EXAMINING AN URBAN WATER SOURCE: GROUNDWATER CHARACTERISTICS OF SAN FRANCISCO'S LOBOS CREEK

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The degree

Master of Arts
In
Geography

by

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San Francisco, California

December, 2009

CERTIFICATION OF APPROVAL

I certify that I have read *Examining an Urban Water Source: Groundwater Characteristics of San Francisco's Lobos Creek* by Jeanne Marie Depman, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirements for the degree: Master of Arts in Geography at San Francisco State University.

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EXAMINING AN URBAN WATER SOURCE:
GROUNDWATER CHARACTERISTICS OF SAN FRANCISCO'S LOBOS CREEK

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Lobos Creek is the potable water supply for people living and working in the Presidio of San Francisco, a population approaching 6,000. Its source is a groundwater basin lying predominantly beneath the densely developed Richmond District and is recharged through precipitation, surplus irrigation, and leaking pipes. Nitrates are the most pervasive water quality problem in San Francisco and have historically been reported as a constituent of concern in Lobos Creek. This study employed continuous-monitoring data loggers to examine three water quality parameters (water temperature, specific conductance, and groundwater level) from July 2008 to April 2009 at two upstream seeps where sampling has shown differing levels of nitrates over the years. Nitrogen isotope analysis of water samples was also conducted. Results of the latter indicated a source of nitrate consistent with sewage entering the creek near one of the study sites. Results of continuous monitoring revealed higher-than-expected water temperatures, contrasting water level patterns, and inconclusive specific conductance measurements. These baseline data illuminate conditions and provide context for future studies around nitrate identification and movement in the groundwater basin.

I certify that the Abstract is a correct representation of the content of this thesis.

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Chair, Thesis Committee Date

ACKNOWLEDGEMENTS

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CHAPTER 1: Introduction

Lobos Creek is a modest geographic feature on the landscape of San Francisco, California, yet has been a significant resource to people since early exploration and settlement. Located in the southwest corner of the Presidio, it has served as a drinking water source for Ohlone/Costanoan Native Americans; Spanish, Mexican, and American military personnel; and people currently living and working in the Presidio, of which there are approximately 2,700 and 3,000, respectively (Jody Sanford, Presidio Trust, 7 January 2008, personal communication). Integrity of this water source is a priority to local resource managers and a statute under the Safe Drinking Water Act of 1974. The Presidio became a national park in 1994 when it was transferred from the U.S. Army. Its 603 hectares (1,491 acres) occupy five percent of the land within the city and county of San Francisco. Visitors to the park exceed five million annually (National Park Service 2009) (Figures 1 and 2).

Lobos Creek, like thousands of streams and rivers in urban environments, is subject to the disturbances and pollution that development and concentrated populations generate. Findlay and Taylor (2006, 313) define an urban stream as “a stream where a significant part of the contributing catchment consists of development where the combined area of roofs, roads and paved surfaces results in an impervious surface area characterising greater than 10% of the catchment”. According to Paul and Meyer (2001) many thresholds of degradation in urban streams are associated with an impervious surface cover of 10-20 percent.

Figure 1. Lobos Creek study site.
Source: Hladik and Orlando 2008

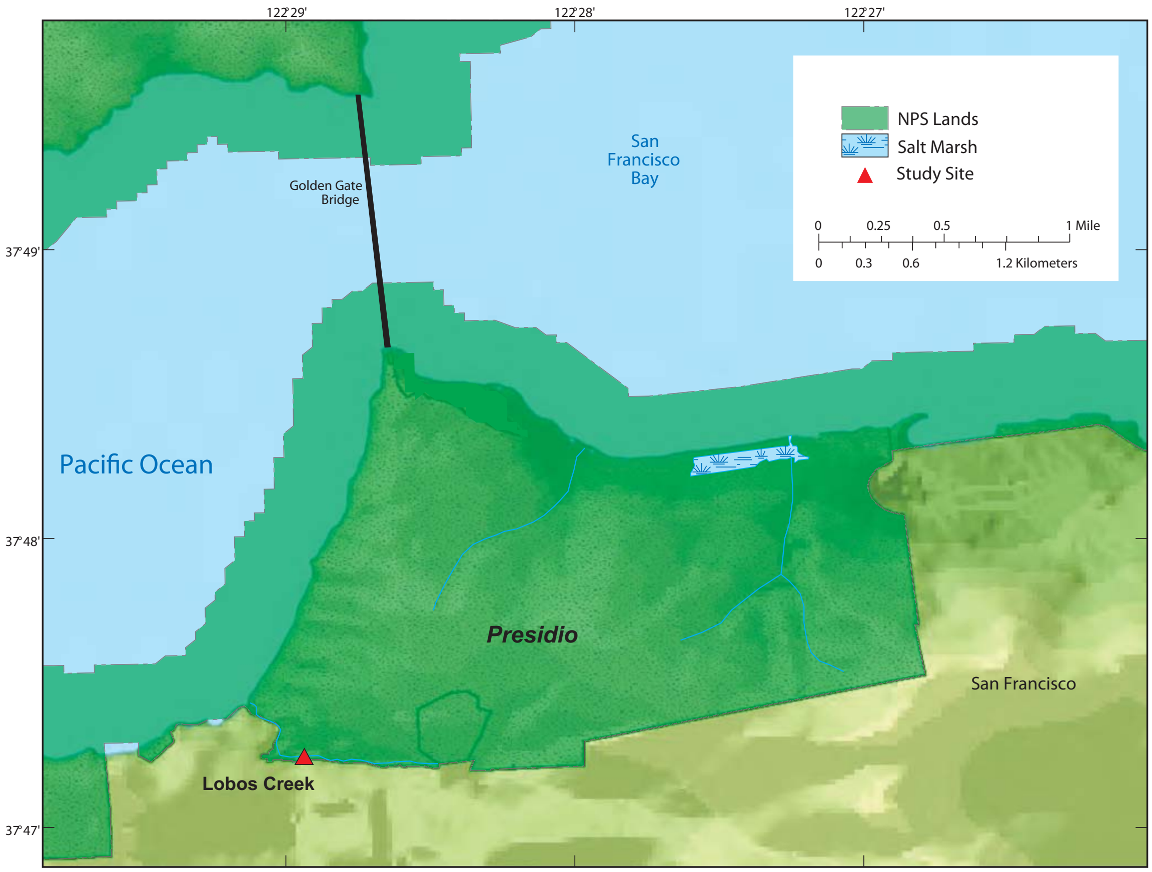


Figure 2. Lobos Creek study site within the Presidio of San Francisco.
Source: Hladik and Orlando 2008

Lobos Creek is a perennial stream that drains a watershed of approximately 8.4 square kilometers in northwest San Francisco. Impervious surface area is greater than 60 percent. Most of the watershed, 85 percent, lies to the south of the Presidio, encompassing much of the densely developed Richmond District (Figure 3).

Urban streams generally exhibit increased loading of nutrients, metals, pesticides, and other contaminants as a result of runoff from urbanized surfaces, municipal and industrial discharges, fertilizer use, and leaking sewer systems (Paul and Meyer 2001). Within acceptable levels, contaminants do not compromise a drinking water supply. Among the constituents, nitrate is likely the most ubiquitous groundwater contaminant in North America (Interstate Technology and Regulatory Council 2000), and elevated levels of nitrates are the most pervasive water quality problem in San Francisco (Phillips, Hamlin and Yates 1993). Nitrates are generally not an adult public health threat. However, ingestion of excess nitrates in drinking water by infants and pregnant women can cause low oxygen levels in the blood, a potentially fatal condition (Nolan et al. 1997). Primary sources of nitrates are sewage and fertilizers which enter a groundwater supply through infiltration and percolation.

The groundwater basin that feeds Lobos Creek lies predominantly beneath the Richmond District. It is the primary source of water for the creek and represents at least 90 percent of flow. Recharge to the basin is from precipitation, irrigation, and leaking storm/sewer and

Figure 3. Lobos Creek watershed outlined in green.

water pipes. According to a study of San Francisco's geohydrology, leaking pipes on the west side of the city account for approximately 34 percent of groundwater recharge (Phillips, Hamlin and Yates 1993).

Monitoring of Lobos Creek's water is implemented through a Water Quality Management Plan administered by the Presidio Trust in accordance with federal and state water quality regulations. A water treatment plant near the mouth of the creek at Baker Beach treats the surface water and distributes it throughout the Presidio.

While nitrates in the drinking water supply for the Presidio have not exceeded the maximum contaminant level (MCL) established by the U.S. Environmental Protection Agency, the source of this constituent warrants attention. Nitrate testing has historically revealed elevated concentrations in some areas of Lobos Creek (Nolte and Associates 1993; Dames & Moore 1994; Kern and Youngkin 1999; National Park Service 2009 unpublished). The source of the nitrates, however, is unknown.

Research Goal and Objectives

This study examines three water quality parameters (water temperature, specific conductance and groundwater level) from July 2008 to April 2009 in two upstream areas of Lobos Creek which have shown differing levels of nitrates over the years. The areas are approximately 150 meters apart and located at the streambank/streambed interface where groundwater emanates from the south bank at seeps.

