

**Preliminary
Water Quality Screening Results**

**Lake Merced
Pilot Stormwater Enhancement Project**



A Supplemental Environmental Project submitted to
the California Regional Water Quality Control Board, San Francisco Bay Region
by the North San Mateo County Sanitation District.

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EXECUTIVE SUMMARY

The North San Mateo County Sanitation District (NSMCSD), a subsidiary of the City of Daly City, and the San Francisco Public Utilities Commission (SFPUC) have established a collaborative effort referred to as the Pilot Stormwater Enhancement Project. The pilot project is assessing the feasibility of diverting treated stormwater runoff from the Vista Grande drainage basin in Daly City into Lake Merced in San Francisco. The primary goal of this phase of the project was to determine whether the intentional introduction of limited volumes of Vista Grande stormwater (about 0.1 to 3.6 million liters per storm event) increased pathogenic human health risk during recreation, based on concentrations of bacterial indicators in South Lake Merced. The stormwater runoff was treated by a Continuous Deflection System (CDS) and a riparian buffer before discharge to the lake. Part of this effort comprises a Supplemental Environmental Project conducted by the NSMCSD.

Bacteriological and chemical monitoring data were collected from South Lake Merced following rainstorms over a two-year period. Data from bacteriological analyses of lake water samples collected following six storms with diversion and three background storms without diversion were examined for statistically significant ($P \leq 0.05$) differences using t-tests. Analyses of diversion event data did not show significant differences in total coliform or *E. coli* concentrations between six sampling stations close to the treated stormwater discharge point and a background station.

The analyses also indicated that the diversions did not significantly increase concentrations of *E. coli* in South Lake Merced. The analyses did show significant increases in total coliform concentrations in the lake following diversions. However, the study data suggest that the higher total coliform concentrations were associated with sources other than the diversion, such as local stormwater runoff from the surrounding watershed washing in soils and wildlife wastes. Human pathogens are generally not associated with these sources. Following the diversions, concentrations of the three bacterial indicators monitored during this study (total coliform, *E. coli* and enterococcus) met single sample water quality criteria for full body contact recreation. These criteria are very conservative given that full body water contact recreation is prohibited at Lake Merced and was not observed during this study. Thus the study results suggest that the higher total coliform concentrations with diversions are not associated with increased human health risk. Other study findings include:

- CDS effluent concentrations of bacterial indicators and metals were generally several orders of magnitude greater than the concentrations found in South Lake Merced. This suggests that the combination of treatment by the riparian buffer and dilution and bacterial die-off in the lake effectively reduced bacterial concentrations.
- The results of chemical analyses of surface soil samples collected from the riparian buffer suggest that metals present in the Vista Grande stormwater runoff did not accumulate in the riparian buffer soils.
- Concentrations of nitrate, TSS and TDS were not effective indicators of fecal contamination in South Lake Merced following diversion of stormwater runoff.

Meeting overall Pilot Stormwater Enhancement Project goals with respect to raising water levels in Lake Merced would necessitate increasing the volume of Vista Grande stormwater runoff diverted to the lake. If the diversion volume is increased, Water Board staff would likely request additional water quality monitoring to continue testing for water quality impacts in the lake. The

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NSMCSD and SFPUC may wish to increase the diversion volume and perform additional monitoring during the 2005/06 wet season. The monitoring design could address filling some current data gaps in the project and reducing uncertainty in some statistical analyses. Additional monitoring could also help determine an approximate diversion volume threshold for negative impacts to lake water quality. Understanding this threshold would inform project planning, including evaluating future options for managing the diverted stormwater.

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Preliminary Water Quality Screening Results

Lake Merced Pilot Stormwater Enhancement Project

1.0 INTRODUCTION

The North San Mateo County Sanitation District (NSMCSD), a subsidiary of the City of Daly City, and the San Francisco Public Utilities Commission (SFPUC) are working to address a number of resource management issues related to Lake Merced. A Memorandum of Understanding between the two parties dated November 26, 2001 established a collaborative effort referred to as the Pilot Stormwater Enhancement Project. The pilot project is assessing the feasibility of diverting treated stormwater runoff from the Vista Grande drainage basin in Daly City into South Lake Merced. Objectives include treating stormwater to remove trash and other pollutants, increasing the water level of the lake and potentially alleviating occasional flooding in the vicinity of South Lake Merced during large precipitation events. Part of this effort comprises a Supplemental Environmental Project conducted by the NSMCSD (2003).

Urban stormwater runoff may contain chemical and biological pollutants associated with adverse environmental and public health effects, trash and other debris, and nutrients that can affect the trophic status of a water body. For example, prior investigations have revealed elevated levels of indicator bacteria in runoff from the Vista Grande drainage basin.¹ The NSMCSD and SFPUC therefore installed facilities to treat the Vista Grande drainage stormwater runoff before discharge into South Lake Merced.

During Phase I of the Pilot Stormwater Enhancement Project, two Continuous Deflection System (CDS) structural stormwater treatment units (designed to remove waterborne trash and large debris) were installed adjacent to the Vista Grande canal, near the southwestern shoreline of South Lake Merced.² During the 2002/03 wet season, stormwater flows up to 10 cubic feet per second were diverted to the CDS, treated, tested, and then returned to the Vista Grande canal (stormwater runoff was not discharged to Lake Merced during this phase of the project).

Phase II of the pilot project initiated diversion of Vista Grande stormwater runoff into South Lake Merced on a pilot basis. Stormwater treatment was expanded using a riparian buffer along the southwestern shoreline of South Lake Merced (Figure 1). The primary goal of this phase of the project was to determine whether the intentional introduction of limited volumes of treated Vista Grande stormwater (about 0.1 to 3.6 million liters per storm event) increased pathogenic human health risk during recreation, based on concentrations of bacterial indicators in South Lake Merced. To meet this objective, the NSMCSD and SFPUC collaboratively prepared a Preliminary Water Quality Screening Plan (PWQSP) that details collection and analysis of water samples from South Lake Merced following storms (NSMCSD and SFPUC, 2004a).³

¹Despite numerous investigations, Daly City has been unable to locate the source of the bacteria.

²The Vista Grande canal is an open channel that conveys stormwater runoff from the Vista Grande drainage basin. A portion of the canal runs parallel to the southwestern shoreline of South Lake Merced.

