 no-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 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.

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 California 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 process.

- **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 2010, SFPUC prepared a technical report which summarized and evaluated Lake Merced water quality data for 2009, based on the previously listed representative parameters. Water quality samples were collected four times in 2009: March, June, September, and December. Results of this evaluation indicated that overall, Lake Merced water quality had remained relatively constant from 1997 through 2009. For 2009, similar to historical observations, dissolved oxygen levels in the Lake were affected by periods of weak stratification. However, DO levels in the upper 5 feet of the lake remained above the cold and warm water quality objectives (SFPUC 2010).

### 3.0 Lake Merced Water Quality Monitoring 2010-2012

The purpose of this memorandum is to provide a summary of the 2010-2012 Lake Merced water quality data and determine if there has been a 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 2012 and a statistical analyses for each parameter. The number of sampling events is listed for each constituent. The average values from 1997-2009 and the average values from 1997-2012 were compared. Results indicate slight increases in the average values of conductivity, hardness, and Total Kjeldahl Nitrogen. There were slight decreases in the
average values of algal biomass, chlorophyll, E. coli, total coliform. There were no relative changes in the average values of nitrate (NO3) and secchi depth. Additionally, the median, minimum, maximum, standard deviation, and coefficient of variance are shown for each parameter. A summary of findings is presented below.

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 in Lake Merced at the surface, 5, 10 and 15ft below the surface as well as concentrations at the bottom of the lake 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. Low DO was only measured at the sediment water interface during summer months when the lake exhibits weak stratification.

3.3 Secchi Depth
Secchi depth data, as shown on Figure 3, have demonstrated a slightly increasing trend at Lake Merced. Secchi depth is a measure of lake clarity or lake health and decreases are usually due to increases in algae and/or mineral particles. There has been no significant change in the average Secchi depth values during this monitoring period.

3.4 Algae and Nitrogen to Phosphorus Ratio (N:P)
Several studies have evaluated the “total nitrogen to total phosphorus ratios” in Lake Merced. Based on water quality data 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 a slight decrease in algal biomass and TKN and a slight increase in 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).

The ratio of TIN to Total Inorganic phosphorous (80% of Total P), for Lake Merced is 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, while a ratio above 15 would indicate that phosphorus is the limiting nutrient.

This report uses the ratio of bioavailable total nitrogen to bioavailable total phosphorous as described above to calculating nitrogen to phosphorous ratios. Based on this approach Lake Merced is nitrogen limited.

3.5 Total Coliform and Escherichia coli (E. coli)
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. Results indicated slight decreases in total coliform and E. coli (Table 1).

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 110, 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 13 years, TSI has ranged from about 50 to 75 without a significant decreasing or increasing trend. Between 2010 and 2012, TSI has remained well above 50 indicating that the Lake Merced remains highly productive.

3.7 Measure of Hydrogen Ions (pH)
Results of water quality monitoring at Lake Merced from 2010 to 2012 indicated statistically similar values for pH compared to historical findings. 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. Figure 7 shows that pH has ranged between 6.5 and 9.0 over the 15 year monitoring period. Additionally, as shown on Table 1, the average pH has remained at 8.1, which is below the fresh water criteria of 8.5.

3.8 Lake Levels
Lake Merced water levels have fluctuated significantly since 1997 as shown on Figure 8. However, since 2006, Lake levels have 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, but have since decreased slightly due to
below average precipitation for 2012. Recorded Lake levels for 2012 ranged from 5-6 feet city datum, however no measurements were taken between January and September 2012 due to construction activities related to seismic upgrades at the Lake Merced Pump Station. Following completion of construction activities in September 2012, daily Lake level recording have resumed at the Lake Merced Pump Station.

4.0 CONCLUSIONS
Overall, Lake Merced water quality has remained relatively constant from 1997 through 2012. Dissolved oxygen levels are affected by periods of weak stratification, but DO levels in the upper 5 feet of the lake continue to remain above the cold and warm water quality objectives. The increasing trend in Secchi depth continued over the past year and the Lake continues to be strongly nitrogen-limited. Coliform levels remained below the regulatory guidelines and the TSI continued to indicate a highly productive Lake. Average pH levels remained below the fresh water criteria and have never exceeded 9.0.

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


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<td>1797</td>
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<td>Surface</td>
<td>Feet</td>
<td>1.81</td>
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<td>Surface</td>
<td>mg/L</td>
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<td>0.069</td>
<td>0.002</td>
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<td>5</td>
<td>mg/L</td>
<td>0.090</td>
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<td>mg/L</td>
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<td>15</td>
<td>mg/L</td>
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<td>0.086</td>
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<td>0</td>
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<td>Nitrogen to Phosphorous Ratio (N:P)</td>
<td>Surface</td>
<td>mg/l</td>
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<td>0.645</td>
<td>0.062</td>
<td>0.385</td>
<td>0.039</td>
<td>3.82</td>
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Note: Samples summarized above were collected at the South Lake, Pump Station sampling location.

mg/l = milligrams per liter
ug/l = micrograms per liter
Figure 1 – Lake Merced Sampling Points
Figure 2 - Dissolved Oxygen, South Lake Pump Station

Surface
- 5 Ft.
- 10 Ft.
- 15 Ft.
7 mg/L - Water Quality Objective for cold water habitat
5 mg/L - Water quality objective for warm water habitat
Figure 3 - Secchi Depth, South Lake Pump Station

Secchi Depth

Trend Line
Figure 4(a) - Algae Concentration and Nutrient Information, South Lake Pump Station

Algae (ug/L)

Total P (mg/l)

Total N (mg/l)

Algae

Total P

Total N

25-Jan-00  25-Jan-01  26-Jan-02  27-Jan-03  28-Jan-04  28-Jan-05  29-Jan-06  30-Jan-07  31-Jan-08  31-Jan-09  1-Feb-10  2-Feb-11  3-Feb-12  3-Feb-13

0  500  1000  1500  2000  2500  3000  3500  4000  4500  5000
Figure 4(b) - Algae Concentration and Nutrient Information, South Lake Pump Station

- Algae Concentration
- Nutrient Information

- N:P Ratio Above P Limited; Below N Limited
- Algae
Figure 5 - Coliform, South Lake Pump Station

- Total Coliform (mpn)
- E. Coli (mpn)
- CDPH Threshold for Recreational Waters
Figure 6 - Secchi and Chlorophyll-a, South Pump Station
Figure 7 - pH, South Lake Pump Station

Surface
- - 5 Ft
- - 10 Ft
- - 15 Ft
Equilibrium with carbon dioxide in atmosphere
Figure 8 - Water Surface Elevations: 1997-2012, South Lake

Water Surface Elevation (ASCE datum) vs. Volume of Lake Additions (AF)

Water Surface Elevation
Lake Addition (acre-feet)

Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09 Jan-10 Jan-11 Jan-12 Jan-13

-1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8

0 100 200 300 400 500 600 700 800

Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09 Jan-10 Jan-11 Jan-12 Jan-13