Questions addressed include:

- Why are these two areas different and what do patterns of these parameters indicate about the nature of the groundwater sources?
- How do precipitation and air temperature influence the parameters?
- How do nitrate and E. coli vary between the two areas, and what does this suggest about potential sources of pollutants?
- What does isotope analysis suggest about potential sources of nitrate?

Scope of the Research

Water temperature and specific conductance are fundamental to a water quality study. Groundwater level, also an important parameter, provides insight to a system's hydrology which can inform conditions susceptible to contamination. Continuous-monitoring data loggers, installed in two areas of Lobos Creek which have shown differing levels of nitrates over the years, are the method by which data for this study are collected. Measurements of water temperature, specific conductance, and groundwater level were taken every 30 minutes from July 2008 to April 2009. This study does not attempt to identify the source of nitrates in Lobos Creek. Rather, it examines basic water quality data, identifies relationships between variables, and reports results. The intent is to illuminate conditions which may lead to identifying the source of nitrates in the creek.

Significance of the Research

Urban watersheds are dynamic, natural systems amongst constructed spaces. Understanding their hydrological processes and water quality conditions are necessary to derive environmental, economic, and social benefits. Lobos Creek is particularly unique due to its value as a potable water supply.

Continuous-monitoring, time-series data are valuable in water quality studies. Diurnal and seasonal trends can be identified, human influences may be detected, and predictions about system behavior can be modeled. This exploratory study in Lobos Creek is believed to be the first to capture continuous data of this nature in upstream areas of the creek. Results of data analysis can inform direction for future studies.

Additionally, this study coincided with testing by the National Park Service (NPS). From October 2008 through May 2009, NPS measured several water quality parameters in four areas of Lobos Creek, two of which were sites where the data for this study were collected. Findings were consistent with previous studies that showed higher levels of nitrates in some areas versus others.

The following chapters include:

- a literature review of
    - » Lobos Creek studies
    - » water temperature, specific conductance, groundwater level
- nitrate, isotope analysis, and coliform bacteria
- Lobos Creek watershed
- methods
- results and discussion
- conclusion

CHAPTER 2: Literature Review

Lobos Creek Studies

Studies of the water supply in the Presidio have examined sources, flow, quality, aquifer volume, demand, distribution, and recycling.

Relatively recent reports that have addressed nitrates as a water quality constituent of concern in Lobos Creek or its groundwater basin include the 1993 U.S. Geological Survey (USGS) assessment of San Francisco groundwater resources, the 1993 Water Supply Evaluation by Nolte and Associates, the 1994 Watershed Sanitary Survey by Dames & Moore, and the 1999 Water Quality Management Plan by the Urban Watershed Project. Additionally, sampling in Lobos Creek for a variety of water quality parameters was conducted by the National Park Service in 2008 and 2009.

In some of the summaries below, locations are referenced by avenues. For most of its course, Lobos Creek flows east to west, perpendicular to avenues which run north/south. A reference to 20th Avenue, for example, is in the creek north of where 20th Avenue ends (Figure 4).

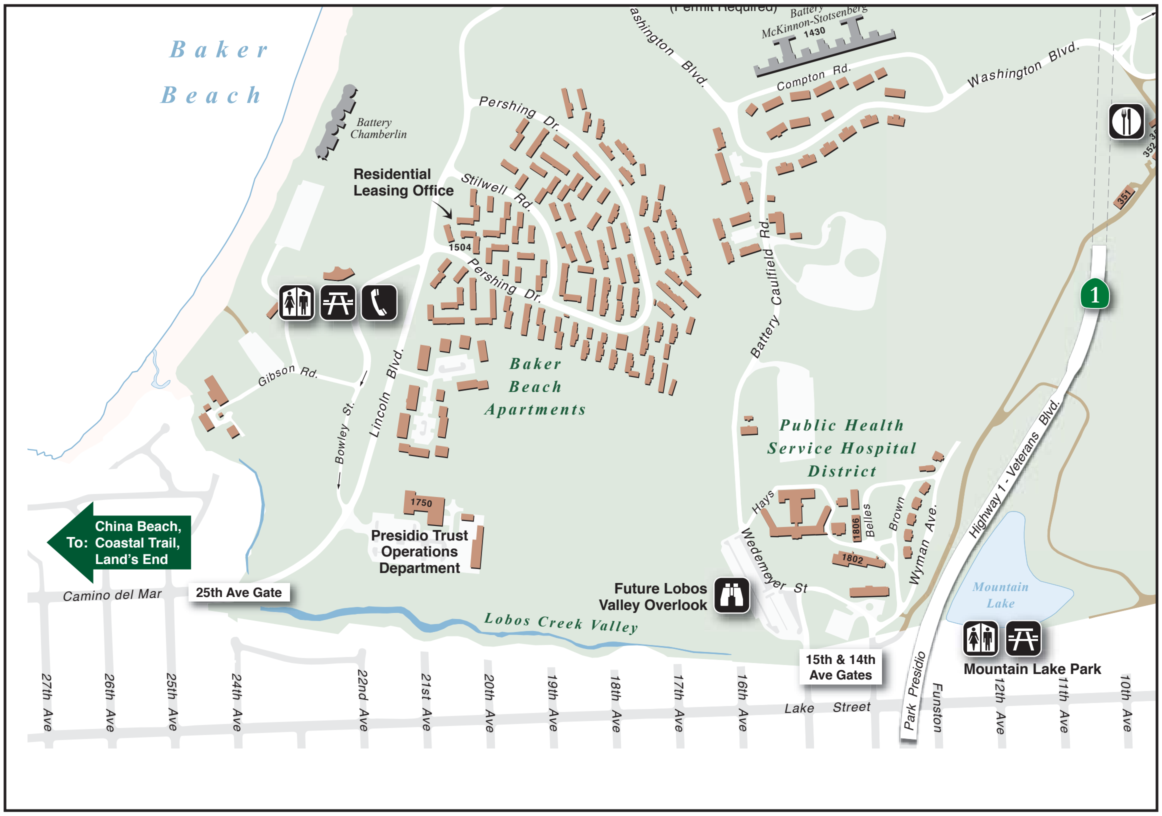

Baker Beach
Battery Chamberlin
Residential Leasing Office
1504
Pershing Dr.
Stilwell Rd.
Washington Blvd.
Battery McKinnon-Stotsenberg
1430
Compton Rd.
Battery Caulfield Rd.
Baker Beach Apartments
Gibson Rd.
Bowley St.
Lincoln Blvd.
Public Health Service Hospital District
1750
Presidio Trust Operations Department
To: China Beach, Coastal Trail, Land's End
Camino del Mar
25th Ave Gate
Future Lobos Valley Overlook
Lobos Creek Valley
Hays
Wedemeyer St
1806
Belles
Brown
Wyman Ave.
1802
15th & 14th Ave Gates
Park Presidio
Funston
Highway 1 - Veterans Blvd.
1
351
Mountain Lake
Mountain Lake Park
Lake Street
27th Ave
26th Ave
25th Ave
24th Ave
22nd Ave
21st Ave
20th Ave
19th Ave
18th Ave
17th Ave
16th Ave
12th Ave
11th Ave
10th Ave

Figure 4

A study by Madison and Brunett (1985) provides context to the following summaries. They examined data from more than 87,000 wells throughout the United States and determined that nitrate-nitrogen (NO3-N) less than 0.2 milligrams per liter (mg/L) was the natural background level and that concentrations greater than 3.0 mg/L could be attributed to anthropogenic effects. Their study is often cited in articles on nitrates in groundwater. Ten mg/L NO3-N is the maximum contaminant level standard set by the U.S. Environmental Protection Agency, pursuant to the Safe Drinking Water Act passed by Congress in 1974. In a temporal perspective, one mg/L corresponds to one minute in two years.

Results from the Nolte and Associates (1993) analysis of Lobos Basin revealed that, for the most part, groundwater fell within regulated limits for primary and secondary standards. However, nitrate was reported as a constituent of concern. Elevated concentrations ranging from 5 to 9.5 mg/L NO3-N were consistent; and 15 mg/L NO3-N was recorded in a monitoring well 500 meters north of the creek.

The Dames & Moore (1994) study reported nitrate contamination and excess levels of total coliform. One likely source was a sewer pipe running beneath Lobos Creek at 17th Avenue. During rain events the pipe became pressurized when full of storm flow and likely leaked sewage. The study indicated that concentrations of nitrates were consistently high yet did not pose a significant threat to water quality. The sewer pipe was repaired in 2003.

Field surveys at Lobos Creek were conducted by the Urban Watershed Project in December 1998 and January 1999 using portable water chemistry meters. Parameters measured were air and water temperature, pH, salinity, conductivity, total dissolved solids, dissolved oxygen, and oxygen saturation. Dissolved oxygen results revealed areas of anoxic groundwater upstream of 18th Avenue. This is significant as it relates to the red flocs bacteria discussion later this paper. Higher total dissolved solids were detected between 18th and 19th Avenue. Nitrate levels were not measured; however, coliform testing indicated significant contamination.