³The PWQSP, which detailed activities during the 2003/04 wet season, was approved by California Regional Water Quality Control Board, San Francisco Bay Region (Water Board) staff in a February 5, 2004 e-mail. A June 3, 2004 letter requested an extension of the pilot program into the 2004/05 wet season and a Water Board letter dated August 18, 2004 approved the extension.

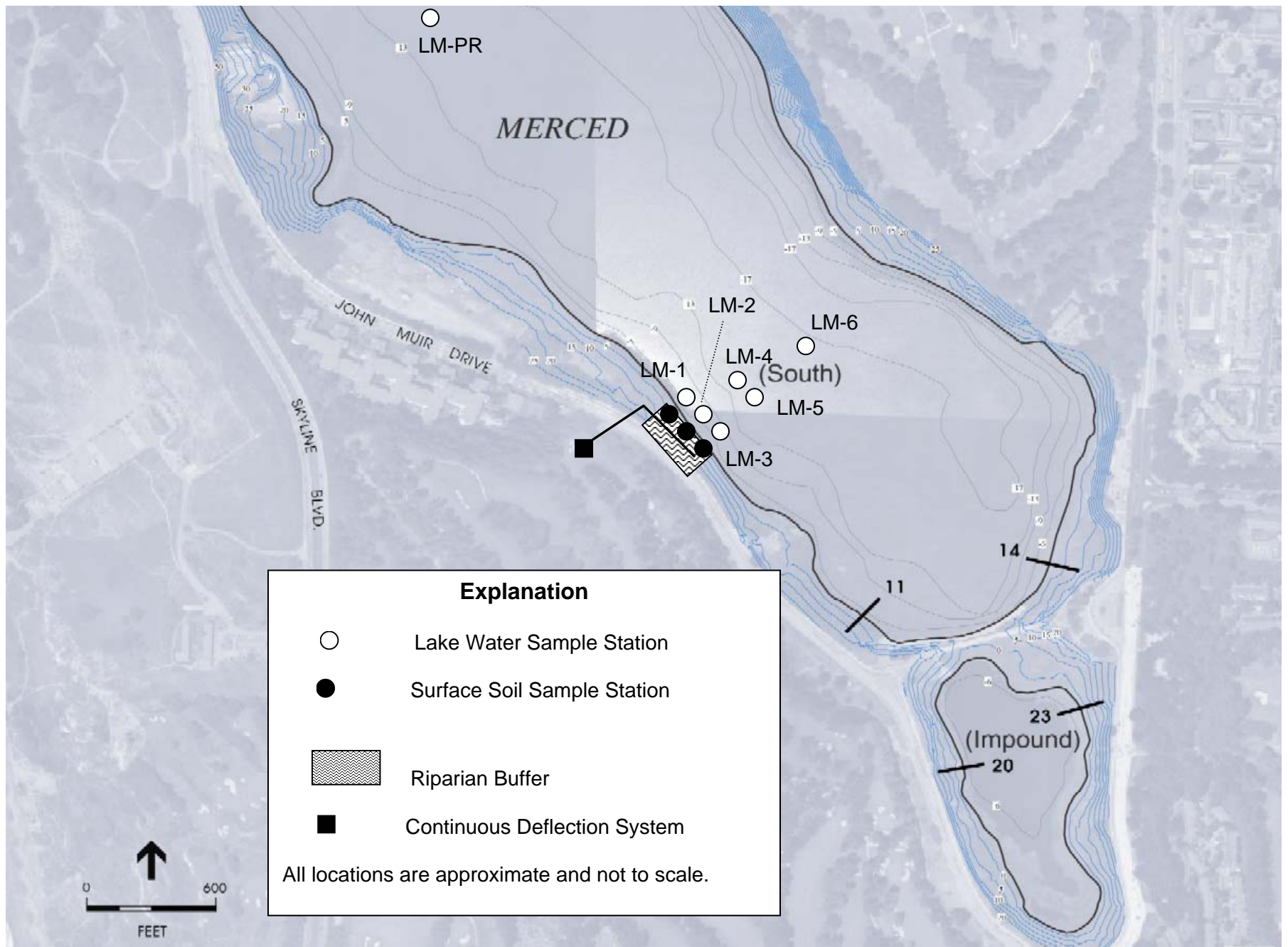


Figure 1. Approximate locations of stormwater treatment area and sample stations.

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The general strategy outlined in the PWQSP included:

- Collecting water samples from South Lake Merced following storm events with pilot diversions of treated stormwater runoff to the lake. Comparing bacteriological concentrations at sampling stations close to the treated stormwater discharge location to a “background” station much farther from the stormwater discharge area.
- Comparing bacterial indicator levels in lake samples collected following storms with diversion to levels following “background” storms without diversion, to determine whether the diversions have an incremental impact on the lake’s bacteriological water quality (i.e., beyond the impact of other runoff entering the lake during storms).

This report documents the results of implementing the PWQSP during the 2003/04 and 2004/05 wet seasons.⁴

2.0 METHODS

2.1 Lake Water Sampling

SFPUC field staff collected grab surface water samples from South Lake Merced following selected 2003/04 and 2004/05 wet season storm events. The majority of sampling episodes were performed after diversion of varying volumes of treated Vista Grande stormwater runoff to the lake. Stormwater from the Vista Grande drainage basin was diverted to the CDS and then conveyed to the riparian buffer, which ranges from 32 to 55 meters in width (average of 46 meters). Vegetation in the buffer includes California blackberry (*Rubus ursinus*), swamp knotweed (*Polygonum amphibium*), stinging nettle (*Urtica dioica*) and, in the shallow water, California bulrush (*Scirpus californica*). The riparian buffer soil is typical of the surrounding area and consists of sandy loam, sand, and loamy sand. Stormwater was discharged to the buffer via a 91-meter long, 46-centimeter diameter PVC pipe containing 6.4-centimeter diameter perforations spaced evenly at 0.76-meter intervals along the entire length of the pipe. Appendix A contains photographs of the riparian buffer area.

Samples were collected from South Lake Merced approximately 1 to 3 days after each diversion was initiated. In addition, some lake samples were collected following “background” storms that did not include diversion of stormwater runoff to South Lake Merced. These lake samples were collected the day after each background storm ended.