Periodic nitrate sampling from late 2003 to early 2007, primarily in winter and spring, by the Urban Watershed Project showed levels as high as 20.5 mg/L NO3-N on the south side of the creek around 20th Avenue and levels no higher than 4.1 mg/L NO3-N on the south side of the creek around 18th Avenue. Cadmium-reduction using a Hach DR/820 Portable Colorimeter was the testing method.

Nitrate and *Escherichia coli (E. coli)* levels were measured monthly by the National Park Service (NPS) from October 2008 through May 2009. Samples were laboratory tested by Analytical Sciences in Petaluma, California. The NPS station identification PRSF_LOB3 is the same location as this study's 18th Avenue site. The NPS station identification PRSF_LOB4 is the same location as this study's 20th Avenue site. Testing results are shown in Tables 1 and 2.

Station ID and Date	NO_3-N mg/L	*E. coli* MPN/100ml
PRSF_LOB3 (18th Ave) 20 Oct 2008	2.4	610
PRSF_LOB3 19 Nov 2008	1.8	Present >QL
PRSF_LOB3 17 Dec 2008	2.4	200
PRSF_LOB3 22 Jan 2009	2.4	220
PRSF_LOB3 19 Feb 2009	3	74
PRSF_LOB3 19 Mar 2009	2.3	110
PRSF_LOB3 15 Apr 2009	1.9	41
PRSF_LOB3 13 May 2009	1.8	420

Table 1. Lab test results of nitrate and *E. coli* at 18th Avenue site

Station ID and Date	NO_3-N mg/L	*E. coli* MPN/100ml
PRSF_LOB3 (20th Ave) 20 Oct 2008	6.3	160
PRSF_LOB4 19 Nov 2008	5.8	690
PRSF_LOB4 17 Dec 2008	6.4	20
PRSF_LOB4 22 Jan 2009	6.4	120
PRSF_LOB4 19 Feb 2009	5.7	20
PRSF_LOB4 19 Mar 2009	5.8	63
PRSF_LOB4 15 Apr 2009	5.4	20
PRSF_LOB4 13 May 2009	7.3	31

Table 2. Lab test results of nitrate and E. coli at 20th Avenue site

In 1991 a USGS study tested groundwater from 22 sites (20 wells and 2 springs) throughout San Francisco. Two of the sites were Lobos Creek springs and one site was a well near the Lobos Creek water treatment plant. The north bank spring concentration was 1 mg/L while the south bank spring concentration and the well concentration were 6.5 mg/L and 6.4 mg/L, respectively (Phillips, Hamlin and Yates 1993). Although these are under the MCL, the higher concentration from the south bank spring is consistent with other testing. The south bank spring location is 12 meters from the 'higher nitrate' site for this study. Among all the USGS testing sites in San Francisco, ten had nitrate-nitrogen concentrations of 10 mg/L or greater, up to 36 mg/L (Table 3).

Overall, these studies indicate an on-going interest in and concern for the quality of water in the creek. A better understanding of the hydrological system and its associated differences among water quality parameters within Lobos Creek can contribute to continuing discussions around watershed management and resource protection.

Water quality and hydrological processes in nature are broad areas of research and the literature is substantial. In the context of urban watersheds the literature on stream temperature, electrical conductivity, and water level is more limited.

As hydrology is becoming a more interdisciplinary science due to the scope of complex environmental problems and the interdisciplinary teamwork required to solve them, the

Map No. (pl. 2A)	Well name or sample source	State well No.	Depth of well	Date	Boron, dissolved (µg/L)	Methylene, blue active substance (mg/L)	Nitrogen, ammonia, dissolved (mg/L)	Nitrogen, nitrate, dissolved (mg/L)	Nitrogen, NO_2+NO_3, dissolved (mg/L)
1	Adam Grant Building	2S/5W-3C1	135	01/08/91	130	0.09	0.03	<0.01	7.1
3	Mt. Zion Hospital	2S/5W-5L1	500	01/10/91	110	0.18	0.03	<0.01	18.0
4	St. Anne's Home	2S/5W-6M1	80	01/08/91	80	0.12	0.03	<0.01	9.6
6	Davies Hospital	2S/5W-8P1	230	01/10/91	150	0.12	0.03	0.09	13.0
10	AC Electric	2S/5W-27L1	100	01/09/91	70	0.12	0.04	0.07	15.0
11	Brussels Street	2S/5W-27N1	20	01/09/91	130	0.23	0.04	0.46	36.0
12	Herz Playground	2S/5W-33L1	81	01/08/91	30	0.21	0.04	<0.01	6.6
14	**Presidio 6**	2S6W-2H1	60	01/10/91	50	0.07	0.03	<0.01	**6.4**
17	Elk Glen-D	2S6W-11R1	360	01/10/91	40	0.10	0.03	<0.01	12.0
18	Elk Glen-S	2S6W-11R2	72	01/10/91	50	0.11	0.08	0.02	10.0
19	French Hospital	2S6W-12A1	100	01/10/91	50	0.19	0.04	<0.01	20.0
21	Arboretum 5	2S6W-12Q2	250	01/10/91	100	0.14	0.04	<0.01	18.0
30	HLA E	2S6W-15P1	68	01/09/91	180	0.06	0.04	<0.01	7.6
36	HLA J	2S6W-22Q1	66	01/09/91	130	0.12	0.04	<0.01	12.0
44	Zoo 03	2S6W-27B5	220	01/09/91	40	0.08	0.09	<0.01	8.9
51	Olympic Golf Club-S	2S6W-35Q1	51	01/09/91	40	0.12	0.29	0.02	0.9
53	San Francisco Golf Club West-D	2S6W-36N2	540	01/09/91	30	0.03	0.10	<0.01	0.8
na	San Francisco Airport-D	3S/5W-34L1	141	01/08/91	1,100	0.81	22.00	<0.01	<0.1
na	San Francisco Airport-S	3S/5W-34L2	35	01/09/91	30	0.05	0.07	0.02	12.0
56	Olympic Golf Club-D	3S/6W-2B3	524	01/09/91	30	0.08	0.04	<0.01	5.6
58	**Spring, south bank of Lobos Creek**	2S6W-1MS1	na	01/08/91	100	0.07	0.04	0.04	**6.5**
59	**Spring, north bank of Lobos Creek**	2S6W-2JS1	na	01/08/91	110	0.07	0.30	0.03	**1.0**

Well name or sample source: HLA, Harding-Lawson Associates. D, deep; S, shallow. Depth of well in feet below land surface.
µg/L, microgram per liter; mg/L, milligram per liter. <, actual value is less than value shown. na, not applicable.
Table 3. USGS sampling sites in San Francisco and San Mateo Counties. See last column.. Source: Phillips, Hamlin and Yates 1993.

work of geographers is particularly germane. A study by Levia and Underwood (2004) highlights this point. Results from an examination spanning six years (1997-2002) of five geography journals and five hydrology journals showed that physical geographers publish considerably more hydrology-content articles (82 percent of 690) in hydrology journals than geography journals. *Hydrological Processes* was the preferred hydrology journal and *Physical Geography* was the preferred geography journal.

Following is a discussion of research relevant to stream temperature, electrical conductivity, and groundwater level. An effort to include as much research by geographers as possible was made.

Thermal Regime

Bruce W. Webb, a Professor of Physical Geography at the University of Exeter in the United Kingdom, has written extensively on trends, behavior, and temporal and spatial variation of river water temperatures. His primary research interest is water quality of stream and river systems. In addition to recent research on sediment behavior in terms of water quality (Webb and De Boer 2007; Harlow, Webb and Walling 2006), Webb was lead editor of a two-volume publication examining the science and practice of hydrology for the 21st century (Webb et al. 2004a, b).

For much of the 20th century a few themes dominated river water temperature studies: thermal influences on stream ecology, the impact of heated effluent discharges, and the factors responsible for river thermal processes (Caissie 2006; Webb et al. 2008).

In terms of stream ecology, the focus was on observing habitat use and the impact of high water temperatures on salmonids. Huntsman (1946) investigated substantial losses of fish that occurred in 1937, 1939 and 1942 in streams of the Canadian Maritime Provinces of Nova Scotia and New Brunswick. The cause was heat stroke due to water temperatures. The event of June 1942 was particularly severe due to rising minimum and maximum water temperatures over seven days. The greatest mortality occurred on 13 June when water temperatures reached a maximum of 31.4 °C. The author attributed additional factors to the loss including the rapid increase in temperatures; fish not yet acclimated to higher summer temperatures; low flow in the streams; cloudless conditions; and rising dew point (nearly 21 °C on 13 June) which reduced radiation at night more than insolation during the day.

The second theme, heated effluent discharges, was and continues to result from electric power generation and industrial processes such as petroleum refining, steel and chemical manufacturing, paper production, glass making, and distilling. Thermal pollution research in the United States emerged in the 1950's with studies on the Delaware River. By 1970 there were more than 300 projects concerned with heated discharges (Langford 1990).

The third theme, factors influencing river temperature, is classified into four groups by Caissie (2006): atmospheric, topography, discharge, and streambed.

Heat exchange at the air/surface water interface occurs as a result of energy exchange mainly through solar radiation, net long-wave radiation, evaporation, and convective heat transfer (Caissie 2006). Testing of data from 584 rivers in the United States demonstrated departures from linearity in terms of the water-air temperature relationship, derived from weekly mean values, at both high (>25 °C) and low air temperatures. For example, increases in the moisture-holding capacity of the atmosphere, which promote greater evaporation from the water surface, and in turn, increase evaporative cooling of the water course, together with enhanced back radiation as water temperatures rise were responsible. In terms of low temperatures, the release of latent heat with ice formation prevented water temperatures from falling much below 0 °C (Webb, Clack and Walling 2003).

A topographic feature, riparian vegetation, and the shade it provides is an effective means of protecting streams against excessive heating. Research has shown that removal of streamside vegetation increases water temperature. A long-term study of Salmon Creek and Steamboat Creek, both in Oregon, showed increases of 6 ˚C and 8 ˚C, respectively, in mean daily maximum water temperature due to vegetation removal (Beschta and Taylor 1988; Hostetler 1991). A period of five to 15 years is the general timeframe required by rivers to recover their natural thermal regime after vegetation regrowth (Murray, Edmonds and Marra 2000). Through deterministic modelling, Sinokrot and Stefan (1993) predicted that if trees along the Straight River in Minnesota disappeared, as a consequence of future climate changes, the water temperature would increase by 6 ˚C. The role of riparian buffers in protecting streams from heating is critical. Burton and Likens (1973) showed that successive opening of the streamside canopy contributed to increases in water temperature. They also pointed out that water temperature tends to recover in buffered sections of streams, presumably due to colder groundwater or water exchange within the stream substratum.

Flow regime and its impact on water temperature has been examined extensively in spatial and temporal contexts. In an eight-year study (1974-1981) of 364 river sites of a U.S. Geological Survey monitoring network in the conterminous United States, significant trends were identified using the seasonal Kendall test and slope estimator for both raw and flow-adjusted temperatures. The trends suggested that water temperature is inversely related to river discharge, such that temperature increases when flow decreases (Smith and Alexander 1983). On a temporal scale, in a contrasting context, variations in water temperature were compared with changes in air temperature and discharge over the period 1901-2000 for the main stem of the River Danube in Austria. Rises in water temperature at station Ybbs and flow changes at station Linz, 50 kilometers upstream, for different seasons were not consistently related. This suggested that flows were not the primary driver behind river temperature trends of the 20th century (Webb and Nobilis 2007).

Thermal processes at the streambed/water interface occur mainly through groundwater contribution and hyporheic exchange. In turn, these influence stream water temperature. Story, Moore and Macdonald (2003) showed that groundwater inflow was responsible for about 40 percent of an approximately 3 °C gross cooling effect in the daily maximum temperature of a small stream in central British Columbia.

The hyporheic zone (region of mixing between surface water and groundwater) acts as a buffer for stream water temperature. The influence of solar radiation and conduction of heat from air on surface water temperature is moderated by groundwater temperatures. In a study along a 24-kilometer reach of the lower Clackamas River in northwest Oregon, Burkholder et al. (2008) examined the relationships among channel morphology, hyporheic exchange, and stream temperature. In summer 2006, hyporheic exchange was identified by temperature anomalies, which are areas where the water temperature differs by at least 1 ˚C from the main channel. These areas were associated with the downstream end of gravel bar channels and downstream of gravel bar heads, where higher gradients and hydraulic conductivity were controlling factors. Results of modeling showed that hyporheic discharge prompted a local cooling by 0.012 ˚C of the maximum daily temperature. Despite this nominal cooling, the authors found that local patches of water, up to 4 ˚C cooler, can be created from hyporheic discharge. These areas within rivers can provide refuge for fish and other aquatic species that are stressed by thermal conditions.

In the context of Lobos Creek, the lack of significant daily water temperature fluctuation revealed in the data suggests groundwater influence and hyporheic effects. Additionally, the sand substrate of Lobos Creek likely contributes to the reduced range of daily maximum and minimum temperatures. This can be inferred based on a study by Johnson (2004) who found that stream reaches with bedrock substrate had wide daily summer stream temperature fluctuations, with high maxima and low minima. In contrast, stream reaches with gravel substrate and below-ground flows had a much narrower range of daily fluctuations.

Research on the impacts of human activities on stream and river temperatures has been ongoing for decades. Examples include forest harvesting, river regulation, and urbanization.

In terms of forest harvesting, the importance of retaining riparian buffer strips to provide shade and prevent water temperature increases is widely accepted (Caissie 2006). A nine-week shading experiment was conducted in summer 1997 along 200 meters of a stream in the H.J. Andrews Experimental Forest, western Cascades Range, Oregon. Results showed that maximum temperatures significantly decreased due to shading while minimum and mean temperatures were not substantially affected. This could be attributed to the imbalanced distribution of daily stream temperature. Mean temperatures are lower than what would be calculated by averages of daily maximum and minimum. Shade can decrease energy fluxes at midday while the daily energy balance for stream temperature remains constant. The author concludes by emphasizing that downstream shading of a stream does not remediate the effects of upstream disturbances such as riparian removal or forest harvest. Not all stream metrics are equally responsive, and biologically, minimum stream temperatures are as important as maximum stream temperatures (Johnson 2004).

Regulating rivers through diversion (i.e., channelization for agriculture irrigation), abstraction (i.e., pumping for public consumption), and impoundment (i.e., reservoirs for hydroelectric power, irrigation, and flood control) is highly complex. The impacts on rivers and streams include decreased flows, increased temperatures, and reduced aquatic habitat area. Petts (1986) examined water quality characteristics of regulated rivers. Temperature-related findings included increased winter water temperatures, which prevented ice formation, for 20 kilometers below Gardiner Dam on the South Saskatchewan River in Canada's Saskatchewan province; and seasonal temperature changes delayed by one month for 200 kilometers below Hume Dam on the River Murray in southeastern Australia.

One of the consequences of urbanization is heat waste. An urban environmental study was conducted on water temperatures of the Ara River system in central Tokyo and its suburbs. The effect of heat input from wastewater effluents was examined. Two decades (1978-1998) of temperature data were analyzed in three ways. First, longitudinal temperature variations for two time periods (December–March 1978-1983 and 1993-1998) were attributed to warm effluents from wastewater treatment plants as a result of rapid urbanization. Second, relationships between air and stream temperatures implied that stream temperatures are not sensitive to wastewater influences in warmer seasons because natural flow is usually much larger than the volume of wastewater effluent and effluent temperatures are similar to those of natural flow. Third, trends based on monthly data implied that increased wastewater effluent is a likely cause of stream temperature increases, though heat exchange with seawater through tidal movement is another possibility (Kinouchi, Tagi and Miyamoto 2007). The authors conclude by suggesting methods to minimize the heating of urban streams. These include man-made wetlands and stabilization ponds to facilitate heat loss, and the reuse of treated wastewater to reduce effluent volume and temperature.

This last point, wastewater effluents, could relate to findings from this Lobos Creek study. The stability of water temperatures revealed in the data suggests groundwater sources, yet higher-than-expected measurements could indicate mixing with sewage or water from leaking pipes beneath the Richmond District.

Electrical Conductivity / Specific Conductance

Electrical conductivity (EC) is a chemical water quality parameter. It is a measure of the ability of a solution to transfer (conduct) electric current and indicates the presence of dissolved solids (salts which dissolve into ions with a positive or negative charge). Electric current in water is carried by ions since electrons do not pass through water by themselves. The greater the concentration of ions, the better the water conducts electricity. The major positively charged ions, called cations, are sodium (Na), calcium (Ca), potassium (K), and magnesium (Mg). The major negatively charged ions, called anions, are chloride (Cl), sulfate (SO4), carbonate (CO3), bicarbonate (HCO3), phosphate (PO4), and nitrate (NO3) (Das et al. 2006).

Electrical conductivity is strongly dependent on water temperature. At higher temperatures water becomes less viscous and ions can move more easily. To compensate for this effect, conductivity readings are standardized to the concentration of ions at a reference temperature of 25 ˚C (20 ˚C is sometimes used). For water, a temperature compensation factor of two percent per degree Celsius is normally used. For example, water at 25 ˚C may conduct 200 microsiemens per centimeter. At 35 ˚C this same water would conduct 240 microsiemens per centimeter. Therefore, temperature compensation is necessary to distinguish conductivity readings due to dissolved solids from those due to temperature (McPherson 1997). Electrical conductivity which is corrected for temperature is called specific conductance (SC).

The unit of measurement of electrical conductivity, or specific conductance, is siemens per centimeter. It is the amount of electricity conducted through one centimeter of water at a specified temperature. Millisiemens are one-one thousandth of a siemens per centimeter and expressed as mS/cm. Microsiemens, as noted in the example above, are one-one millionth of a siemens per centimeter and expressed as µS/cm. Throughout this paper, specific conductance measurements are expressed as millisiemens per centimeter (mS/cm). Table 4 lists specific conductance ranges of common solutions.