During each sampling episode, SFPUC staff collected lake water samples at seven sample stations. Stations LM-1 through LM-6 were in the vicinity of the riparian buffer, ranging from the shoreline to about meters <check with SFPUC> offshore. Station LM-PR was intended to provide background ambient water quality data in the lake and therefore located at a greater distance (approximately meters) from the stormwater discharge area (Figure 1). A field duplicate water sample was collected during most sampling episodes.⁵ Dissolved oxygen, pH, temperature and conductivity were also measured *in-situ* at each sampling location using field instruments. In addition, a vertical temperature profile was collected at each sampling location to gather data on potential thermal stratification of the lake at the time of sampling.

⁴NSMCSD and SFPUC (2004b) previously completed a status report documenting the status of the project following the 2003/04 wet season.

⁵A field duplicate was not collected during the December 9, 2004 sample event.

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2.2 CDS Effluent Sampling

Flow rates and duration through the CDS were recorded⁶ and grab water samples of CDS effluent were collected (station LM-CDS). CDS effluent samples were collected approximately one hour after each diversion event was initiated. Dissolved oxygen, pH, temperature and conductivity were also measured in the effluent using field instruments.

2.3 Riparian Buffer Soil Sampling

SFPUC field staff collected surface soil samples from the riparian buffer to help determine whether metals present in the diverted stormwater had accumulated in the riparian buffer soils. Two episodes of soil sampling were performed at three locations (Figure 1). The first episode was performed before any diversion of stormwater to South Lake Merced and the second episode took place after all the diversions were complete. The results of the two episodes were compared to help assess whether metals had accumulated in the buffer soils.

2.4 Laboratory Analysis

SFPUC's water quality laboratory analyzed each lake sample collected during the 2003/04 wet season for the following bacteriological and chemical parameters:

- Bacteriological indicators - total coliform, *E. coli*, and enterococcus.
- Metals - chromium, copper, nickel, lead, and zinc.⁷
- Nutrients - ammonia, nitrite, nitrate, total Kjeldahl nitrogen (TKN), phosphorus and ortho-phosphate.
- Conventional water chemistry analytes - alkalinity, hardness, total dissolved solids (TDS) and total suspended solids (TSS).

Lake samples collected during the 2004/05 wet season were analyzed for the above bacteriological indicators only.

SFPUC's water quality laboratory analyzed each CDS effluent samples for the following bacteriological and chemical parameters:

- Bacteriological indicators - total coliform, *E. coli*, and enterococcus.
- Metals - seventeen metals identified in the "CAM 17" list in the California Code of Regulations.
- Nutrients - ammonia, nitrite, nitrate, total Kjeldahl nitrogen (TKN), phosphorus and ortho-phosphate.
- Conventional water chemistry analytes - alkalinity, hardness, total dissolved solids (TDS) and total suspended solids (TSS).
- Total petroleum hydrocarbons (TPH).⁸

Lake and CDS effluent samples undergoing bacteriological assays were serially diluted in sterile buffered water (APHA, 1998) and replicate 100 mL portions were mixed with Colisure media (IDEXX Laboratories Inc., Westbrook, ME, USA) for the detection of total coliform and *E. coli* or Enterolert media (IDEXX) for the detection of enterococcus. Mixtures were transferred to

⁶Flow rates and volume were not available for the October 25-26, 2004 storm event.

⁷Metals were not analyzed for in a lake water sample collected on March 27, 2004.

⁸TPH was analyzed for in the March 25, 2004 CDS effluent sample only.

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IDEXX enumeration vessels (i.e., QuantiTray 2000) and incubated at 35°C for 24-48 hours (Colisure) or 41°C for 22-24 hours (Enterolert). Most Probable Number (MPN) of bacteria were determined by enumerating positive wells in QuantiTrays by visual inspection, including examination under 365 nm ultraviolet light, per manufacturer's instructions. Non-bacteriological analyses of lake and CDS effluent samples were performed in accordance with standard methods (APHA, 1998).

Soil samples collected from the riparian buffer were analyzed for the following metals: silver, arsenic, cadmium, chromium, copper and lead.⁹ <SFPUC - chemical analysis methods for soil samples and which lab?>

2.5 Recreational Observations

Beginning December 27, 2004, SFPUC field staff recorded observations regarding recreational activities in South Lake Merced and its vicinity. Observations recorded included numbers of people recreating, approximate locations, and the types of recreational activities. Appendix B contains forms completed by SFPUC staff documenting the observations.

2.6 Data Reporting and Analyses

The results of lake water sample and CDS effluent bacteriological assays are reported as MPN of total coliform, *E. coli* and enterococcus per 100 mL. These data were also log-transformed and average bacteriological values are reported as the geometric mean (\log_{10} MPN/100 mL) presented with their corresponding 95% confidence limits. Some bacteriological data were examined for statistically significant ($P < 0.05$) differences using t-tests.

3.0 RESULTS

3.1 Bacteriological Assays of Lake Water Samples

The primary goal of this project was to determine whether the intentional introduction of limited volumes of treated Vista Grande stormwater increased pathogenic human health risk during recreation, based on concentrations of bacterial indicators in South Lake Merced. To meet this objective, two hypotheses were tested:

- H_0 : following storm events with diversion of treated stormwater runoff to South Lake Merced, there is no difference between bacteriological concentrations at each of the lake sampling stations near the treated stormwater discharge location (LM-1 through LM-6) and a "background" sampling station farther from the stormwater discharge area (LM-PR).
- H_1 : following storm events, there is no difference between bacteriological concentrations at each South Lake Merced sampling station when treated stormwater runoff is diverted to the lake and when treated stormwater runoff is not diverted to the lake.

Confirmation of these two hypotheses would support the premise that diverting treated stormwater runoff into South Lake Merced does not impact bacteriologic water quality in the lake.

⁹The soil samples collected during the first sampling episode were also analyzed for nickel and zinc. Samples from the second episode were also analyzed for mercury, selenium and iron.

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Bacteriological data were collected following eleven storm events (Table 1), eight with diversion of treated stormwater to South Lake Merced (Appendix D presents the flow rates of the CDS discharge during diversions). However, during two of the eight diversion events (storm numbers 3 and 7 on Table 1), the Vista Grande Canal overflowed directly into South Lake Merced in the vicinity of sample stations LM-1, LM-2 and LM-3, likely significantly increasing bacterial concentrations in the lake. Conditions in South Lake Merced during canal overflows are not appropriate for testing the above hypotheses, since the overflows appear to overwhelm water quality in the lake. Data associated with overflow events were therefore excluded from the statistical testing.

Table 1. Overview of monitored storm events.

Storm Number	Lake Sampling Date	Volume Diverted (liters)	Comments
1	2/04/04	0	Background Storm No.1
2	2/19/04	0	Background Storm No.2
3	2/25/04	1,071,500	The Vista Grande Canal overflowed directly to South Lake Merced and combined sewer overflows entered the lake.
	3/03/04	0	Follow-up sampling to 2/25/04 sampling.
4	3/27/04	117,300	
5	10/27/04	Not available	Diversion flow rate and volume not available for this storm event.
6	12/09/04	109,200	
7	12/29/04	3,581,800	The Vista Grande Canal overflowed directly to South Lake Merced.
	1/05/05	0	Follow-up sampling to 12/29/04 sampling.
8	1/10/05	3,249,000	
9	1/27/05	0	Background Storm No.3
10	2/17/05	2,653,900	
11	3/24/05	563,700	

Tables 2 and 3 summarize the results of the bacteriological assays of the lake samples (Table C-1 in Appendix C contains individual sample results). Statistical analyses were performed to test the above hypotheses using log-transformed¹⁰ concentration data on two of the three bacterial indicators monitored during this study (total coliform and *E.coli*).¹¹ Bacteriological data were examined for statistically significant ($P \leq 0.05$) differences using t-tests (SPSS for Windows Release 7.0).¹² H_0 was tested as follows: for each diversion event, data from each of the lake sampling stations near the treated stormwater discharge location (LM-1 through LM-6) were individually compared to data from the background station (LM-PR). To test H_1 , individual comparisons were made using data from each lake sample station. For each station, data collected following storm events with diversion were compared to data collected following background storm events without diversion. Appendix E contains summaries of the statistical test results.

¹⁰The log-transformed data generally conformed to the Normal (Gaussian) distribution.

¹¹Statistical analyses evaluating enterococcus data were not performed due to sparse data (see Section 3.1.3).

¹²Non-detect results were assumed to have a value equal to the detection limit during statistical calculations.

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Table 2. Geometric mean concentrations (\log_{10} MPN/100 mL) of total coliform in South Lake Merced following storm events with and without stormwater diversion.

Sample Station	Diversion?	n	\log_{10} total coliform (MPN/100 mL) ¹	95% Confidence Interval for Mean	
				Lower Bound	Upper Bound
LM-1	Yes	6	3.3 (1,928)	2.9	3.6
	No	3	2.7 (497)	2.2	3.2
LM-2	Yes	6	3.3 (1,950)	3.0	3.6
	No	3	2.6 (437)	2.3	3.0
LM-3	Yes	6	3.3 (1,980)	3.1	3.5
	No	3	2.7 (450)	2.2	3.1
LM-4	Yes	6	3.1 (1,359)	2.8	3.4
	No	3	2.6 (377)	2.3	2.9
LM-5	Yes	6	3.2 (1,567)	2.8	3.5
	No	3	2.7 (486)	1.8	3.6
LM-6	Yes	6	3.1 (1,303)	2.8	3.5
	No	3	2.6 (372)	2.4	2.7
LM-PR	Yes	6	3.1 (1,396)	2.9	3.4
	No	3	2.7 (479)	2.1	3.2

¹Base ten mean concentrations in parentheses.

Table 3. Geometric mean concentrations (\log_{10} MPN/100 mL) of *E.coli* in South Lake Merced following storm events with and without stormwater diversion.

Sample Station	Diversion?	n	\log_{10} total coliform (MPN/100 mL) ¹	95% Confidence Interval for Mean	
				Lower Bound	Upper Bound
LM-1	Yes	6	1.7 (52)	1.4	2.0
	No	3	1.5 (31)	0.3	2.7
LM-2	Yes	6	1.7 (55)	1.1	2.4
	No	3	1.6 (40)	0.7	2.5
LM-3	Yes	6	2.0 (98)	1.7	2.3
	No	3	1.6 (43)	0.8	2.5
LM-4	Yes	6	1.4 (27)	1.0	1.9
	No	3	1.6 (43)	0.8	2.5
LM-5	Yes	6	1.9 (72)	1.2	2.5
	No	3	1.3 (22)	-0.1	2.8
LM-6	Yes	6	1.6 (41)	1.1	2.1
	No	3	1.5 (34)	0.3	2.8
LM-PR	Yes	6	1.8 (60)	1.3	2.3
	No	3	1.6 (42)	0.3	3.0

¹Base ten mean concentrations in parentheses.

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3.1.1 Total Coliform

H₀: T-tests did not show significant differences in total coliform concentrations following diversion events between each of the six sampling stations near the treated stormwater discharge point (LM-1 through LM-6) and the background station (LM-PR).

H₁: T-tests showed significant differences in total coliform concentrations at sample stations LM-1 through LM-4, LM-6 and LM-PR between diversion events and background storm events. Significant differences in total coliform concentrations were not found for sample station LM-5. Geometric means at each sample station were higher following diversion events than background storm events (Table 2).

3.1.2 *E. Coli*

H₀: T-tests did not show significant differences in *E. coli* concentrations following diversion events between each of the six sampling stations near the treated stormwater discharge point (LM-1 through LM-6) and the background station (LM-PR).

H₁: T-tests did not show significant differences in *E. coli* concentrations at each sample station (LM-1 through LM-6 and LM-PR) between diversion events and background storm events.

3.1.3 Enterococcus

Statistical analyses evaluating enterococcus data were not performed because this indicator was detected in less than 25% of the lake samples collected during this study (Table C-1, Appendix C). In addition, approximately half of these detections were in samples collected following the two storm events with canal overflow. Detection limits for enterococcus also varied, further confounding attempts to quantitatively analyze these data. With the exception of samples collected following canal overflow, most detections of enterococcus were at the low concentration of 10 MPN/100 mL.