Solution	Specific Conductance mS/cm
Deionized water	0.0005 – 0.003
Rainwater	<0.015
Rivers	0.05 – 1.5
Drinking water	0.5 – 0.8
Brackish water	1.3 – 28
Industrial discharges	0.1 – 10
Sea water	43 – 56

Table 4. Specific conductance ranges of common solutions

Dissolved salts affect the quality of water used for drinking, irrigation, recreation, and some industries. They also impact freshwater species which tolerate salinity within a range of 0.15 and 0.5 mS/cm. Rivers in the United States generally range 0.05-1.5 mS/cm (U.S. Environmental Protection Agency 2009). Conductance varies with water sources such as groundwater, municipal waste water, and precipitation. Catchment geology impacts measurements. For example, streams that run through areas with granite bedrock tend to have lower conductance due to the silica content of granite which remains uncharged when dissolved in water (Moore, Richards and Story 2008). Conversely, clay soils contain materials that ionize when washed into the water. Significant changes in conductance could be an indicator that a discharge or some other source of pollution has entered a stream.

Sources of ions include wastewater from septic systems and sewage treatment plants, urban runoff from roads, agricultural runoff, atmospheric deposition, soil, and rocks. The measured value of SC indirectly indicates the level of solutes in water. However, organic compounds such as oil, phenol, and alcohol do not form ions when dissolved. They do not conduct electric current very well and therefore have a low conductivity in water (U.S. Environmental Protection Agency 2009). Only substances that form charged ions will influence electrical conductance (R. Dan Moore, Professor, Department of Geography, University of British Columbia, 14 May 2009, personal communication). An overarching statement that all contaminants can be reflected by higher SC cannot be made.

Specific conductivity has many applications in water studies. It is used to monitor the mixing of fresh water and saline water, map contaminated groundwater and saline water intrusion, estimate contributions of precipitation and subsurface water (Hayashi 2004), and assess the extent of anthropogenic influence on a watershed.

Measurements can also be used as a tool for identifying groundwater discharge zones, sources of runoff, and hydrologic behavior. The Stuart-Takla Fish-Forestry Interaction Project examined differences in SC between two different catchments in north-central British Columbia. Greater streamwater SC in catchment A suggested deeper, slower flow-paths than in catchment B. Little variation in groundwater levels of catchment A, differ-ences in baseflow generation, and different streamflow responses to snowmelt and summer drought were evidence of contrasting hydrologic behavior of the catchments as originally suggested by SC measurements (Moore, Richards and Story 2008).

Calles (1982), Kobayashi, Suzuki, and Nomura (1990), and Kobayashi, Kodama, and Ishii (1995) monitored specific conductance of streams in catchments in central Sweden and northern Japan. By examining evapotranspiration and discharge spatially and temporally, Calles concluded that evapotranspiration was partly responsible for the diurnal variation in specific conductance. Similarly, Kobayashi, Suzuki, and Nomura (1990), and Kobayashi, Kodama, and Ishii (1995) determined that diurnal fluctuation of streamflow and specific conductance were attributed to evapotranspiration. A reduction of streamflow during the day accompanied a reduction of ion concentration. Additionally, the diurnal behavior suggested that streamflow was generated from two sources of water, possibly from shallow soil and deep soil/bedrock.

Kobayashi, Ishii and Kodama (1999) used specific conductance and streamwater temperature variations to compute the contributions from surface and subsurface flow paths in a forested catchment in the northern part of Hokkaido Island, Japan.

Pellerin et al. (2007) evaluated the use of specific conductance as a continuous, inexpensive tracer for urban hydrograph separation by comparison with a conservative isotopic tracer, deuterium, and a non-conservative tracer, silica. Isotopic tracers are generally considered indicators of water sources, while non-conservative chemical tracers such as SC and silica are considered flowpath tracers due to interactions with mineral material and constituents en route to the stream. The primary purpose of the study was to determine the contribution of impervious surface runoff and subsurface discharge in stormflow generation in an urban watershed in northeast Massachusetts. Specific conductance was measured at 15-minute intervals between August 2001 and September 2003 at the mouth of the watershed using a portable sensor with retrievable data loggers. A comparison of two storms, among 19 total rainfall events examined, indicated that contributions of runoff and antecedent discharge were generally comparable when calculated using the tracers. Results of the overall study suggested that less than half of the rainfall on impervious surfaces was routed to the stream channel in the study catchment.

Kney and Brandes (2007) developed a method to account for the natural geologic portion of an SC measurement so that the extent of anthropogenic influence could be assessed. Alkalinity was measured in combination with conductivity since alkalinity can be used as an index of bedrock geology. There is a strong relationship between SC and alkalinity under natural conditions. High SC values combined with low alkalinity values indicate human impact. The method is applicable to humid temperate regions of the eastern and central United States where alkalinity is greater than 30 milligrams per liter due to carbonate bedrock.

Hayashi (2004), Das et al. (2006), and Kney and Brandes (2007) note the advantage of using SC measurements over total dissolved solids analysis as an initial indicator of pollution. Measuring specific conductance is relatively quick and inexpensive, while determination of total dissolved solids requires sampling and chemical analysis which takes time and money. For volunteer monitoring groups, a handheld instrument can be used to measure specific conductivity *in situ*.

According to records at the water treatment plant, SC daily readings for Lobos Creek, approximately 0.6 mS/cm, are consistent throughout the year, and have been for at least the past ten years. Measurements are taken downstream where water enters the plant for treatment (Scott Sacks, Presidio Trust, 13 April 2009, personal communication).

Groundwater Level

An area of water research for millennia has been groundwater. Broadly speaking, topics include groundwater flow and well hydraulics, hydrogeochemistry, transport and fate of contaminants, and management and policy. In 2005, groundwater provided 51 percent of all drinking water for the United States population (http://www.groundwater.org/gi/depend.html last accessed 12 May 2009).

A fundamental indicator of the status of groundwater is water level in wells. Logging of water level is critical to evaluations of the quantity and quality of groundwater and its interaction with surface water. It also serves as essential data to develop hydrologic models, forecast trends, and to design groundwater management and protection programs.

A review of the current literature on water level reveals extensive research on impacts to ecosystems, its use in computer modeling for climatic variation, and the impact of regulation. Since this paper examines water level from a groundwater rather than surface water perspective, research and current technology in this context are discussed.

Groundwater levels change in response to natural processes and human activities. The changes are driven by withdrawal (also known as discharge or extraction), replenishment (recharge), and storage in an aquifer. Change over time is typically more apparent on a seasonal scale than hourly or diurnal cycles. Examples of natural processes are:

- precipitation
- evapotranspiration
- changing seasons
- climatic conditions such as drought
- tidal movements and earthquakes

Human activities impact groundwater levels at varying temporal and spatial scales. Equilibrium as a response to changes in a groundwater system, and a cycle of urbanization on a watershed are concepts of scale. The cycle begins with initial landscape stability or equilibrium, transitions to a period of construction and landscape alteration, and ends with an urban landscape and the establishment of new conditions of equilibrium (Wolman 1967). Activities such as population growth and rapid urban development can impact groundwater levels relatively quickly in the alteration phase; while groundwater levels, over greater spatial scales, as a result of deforestation, wetland draining, impoundment, and irrigation, may exhibit a slower response.

The length of time over which water level data are collected and the areas where measurements are recorded depend on research objectives. For example, water level data collected over periods of days to months are useful for determining aquifer hydraulic properties, mapping the altitude of the water table, and monitoring groundwater and surface water interaction.

Data collected over years to decades are useful for complex issues such as examining aquifer development, defining water level fluctuations, monitoring climatic variability, and tracking trends over time (Alley and Taylor 2001).

Water level monitoring during periods of significant land use change is critical to the protection of aquifers. A regional example is the water level declines of the High Plains aquifer in central United States. Underlying an area of 450,000 square kilometers (45 million hectares) in parts of eight states, groundwater from the aquifer was pumped for agricultural and ranching irrigation starting in the 1930's. By 1980, water levels in some areas of the aquifer had declined by more than 30 meters. In 1988, water level monitoring began in 7000 observation wells to assess changes in the aquifer. The area-weighted, average water level change from about 1940 to 2007 was a decline of four meters. Although monitoring was established after substantial declines had occurred, the data collected have served to guide water resource agencies in evaluating options for groundwater management (McGuire 2009).

In a groundwater hydraulics study, the recharge process beneath sand dunes in the Crescent Lake National Wildlife Refuge in western Nebraska was examined. Water level data from observation wells installed between two lakes indicated that the water table divide moved laterally depending on wet or dry conditions. (Winter, Rosenberry and LaBaugh 2003).

Climatic variation can influence water level fluctuations. For example, a measure of drought conditions can be reflected in water level data. The need for continuous data collection, rather than once per month for example, over different geologic settings is a critical component to developing a complete picture of drought status. After a severe drought in the late 1920's, the state of Pennsylvania established a well network to monitor water level fluctuations for indications of drought. Data, 80 percent of which are now transmitted by satellite telemetry to the USGS, are used to inform decisions around drought declarations and water restrictions (Taylor and Alley 2002). The drought emergency declared in 55 counties in Pennsylvania in 1999 was largely supported by network data.