3.2 Chemical Analyses of Lake Water Samples and Field Instrument Data

Table 4 summarizes the results of chemical analyses of lake water samples for metals. Table 5 summarizes nutrient and conventional water chemistry results. The tables in Appendix F summarize the results of *in-situ* measurements of depth, temperature, pH, conductivity, and dissolved oxygen in South Lake Merced. Appendix F also contains temperature and dissolved oxygen depth profiles.

3.3 CDS Effluent Analysis

Table C-1 (Appendix C) summarizes the results of chemical analyses of CDS effluent samples (sample station LM-CDS) for bacteriological indicators. Table 6 summarizes results for metals and Table 7 summarizes results for nutrients, conventional water chemistry and total petroleum hydrocarbons. Table 7 also includes CDS effluent field instrument measurements of dissolved oxygen, pH, temperature and conductivity.

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Table 4. Summary of lake water sample metals analysis results.

Date	Sample Collection Station	Chromium μg/L	Copper μg/L	Nickel μg/L	Lead μg/L	Zinc μg/L
2/4/2004 (No diversion)	LM-PR	0.6	0.3	0.5	1.0	0.7
	LM-1	0.6	0.9	0.5	1.0	0.7
	LM-2	0.6	0.4	0.5	1.0	0.7
	LM-3	0.6	0.4	0.5	1.0	0.7
	LM-4	0.6	0.6	0.5	1.0	0.7
	LM-5	0.6	0.3	0.5	1.0	0.7
	LM-6	0.6	0.3	0.5	1.0	0.7
	LM-1 (FR)	0.6	0.4	0.5	1.0	0.7
2/19/2004 (No diversion)	LM-PR	0.6	0.9	0.5	1.0	3.0
	LM-1	0.6	0.9	0.5	1.0	1.8
	LM-2	0.6	1.1	0.5	1.0	2.0
	LM-3	0.6	0.7	0.5	1.0	2.0
	LM-4	0.6	1.1	0.5	1.0	2.3
	LM-5	0.6	1.1	0.6	1.0	3.1
	LM-6	0.6	0.9	0.6	1.0	2.6
	LM-2 (FR)	0.6	0.6	0.5	1.0	1.8
2/25/2004 (Diversion and canal overflow)	LM-PR	0.6	0.8	0.5	1.0	4.3
	LM-1	1.1	2.4	0.5	1.0	69.6
	LM-2	1.5	2.5	0.5	1.0	8.3
	LM-3	1.2	1.4	0.5	1.0	8.5
	LM-4	0.6	1.0	0.5	1.0	8.4
	LM-5	0.7	0.8	0.5	1.0	3.2
	LM-6	0.8	0.8	0.5	1.0	9.1
	LM-3 (FR)	0.8	1.5	0.5	1.0	10.6

FR - Field Replicate

3.4 Riparian Buffer Soil Sample Analysis

Two episodes of soil sampling were performed at three locations (Figure 1). The sample stations were designated LMS-1, LMS-2, and LMS-3. The first sampling episode was performed on February 6, 2004, before any diversion of treated stormwater to South Lake Merced had occurred. The second episode took place on May 20, 2005, after all of the diversions were complete. Table 8 summarizes the results of the soil sample chemical analyses for metals.

3.5 Recreational Observations

Table 9 summarizes observations recorded by SFPUC field staff regarding recreational activities in South Lake Merced and its vicinity (Appendix B contains completed recreational use forms). The most common recreational activities observed were jogging, walking and rowing. These activities were observed at various times of day and during a variety of weather conditions, including wet conditions. Full body contact recreation (e.g., swimming and wading) is prohibited in Lake Merced and was not observed.

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Table 5. Summary of lake water sample nutrients and conventional water chemistry analysis results.

Date	Sample Station	Alkalinity mg/L	Hardness (CaCO ₃) mg/L	Ammonia-N mg/L	Nitrite-N mg/L	Nitrate mg/L	Phosphorus mg/L	Ortho Phosphate mg/L	TDS mg/L	TKN mg/L	TSS mg/L
2/4/2004 (No diversion)	LM-PR	158	154	0.1	0.02	0.3	0.5	0.3	297	2.4	14
	LM-1	164	156	0.1	0.02	8.3	0.5	0.3	285	NA	12
	LM-2	164	156	0.1	0.02	11.3	0.5	0.3	303	2.3	16
	LM-3	158	154	0.3	0.02	4.5	0.5	0.3	303	4.9	13
	LM-4	158	156	0.2	0.02	4.8	0.5	0.3	277	8.3	13
	LM-5	158	156	0.1	0.02	10.1	0.5	0.3	286	5.5	NA
	LM-6	160	154	0.1	0.02	0.3	0.5	0.3	290	2.2	13
	LM-1 (FR)	160	156	0.5	0.02	0.3	0.5	0.3	283	5.2	16
2/19/2004 (No diversion)	LM-PR	160	156	0.6	0.02	0.3	0.5	0.3	249	1.2	12
	LM-1	160	156	NA	0.02	0.3	0.5	0.3	224	NA	11
	LM-2	160	156	0.2	0.02	0.3	0.5	0.3	237	3.9	11
	LM-3	160	156	0.2	0.02	0.3	0.5	0.3	221	1.7	9
	LM-4	160	156	0.2	0.02	0.3	0.5	0.3	185	3.6	14
	LM-5	160	156	0.2	0.02	0.3	0.5	0.3	224	0.9	10
	LM-6	160	156	0.5	0.02	0.3	0.5	0.3	256	1.8	11
	LM-2 (FR)	160	156	0.3	0.02	0.3	0.5	0.3	252	1	12
2/25/2004 (Diversion and canal overflow)	LM-PR	156	156	3.7	0.02	0.3	0.5	0.3	231	4.8	13
	LM-1	56	80	0.1	0.02	1.4	2.7	0.6	170	NA	13
	LM-2	128	120	2.4	0.02	1.3	0.8	0.3	151	18.1	6
	LM-3	140	128	0.6	0.02	0.8	0.5	0.3	187	12.7	11
	LM-4	152	152	NA	0.02	0.3	0.5	0.3	210	6.7	13
	LM-5	152	152	NA	0.02	0.3	0.5	0.3	167	16.3	11
	LM-6	156	156	NA	0.02	0.3	0.5	0.3	218	2.3	11
	LM-3 (FR)	104	88	0.3	0.02	0.3	0.5	0.3	135	11	10
3/27/2004 (Diversion)	LM-PR	158	154	0.05	0.02	0.3	NA	0.3	344	1.6	9
	LM-1	158	154	0.11	0.02	0.3	NA	0.3	375	NA	10
	LM-2	158	154	0.07	0.02	0.3	NA	0.3	318	0.6	8
	LM-3	158	154	0.07	0.02	0.3	NA	0.3	319	2.5	12
	LM-4	158	154	0.02	0.02	0.3	NA	0.3	317	1.5	10
	LM-5	158	154	0.10	2.22	0.3	NA	0.3	335	2.3	9
	LM-6	158	154	0.04	0.02	0.3	NA	0.3	361	1.3	10
	LM-? (FR)	158	154	0.05	1.36	0.3	NA	0.3	272	2	11

Notes:
FR – Field Replicate
NA – Not Available

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Table 8. Summary of riparian buffer soil sample metals analysis results.

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Table 9. Recreational activities at South Lake Merced and vicinity.

Date	Time	Weather	Observations
12/27/2004	9:00 am - 12:00 pm	Clear, sunny, mild temp	Many joggers and walkers present; 5 single person rowers present in early morning
1/7/2005	9:00 am - 10:30 am	Rainy, cool	No recreational activity
1/27/2005	9:00 am - 11:00 am	Sunny, calm, cool	2 single seat rowers; 2 fishermen on pier; several walkers/joggers; people "hanging out"
1/28/2005	1:00 pm - 3:30 pm	Breezy, cloudy, rain early in day	Shooting range open, ~3 shooters; walkers/joggers on trail >20 people; 2 people bird feeding; filming a movie, crew ~10 people; rowing crews, 15 people
2/14/2005	2:30 pm - 5:00 pm	Light to medium rain, cool, low wind	No pedestrians on trail; 2 team crew boats
2/17/2005	9:00 am - 11:30 am	Partly cloudy, temp upper 50's, windy	1 fisherman at boat house pier; 2 single seat rowers; several joggers/walkers on path (~12)
3/22/2005	2:00 pm - 4:15 pm	Rainy, breezy, cool	2 hardcore joggers; no boats
3/24/2005	9:30 am - 12:00 pm	Sunny, mild	2 skullers; lots of joggers/walkers

4.0 DISCUSSION

4.1 Bacteriological Analyses of Lake Water

The primary goal of this study was to determine whether the intentional introduction of limited volumes of treated Vista Grande stormwater increased pathogenic human health risk during recreation, based on concentrations of bacterial indicators in South Lake Merced. Data from bacteriological analyses of lake water samples collected following six storms with diversion and three background storms without diversion were statistically analyzed.¹³ Analyses of diversion event data did not show significant differences in total coliform or *E. coli* concentrations between six sampling stations close to the treated stormwater discharge point (LM-1 through LM-6) and a background station (LM-PR).

Statistical analyses also did not show significant differences in *E. coli* concentrations at each sample station (LM-1 through LM-6 and LM-PR) between diversion events and background storm events. The analyses did show significant differences in total coliform concentrations at most sample stations between diversion events and background storm events. Geometric means at each sample station were higher following diversion events than background storm events (Table 2). However, the higher total coliform concentrations were likely associated with

¹³The results of the statistical analyses should be considered preliminary due to the small number of samples collected to-date.

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sources other than the diversion of Vista Grande stormwater runoff and did not indicate increased human health risk due to pathogens in the lake, based on the following observations:

- Total coliform concentrations at the background station (LM-PR) were significantly higher following diversion events than concentrations at this station following background storms. This suggests that local stormwater runoff entering the lake from the surrounding watershed increased total coliform concentrations in the lake, rather than the intentionally diverted and treated Vista Grande stormwater.
- Average rainfall during storms with diversion (1.76 inches)¹⁴ was greater than average rainfall during background storms (1.02 inches). Thus, a greater volume of local stormwater runoff from the surrounding watershed and associated bacteria entered the lake during diversion storm events than background storms.
- USEPA (2002) recommends the use of *E. coli* or enterococcus rather than total coliform as bacteriological indicators of human health pathogenic risk. Total coliforms occur naturally in the environment and may not be indicative of human pathogens. Based on the *E. coli* and enterococcus lake monitoring results, increased coliform concentrations following diversions were likely due to sources generally not associated with human pathogens (e.g., local stormwater runoff from the surrounding watershed washing in soils and wastes from abundant wildlife, especially birds <SFPUC has documentation on abundant wildlife?>). If the increased levels of total coliform had been associated with human pathogens, *E. Coli* concentrations would likely also have significantly increased following diversion events (they did not). The low enterococcus concentrations in most lake samples (Table C-1, Appendix C) also suggest that total coliform sources were not associated with human pathogens.
- Excepting sample events following storm events with canal overflow, total coliform concentrations met conservative single sample water quality criteria for full body contact recreation in Lake Merced (see Section 4.2).

CDS effluent concentrations of total coliform, *E. coli*, and enterococcus were generally several orders of magnitude greater than the concentrations of these bacterial indicators found in South Lake Merced. Casteel (2005) used data from five of the study diversion events (flows during these events ranged from 500 to 3,000 gallons per minute) to calculate that South Lake Merced levels of total coliform, *E. coli*, and enterococcus were 0-99.4%, 99-99.8% and 99.8-99.97% lower, respectively, than levels in Vista Grande stormwater runoff. While part of these reductions was likely attributable to treatment by the riparian buffer, other contributing factors probably included dilution of diversion waters in South Lake Merced¹⁵ and bacterial die-off in the lake.

4.2 Bacteriological Water Quality Criteria

Bacteriological water quality criteria for Lake Merced are set conservatively using full body water contact standards, even though SFPUC Resolution No. 10,435 prohibits such use of the lake.

¹⁴Based on sum of daily rainfall from the sample date and the three preceding days, using daily rainfall data collected at the Oceanside treatment plant rain gauge in Daly City during the 2003/04 and 2004/05 wet seasons (Appendix G).

¹⁵Based on the volumes of diverted stormwater and the capacity of Lake Merced (2.6 billion liters), complete mixing would result in about 3 to 4 orders of magnitude dilution. It appears unlikely, however, that complete mixing of the diversion and lake waters would occur before the lake samples were collected.