In an ecological context, water level research began in 1998 to evaluate the potential for restoration of a wetland ecosystem in the Seney National Wildlife Refuge of south central Upper Peninsula, Michigan. Wetlands were drained in 1912 in a failed attempt to convert land to agricultural use. In order to assess the average range of water level fluctuations under existing conditions, a combination of long-term groundwater observation wells and combined groundwater and surface water gaging stations were installed over an area of nine square miles. Data collected at the sites have been used to determine how much groundwater levels need to be raised to support wetland ecologic functions and to manage wildlife habitat and flood control in a perennially flooded pool in the wetland (Taylor and Alley 2002).

Another area of groundwater research is the relationship between water level and water quality. One aspect is understanding the migration of groundwater contaminants from their sources through a groundwater system. For example, fluctuations in contaminant concentrations over time may be related to a particular event or seasonal changes in groundwater recharge. Long-term water level measurements provide critical information to managing the integrity of groundwater. Following is an example of a coastal public water supply degraded by saline water.

Excessive groundwater withdrawals in northeast New Jersey, which led to saline water intrusion, illustrate how water level data are used to monitor water quality. After increasingly greater withdrawals over decades, saline water, naturally present in deeper parts of the aquifers, migrated toward pumping stations. An increase in chloride and dissolved solids concentrations extensively degraded the groundwater. The well field was abandoned in the 1980's for wells farther inland. The New Jersey Department of Environmental Protection, in conjunction with the U.S. Geological Survey, now monitor changes in water levels and chloride concentrations in each of the aquifers. In addition, groundwater withdrawals are regulated and monitored. Over 1,000 observation wells collect water level data for mapping changes in aquifer development; and water samples are routinely collected for analysis (Taylor and Alley 2002).

Linked to the land use example above is the issue of development, water quality and water level. This is illustrated by population growth in the Gallatin Valley of southwestern Montana. Growth has occurred outside of established cities in areas where each home has its own well and septic system. Concerns about the effect of infiltrating septic wastewater on groundwater supplies led to a program of monitoring groundwater and surface water quality. Since the 1940's periodic surveys of water levels in the valley have been made but long-term water level measurements were practically non-existent. In 1997, a long-term water level monitoring network consisting of 101 observation wells was established. Data have provided information on trends and variations in annual recharge that affect either the amount of dilution or the loads of contaminants introduced to the groundwater system from septic wastewater (Taylor and Alley 2002).

CHAPTER 3: Nitrate, Isotope Analysis, and Coliform Bacteria

Nitrate is a stable oxidized form of nitrogen and occurs naturally in soil and water. It is an inorganic compound, dissolves easily in water and does not bind to soils. Consequently, it is highly mobile. In the ground, nitrates are the nutrition for plants. In terms of agriculture, intensive farming can rob the soil of its natural nitrogen source. When this occurs manure and nitrate fertilizers are applied to the soil to increase crop production. When more nitrogen is added to the soil than plants can use, an imbalance occurs. Excess nitrates can leach into groundwater and this leads to water quality issues.

The U.S. Geological Survey's National Water Quality Assessment Program (NAWQA) was begun in 1991. Over 10,000 samples collected through 1992 showed that soil-drainage characteristics and the amount of nitrogen contributed by fertilizer, manure, and atmospheric sources influenced the concentration of nitrates in groundwater (Figure 6).

Nitrates in Drinking Water

When water containing nitrates in excess of 10 mg/L NO3-N is consumed by infants and pregnant women, a condition called methemoglobinemia (also known as blue baby syndrome) can develop over a period of a few days. It causes the level of oxygen carried

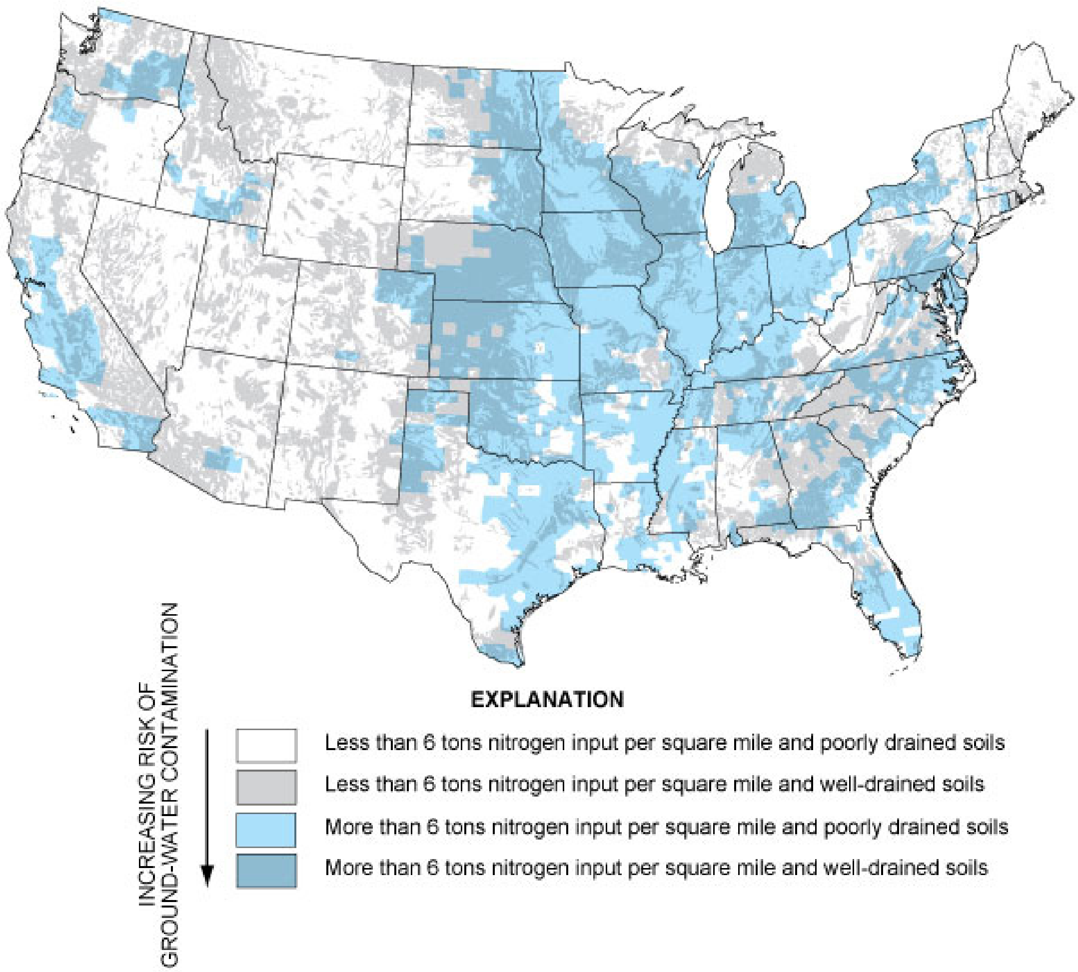


Figure 6. U.S. Geological Survey nitrate risk map. Source: Nolan and Ruddy 1996.

throughout the body to decrease resulting in asphyxiation. The most obvious symptom is a bluish color of the skin, particularly around the eyes and mouth. Immediate medical attention is necessary and full recovery occurs in most instances. Infants up to about six months old are most susceptible because certain bacteria in their digestive system change nitrate into toxic nitrite (NO2). The nitrite converts hemoglobin, which carries oxygen to all parts of the body, to methemoglobin, which does not carry oxygen. Hence, the level of oxygen decreases as methemoglobin increases. Around the age of three months, an increase in the amount of hydrochloric acid in a baby's stomach kills most of the bacteria that convert nitrate to nitrite. By six months, a baby's digestive system is usually fully developed and none of the bacteria remain (Knobeloch et al. 2000; Fewtrell 2004).

Methemoglobinemia is currently the only proven disease directly attributable to nitrate-contaminated groundwater (Interstate Technology and Regulatory Cooperation 2000). However, there are other negative health effects connected to this contaminant that are being studied. These include miscarriages, non-Hodgkin lymphoma, stomach cancer, and leukemia (Fewtrell 2004). A recent study by researchers at Rhode Island Hospital found substantial links between increased levels of nitrates and increased deaths from Alzheimer's, Parkinson's, and diabetes (http://www.medicalnewstoday.com/articles/156507.php last accessed 8 July 2009).

Because methemoglobinemia is not perceived as a grave health threat compared to contamination by volatile organic compounds (chlorinated solvents and fuel components) or certain metals, nitrate is not treated as a contaminant of highest concern (Interstate Technology and Regulatory Cooperation 2000). Groundwater remediation of nitrate contamination has not received as much attention as known carcinogenic contaminants.

Nitrates are colorless, tasteless and odorless. They dissolve easily in water, do not evaporate, are mobile in groundwater, and extremely difficult to remove. Demineralization by distillation or reverse osmosis, ion exchange, and blending are methods to reduce or remove nitrates. Distillation is a process of boiling water, capturing the resulting steam, and condensing it back in to water. The nitrates remain concentrated in the boiling tank. Reverse osmosis reduces nitrates by putting water under pressure and forcing it through a membrane that filters out the nitrates. Both of these high-maintenance, low-yield systems require significant time and energy to operate efficiently. Ion exchange replaces nitrates with another substance, often chloride, contained in resin beads. Nitrates and chloride trade places essentially. A drawback to this method is that the resin beads will also take up sulfate in exchange for chloride. Therefore, if sulfates are present in the water supply, the capacity of the beads to take up nitrates is reduced. The third method to reduce nitrates is to dilute the water by blending it with water that has low nitrate concentrations. Blending the two waters produces water that is low in nitrate concentrations (State Water Resources Control Board 2008).