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The water quality objectives for full body contact recreation are derived from epidemiological studies of bathers recreating in surface waters that received bacteriological contamination via wastewater treatment effluent (Stevenson, 1953; Cabelli, 1982; USEPA, 1986 and Wymer and Dufour, 2002). The basis for the objectives is an assumed tolerable gastrointestinal (GI) illness rate of 19 illnesses per 1,000 recreation events in freshwater (USEPA, 1986). The relationship between indicator organism concentration and risk of GI illness assumes that each recreator ingests a constant volume of water. Although no such volumes are directly documented in the regulations, state and federal guidance documents typically estimate volumes ingested of between 50ml and 100ml per recreation event. Table 10 provides a summary of the applicable water quality standards for full body contact recreation in Lake Merced.

Table 10. Water quality criteria for full body contact recreation in Lake Merced.

Indicator Bacteria	Estimate of Central Tendency (MPN/100mL)	Basis	Single Sample Maximum (MPN/100mL)	Basis
Total coliform	240 (median)	Basin Plan (SFBRWQCB, 1995)	10,000	Basin Plan (SFBRWQCB, 1995)
<i>E. coli</i> ¹	<126 (geometric mean)	USEPA and SFPUC criteria for issuing a health advisory for swimming beaches. ²	576	Infrequently used full body contact recreation (upper 95% CL).
Enterococcus ¹	<33 (geometric mean)	USEPA and SFPUC criteria for issuing a health advisory for swimming beaches. ²	151	Infrequently used full body contact recreation (upper 95% CL).

Notes:

¹USEPA, 1986

²Swimming in Lake Merced is prohibited by a SFPUC resolution adopted in 1950.

A recent review of epidemiological studies supports the use of *E. coli* as the currently best available predictor of GI illness for the regulation of recreational water (Wade et al., 2003). However, the applicability of bacterial indicator organisms to predict health risks associated with stormwater runoff has been widely questioned (Noble and Fuhrmann, 2001; Jiang et al., 2001 and Noble et al., 2003). The underlying question is whether it is reasonable to assume that stormwater runoff contains the same pathogens in the same ratios as effluent-impacted surface waters. The only published studies addressing this question investigate health effects associated with human exposure to dry weather urban runoff (Haile et al., 1999).

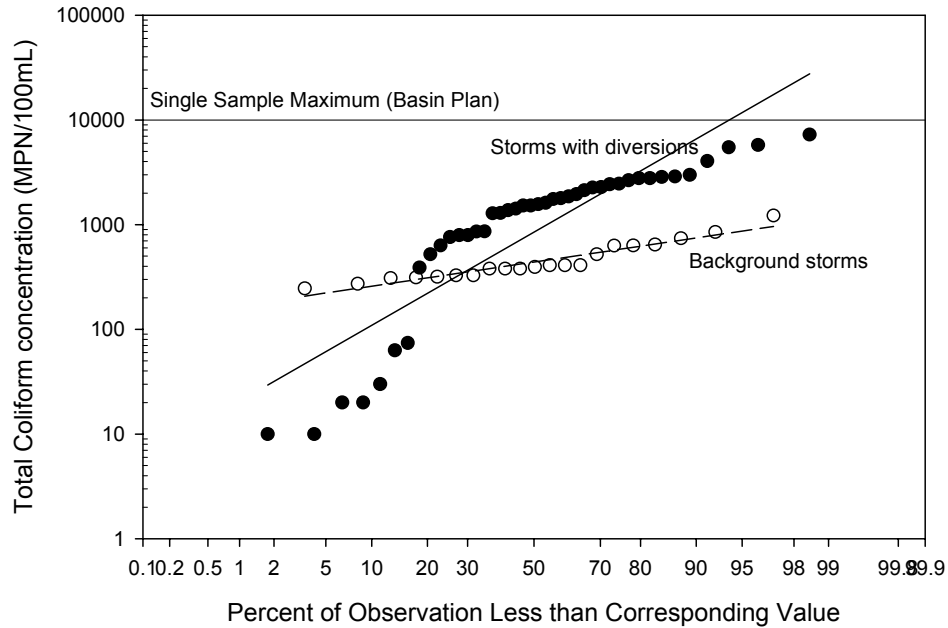
Despite these limitations, bacteriological concentration data from the storms monitored during this study (excluding the two storms with canal overflow into South Lake Merced) were compared to water quality criteria. Because of the inherent high variability of bacterial water quality data, the study data were fit to a lognormal distribution via the Method of Maximum Likelihood (Nash et al, 1979; Olivieri et al, 1999).¹⁶ The resulting distributions were used to estimate the bacteriological concentrations in South Lake Merced following storm events. Probability plots of total coliform, *E. coli* and enterococcus concentrations (Figures 2 through 4) illustrate that bacteria concentrations were well under single sample maximum concentration

¹⁶USEPA recommends the use of a lognormal distribution for environmental data samples (USEPA 1991).

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criteria for full body contact recreation. These criteria are very conservative given that full body water contact recreation is prohibited at Lake Merced and was not observed during this study (see Section 3.5).

Figure 2
Probability Plot of Total Coliform Concentrations
in Lake Merced During Storm Events



4.3 Chemical Analyses of Lake Water

In addition to bacteriological data, this study collected limited data on concentrations of metals, nutrients and conventional water chemistry analytes in lake water samples (Tables 4 and 5). Review of these data suggests that concentrations at sampling stations near to the treated stormwater discharge location (LM-1 through LM-6) were generally similar to concentrations at the background station located farther from the stormwater discharge area (LM-PR). Due to the sparse quantity of data available, statistical analyses were not performed to confirm this finding. Relatively elevated levels of chromium, copper and zinc in samples collected on February 25, 2004 at the three stations closest to the shoreline (LM-1, LM-2 and LM-3) were likely due to overflow of the Vista Grande canal into South Lake Merced.

CDS effluent concentrations of chromium, copper, nickel, lead and zinc (Table 6) were generally several orders of magnitude greater than the concentrations of these metals found in South Lake Merced during this study (Table 4).