Occurrence in Lobos Creek

Agriculture around Lobos Creek was practiced in the late 19th and early 20th centuries. Concerns over excess levels of nitrates date to this period.

A memo dated 25 October 1882 from the military Headquarters Department of California, Presidio of San Francisco, reads:

> "It having been observed that the gardens on Lobos Creek, which are heavily covered with fresh manure, drain into the springs which supply drinking water to the posts of Fort Point, Presidio, and Fort Point San Jose, and to the City of San Francisco, a Board of Officers is hereby appointed to examine and report the facts in the case; to what extent the wholesomeness of the water will probably be affected thereby, and will recommend necessary action" (Kelton 1882).

An 1884 newspaper article reported on water samples from Lobos Creek that had been analyzed by a committee of doctors. "They contain too great an amount of nitrates, which represent the animal and vegetable matter that has already decayed and oxidized. The source of these nitrates is evidently the drainage (under the surface) of numerous cow ranches, habitations, frequently manured market gardens and the Marine Hospital grounds, which lie above and around Point Lobos Creek and on its water-shed" (The Call Supplement 1884, 1).

Construction of the Marine Hospital on the Presidio Reservation overlooking Mountain Lake was completed in 1875. It encompassed 34 hectares (85 acres) and included a three-hectare (eight-acre) vegetable garden. By 1892 the garden had grown to 16 hectares (40 acres). The method of fertilizing the garden with manure concerned military authorities. Colonel Graham sought to discontinue cultivation on the grounds that drainage of the garden compromised the purity of water in Mountain Lake and Lobos Creek (Thompson 1997).

Another historic account of the integrity of the water supply was detailed in a report by Samuel Storrow, Civil Engineer, and Margaret Henderson, Bacteriologist at University of California. They made the argument that contamination of Lobos Creek was caused by sewage from the "thickly settled Richmond District on the south side of the creek" (Storrow 1909, 15).

Charles Gilman Hyde, Professor of Sanitary Engineering at University of California, focused on purification methods and recommended rapid sand filtration coupled with chemical sterilization using calcium hypochlorite, a bleaching powder (Hyde 1911).

In 1923, George S. Gillis, Lieutenant-Colonel of the U.S. Army, pointed to "the building up of the city's residence district along the south side of the reservation" as evidence of contamination (Gillis 1923, 11).

Nitrate contamination is attributable to sources and activities other than agriculture and urban development.

Contamination Related to Military Activity

Construction of Fort Point in the 1850's and coastal batteries in 1868 to house heavy artillery mark the start of landscape alteration on the Presidio for defense purposes (Thompson 1997). Over the next one hundred years, more coastal batteries, underground storage tanks, missile silos, landfills, and laboratory facilities were integrated into the Presidio's landscape. With these installations came the potential for sources of contaminants to the environment. The Arms Control Research Center conducted a three-year study of the Presidio in the 1980's. At the time, the Presidio was ranked 5th among 141 military bases in California for the number of toxic sites. There were 66 within its 603 hectares (1,491 acres). In the immediate vicinity of Lobos Creek (within approximately 500 meters) are two landfills likely to contain asbestos, medical waste, and heavy metals; an abandoned Nike missile silo that accommodated nuclear warheads and may not have been cleaned up before it was paved over in 1974; at least 17 underground storage tanks that held solvents, lubricants, home-heating oil and other chemicals (there are more than 200 underground storage tanks in the Presidio); and the remains of a Public Health Services Hospital where plague research was conducted (Bloom 1991).

The U.S. Army's Enhanced Preliminary Assessment of the Presidio's environmental problems, released in 1989, admits to a lack of knowledge about the landfills. "None of the landfilling has been conducted in accordance with engineered plans. Thus, the exact locations, extent, and depth of deposited wastes are not precisely documented but rather exist only in institutional memory" (Bloom 1991, 23). Additionally, radioactive materials were occasionally disposed of at the Presidio between 1946 and 1972.

Nitrogen is a major element in the manufacture of explosives, which primarily utilizes ammonium nitrate and diesel fuel (Interstate Technology and Regulatory Cooperation 2000). The Interstate Technology and Regulatory Council identified 46 military sites in the United States where nitrate concentrations in groundwater, possibly due to weapons manufacturing, testing, loading and packing, range from 20 mg/L to over 200 mg/L (Interstate Technology and Regulatory Cooperation 2000). The Presidio is not listed among these 46 'Major Explosives Contamination' sites. However, considering the U.S. Army quote above, the now defunct nuclear explosives at the Presidio, and the higher concentrations of nitrates in the water, it is interesting to note the parallel.

Contamination Related to Geology

Approximately 20 percent of the global nitrogen pool is tied up in rock (Schlesinger 1997). An emerging area of research is the contribution of nitrogen from rock to nitrate contamination of surface water and groundwater. Geologic nitrogen may contribute to nitrogen saturation which leads to leaching and consequently, elevated concentrations of nitrates in surface water and groundwater.

A 2.5 year study in the Mokelumne River watershed in the central Sierra Nevada conducted in the mid-1990's found that differences in streamwater nitrate concentrations were attributable to differences in bedrock lithology, rather than other watershed factors. A close correlation was noted between high-nitrate streams and bedrock containing metasedimentary and metavolcanic rock (rock that has undergone physical changes as a result of high temperature and pressure). Nitrogen concentrations were highest in phyllite, followed by slate, biotite schist, metavolcanic breccia, and greenstone. Median streamwater nitrate concentrations from catchments with geologic sources of nitrogen ranged from 0.3 to 1.4 mg/L compared to median values less than 0.03 mg/L for catchments with no detectable source of geologic nitrogen. Moreover, an estimated mass balance for the entire watershed indicated that more than 90 percent of the nitrate in the streams originated from the 10 percent portion of the watershed containing geologic nitrogen (Holloway et al. 1998; Holloway and Dahlgren 2002). Weathering releases the nitrogen, especially during early fall and winter when rains flush out nitrogen that has weathered from rocks over the summer.

Another study in California, in the Sierra Pelona basin in north central Los Angeles County, concluded that 10 percent of groundwater nitrogen originated from bedrock sources while more than 49 percent of the nitrate was attributed to sewage and other fecal matter sources (Williams et al. 1998).

A link between geologic nitrogen and the Lobos Creek watershed could be greenstone. It is a metamorphosed basalt rock of the Franciscan Complex, the basement so to speak, of the Coast Ranges east of the San Andreas Fault. The Franciscan Complex underlies much of coastal Northern California. Although graywacke sandstone and argillite are the predominant rocks of the Franciscan Complex, greenstone is a component. About 20 to 25 percent of the Marin Headlands terrane, a fragment of the Pacific Plate and one of about ten along the coast near San Francisco comprising the Franciscan Complex, is basalt which has been subjected to some level of alteration into greenstone (Will Elder, Geologist, National Park Service, 15 May 2009, personal communication). The Marin Headlands terrane underlies a portion of the Lobos basin (Figure 7). The contribution of nitrogen from greenstone to groundwater or surface water of the Lobos basin could be explored.