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Figure 2. Probability plot of *E. coli* concentrations in Lake Merced during storm events

Figure 3. Probability plot of enterococcus concentrations in Lake Merced during storm events

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In addition to the monitoring performed during this study, SFPUC routinely monitors two locations in South Lake Merced approximately quarterly for nutrients and other general water quality parameters. One location (designated “pistol range”) corresponds approximately to the background sample station in this study (LM-PR) and the other location (designated “pump station”) is approximately 50 yards north of LM-6. SFPUC staff recently analyzed this monitoring data over a time period spanning this pilot study. The analysis indicated that typical trends of higher nutrient concentrations in the summer and lower winter concentrations held true. SFPUC concluded that, based on current and past nutrient concentration trends within the lake, the pilot stormwater diversions during this study have not had a negative impact on overall lake water quality (Largent, 2005, personal communication).

4.4 Lake Stratification and Representative Sampling

South Lake Merced is relatively shallow (i.e., generally less than 20 feet deep). Based on bimonthly ambient multi-level monitoring data collected by the SFPUC, South Lake Merced experiences primarily isothermal conditions with infrequent, weak stratification (EDAW, 2003). During the summer there is a period of slight stratification evident in some profiles, but with current lake elevations it is not sufficiently strong to impede mixing on a seasonal basis. During the winter the lake typically does not stratify at all.

Appendix F presents temperature and dissolved oxygen depth profiles. Temperature varied only slightly with depth. Variations in dissolved oxygen concentrations mainly occurred at deeper offshore locations (LM-PR, LM-4, LM-5 and LM-6) and only at depths near the bottom of the lake. These findings suggest that water quality conditions at the surface of South Lake Merced were generally representative of conditions deeper in the lake. Thus bacteriological and chemical concentrations in the surface samples collected during this study were inferred to represent concentrations deeper in South Lake Merced.

4.5 Riparian Buffer Soil Sample Analysis

SFPUC field staff collected surface soil samples from the riparian buffer to help determine whether metals present in the diverted stormwater runoff had accumulated in the riparian buffer soils. Two episodes of soil sampling were performed at three locations (Figure 1). The first sampling episode was performed before any diversion of stormwater to South Lake Merced had occurred whereas the second episode took place after all the diversions were complete.

Comparison of concentrations of metals (Table 8) collected during both of the sample episodes (silver, arsenic, cadmium, chromium, copper and lead) suggests that accumulation in the riparian buffer soils did not occur. Natural variability appears to account for the observed concentration differences. For example, at locations where metals concentrations were higher in the second episode compared to the first episode (copper at LMS-2 from 8 mg/kg to 30 mg/kg and lead at LMS-2 from 53 mg/kg to 210 mg/kg), decreases in concentrations were observed at other sample stations (copper at LMS-3 from 23 mg/L to 12 mg/L and lead at LMS-1 from 271 mg/L to 157 mg/L).

4.6 Potential Indicators of Fecal Contamination

A recent study suggested that nitrate and conductivity are potential indicators of fecal contamination in the Tomales Bay watershed. This finding is likely dependent on conditions in this relatively rural watershed and not directly applicable to other watersheds, including the urban area investigated during this study. However, this methodology was tested by plotting

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concentrations in South Lake Merced (following diversion of stormwater runoff) of nitrate, TSS and TDS¹⁷ against total coliform and *E. coli* concentrations (Appendix H).¹⁸ Correlations were weak in all cases ($r^2 \leq 0.5$). Thus data from this study suggest that nitrate, TSS and TDS are not effective indicators of fecal contamination in South Lake Merced following diversion of stormwater runoff.

5.0 CONCLUSIONS

Bacteriological and chemical monitoring data were collected from South Lake Merced following rainstorms over a two-year period. Based on data from six monitoring events following storms with intentional diversion of Vista Grande drainage stormwater runoff (treated by a CDS and riparian buffer) to South Lake Merced and three background storms without diversion, the following conclusions were reached:

- The introduction of limited volumes of treated Vista Grande stormwater runoff did not significantly increase concentrations of *E.coli* in South Lake Merced. Significant increases in total coliform concentrations were likely associated with sources other than the intentional stormwater diversion (e.g., local stormwater runoff from the surrounding watershed washing in soils and wildlife wastes).
- Following the diversions, concentrations of the three bacterial indicators monitored during this study (total coliform, *E. coli* and enterococcus) met single sample water quality criteria for full body contact recreation. These criteria are very conservative given that full body water contact recreation is prohibited at Lake Merced and was not observed during this study.
- CDS effluent concentrations of bacterial indicators and metals were generally several orders of magnitude greater than the concentrations found in South Lake Merced. This suggests that the combination of treatment by the riparian buffer and dilution and bacterial die-off in the lake effectively reduced bacterial concentrations.
- The results of chemical analyses of surface soil samples collected from the riparian buffer suggest that metals present in the Vista Grande stormwater runoff did not accumulate in the riparian buffer soils.
- Concentrations of nitrate, TSS and TDS were not effective indicators of fecal contamination in South Lake Merced following diversion of stormwater runoff.

6.0 RECOMMENDATION

Meeting overall Pilot Stormwater Enhancement Project goals with respect to raising water levels in Lake Merced would necessitate increasing the volume of Vista Grande stormwater runoff diverted to the lake. If the diversion volume is increased, Water Board staff would likely request additional water quality monitoring to continue testing for water quality impacts in the lake. The NSMCSD and SFPUC may wish to increase the diversion volume and perform additional

¹⁷Nitrate, TSS and TDS data were only available from two sampling episodes with diversion.

¹⁸Enterococcus was not included in the analysis because this indicator was detected in less than 25% of the samples collected during this study.

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monitoring during the 2005/06 wet season.¹⁹ The monitoring design could address some current data gaps in the project, including allowing for statistically testing possible impacts of parameters other than bacterial indicators (e.g., metals and nutrients). Additional monitoring data might also allow statistical analyses to approximately match diversion and background storm sizes, reducing the uncertainty in comparisons of lake water quality with and without diversions. In addition, the monitoring design could help determine an approximate diversion volume threshold for negative impacts to lake water quality. Understanding this threshold would inform project planning, including evaluating future options for managing the diverted stormwater.

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¹⁹Field staff should continue to perform any future diversion activities in accordance with the operations plan attached to the PWQSP (NSMCSD and SFPUC, 2004a) or a similar operations plan.

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