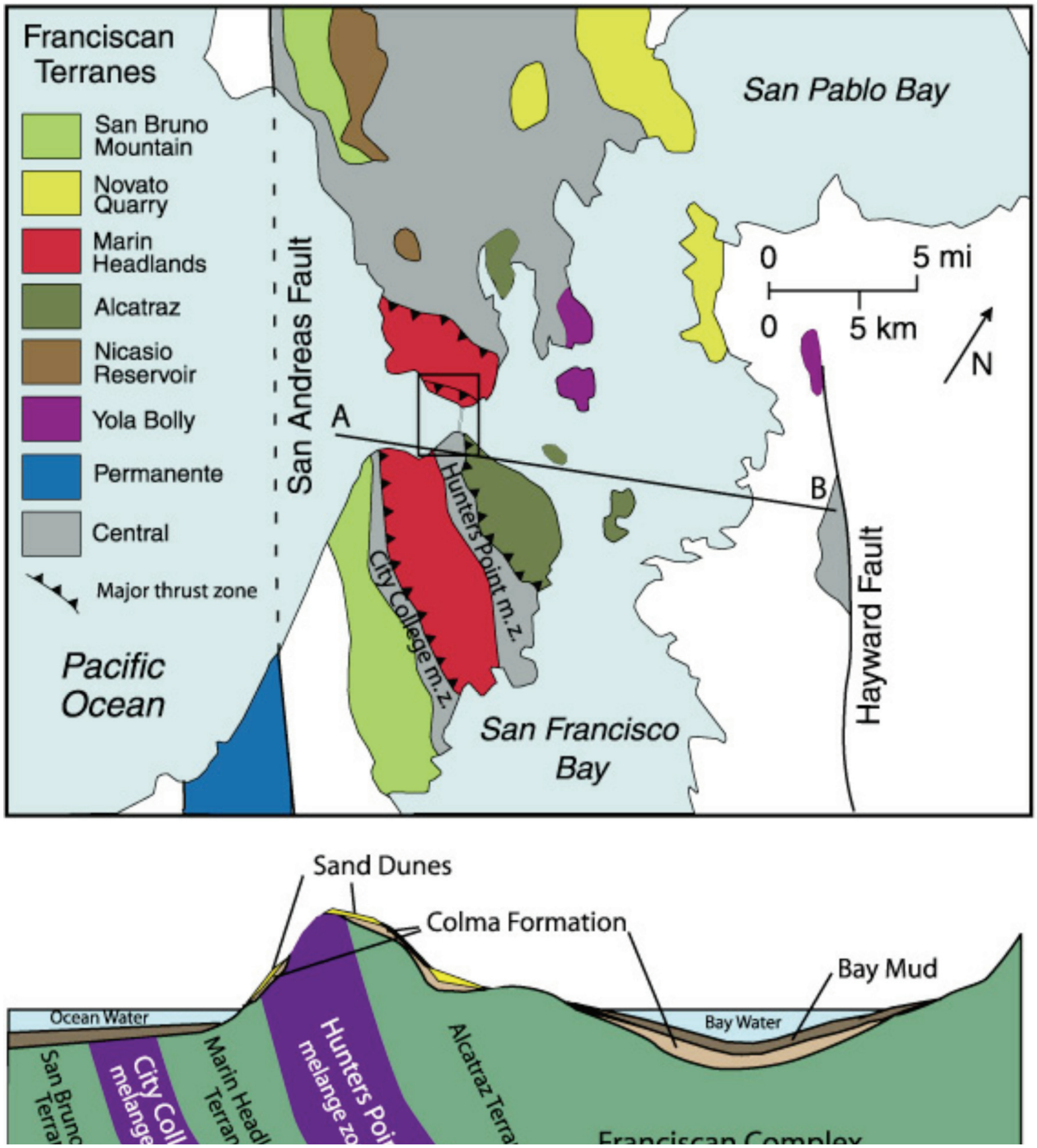


Figure 7. Top image: Terranes of the Franciscan Complex in the San Francisco Bay Area. Bottom image: Cross-section through northern San Francisco Peninsula across bay to Oakland (not to scale).
Source: Elder 2001

Isotope Analysis

During the course of investigating the potential for nitrates to still be present in the watershed as a result of manure used as fertilizer on gardens 100 years ago, the idea for stable isotope analysis was brought up through discussion with an agriculture researcher at University of California, Davis. While nitrate from manure applied 100 years ago could no longer be present in the system, the isotopic signature of nitrate could give an indication of the sewage to (garden) fertilizer ratio currently present.

Conventional nitrate analysis of water samples indicates levels of NO3-N or NO3 in milligrams per liter or parts per million, yet does not discriminate between sources. Nitrogen isotope analysis provides an indication of sources of nitrate in water. In conjunction with hydrologic data and water chemistry, it has been effective in terms of source identification of nitrate contamination in agricultural studies (Gormly and Spalding 1979; Rolston et al. 1996; Townsend, Young and Macko 2003) and urban studies (Silva et al. 2002; Fukada, Hiscock and Dennis 2004; Jin et al. 2004).

In Austin, Texas, water samples taken from two creeks during baseflow and stormflow conditions showed little difference in nitrate concentrations. However, isotopic analysis indicated a single nitrate source, likely sewage/animal waste, during baseflow, and a mixture of sources, including synthetic nitrate fertilizer, during stormflow (Ging, Lee and Silva 1996). In another urban study, water samples from 27 city wells in sewered and septic areas of

Tacoma, Washington had nitrate concentrations approaching or at the limit of the drinking water standard of 10 mg/L NO3-N. In addition to isotopes of nitrate, samples were analyzed for concentrations of nitrate, chloride and sulfate. Results of isotopic analysis of two of the samples from sewered wells were consistent with a fertilizer source, while the isotopic signal indicated septic input and other sources in the other samples (Inkpen et al. 2000).

Isotope analysis has also been used to determine geologic sources of nitrate contamination of water. Holloway and Dahlgren (2002) review techniques for measuring isotopic composition of nitrogen in rock. The sealed-tube combustion method involves combusting rock with copper and cupric oxide in quartz glass chambers for analysis by mass spectrometry. Pyrolysis involves extracting nitrogen from rock at 960 °C by elemental analyzer.

Further to the Mokelumne River watershed study, the δ15N in low-order streams draining areas with nitrogen-bearing bedrock in this watershed were between +2.8 and +5.7 0/00, eliminating fecal matter as a primary source of nitrogen (Holloway 1999). And further to the Sierra Pelona basin study, the δ15N of rock and undisturbed soil leachates in this region were low (<2 0/00) in comparison to soil leachates from plots influenced by cattle feedlots and septic system leachates (Williams et al. 1998).

Nitrogen is a chemical element with two stable isotopes, nitrogen-15 (15N) and nitrogen-14 (14N). Isotopes are atoms of the same atomic number but different atomic weights. The atomic number of a chemical element is the quantity of protons (positive charges) in the nucleus of each of its atoms. The atomic weight is based on the quantity of protons and neutrons in the nucleus of each of its atoms. When quantities of neutrons vary, isotopes result. The 15N isotope has seven protons and eight neutrons. Isotopes can exist in both stable and unstable (radioactive) forms (Faure and Mensing 2005). The natural abundance of 14N in the earth's atmosphere is 99.63 percent, while the natural abundance of 15N in the earth's atmosphere is 0.37 percent. The wide difference in the isotopic abundance allows for the determination of distinctive isotopic signatures to define specific natural and anthropogenic sources. Although the isotopic composition of nitrogen in the earth's atmosphere is relatively constant, in other compounds it is variable (Inkpen et al. 2000).

Nitrogen isotopic analysis involves establishing the ratio of 15N to 14N in nitrate in a sample relative to the ratio observed in a standard and is defined according to equation 1:

$$\delta\ 0/00 = [(Rsample - Rstandard)/Rstandard] * 1000 \qquad \text{(eq. 1)}$$

where δ is a value in parts per thousand (0/00) and R is the ratio of the sample and the standard, respectively. The international standard for nitrogen is N2 found in atmospheric air, which has a delta value of 0 0/00. Therefore, δ indicates whether the sample is enriched (+) or depleted (-) in 15N with respect to atmospheric N2 (Townsend, Young and Macko 2003).

The range of common ^{15}N values for nitrate is between about -10 and +25 0/00. They are listed in Table 5.

Substance	**$\delta^{15}N$ (0/00)**
Commercial fertilizer	-3 – +2
Soil organic nitrogen	+2 – +8
Sewage	+6 – +25
Animal waste	+9 – +25

Table 5. ^{15}N values for various substances. Source: Rolston et al. 1996; Silva et al. 2002.

Coliform Bacteria

Coliform bacteria are a group of relatively harmless microorganisms that live in large numbers in soils, plants, and the intestines of warm-blooded and cold-blooded animals. They are used as an indicator organism to indicate the potential for disease-causing bacteria to be present in water. Therefore, if coliform bacteria are present, it is presumed that a contamination pathway exists between the bacteria source and the water supply and disease-causing bacteria may use this pathway to enter the water supply. Most coliform bacteria do not cause disease, but the greater their number the greater the likelihood that disease-causing bacteria may be present.

Since it is difficult, time-consuming and expensive to test directly for the presence of a large variety of pathogens, water is tested for total coliform instead. Monthly sampling requirements are based on population served. For example, a water supply serving a population of 5,801-6,700 must be sampled a minimum of seven times per month. If a sample tests positive for total coliform, it must then be tested for fecal coliform and *Escherichia coli (E. coli)* (http://www.epa.gov/ogwdw/disinfection/tcr/basicinformation.html last accessed 19 June 2009).

Results from coliform bacteria tests are normally expressed as Present (P) or Absent (A). Present indicates that at least one bacterium was present in each 100 milliliters (ml) of water. Bacteria results can also be expressed as colony forming units (cfu) or Most Probable Number (MPN). The latter means that the lab estimates the number of bacteria in the sample based on a statistical test. The maximum contaminant level in drinking water for total coliform is 0 per 100 ml of water (http://www.epa.gov/OGWDW/contaminants/index.html last accessed 6 September 2009).

Fecal coliform bacteria are a subgroup within the coliform bacteria group. They are different because they grow at higher temperatures and are found only in the fecal waste of warm-blooded animals. Fecal coliform bacteria levels are expressed as the number of colonies per 100 ml of water. The maximum contaminant level in drinking water for fecal coliform is 0 per 100 ml of water (http://www.epa.gov/OGWDW/contaminants/index.html last accessed 6 September 2009).

Escherichia coli (E. coli) is one of six species of fecal coliform bacteria. It too is commonly found in the fecal waste and intestines of animals and humans. A positive *E. coli* test result is a strong indication that human sewage or animal waste has contaminated the water. Hundreds of strains of *E. coli* exist. Although most are harmless and live in the intestines of healthy humans and animals, a few can produce a powerful toxin that causes illness. The maximum contaminant level in drinking water for *E. coli* is 0 per 100 ml of water (http://www.epa.gov/OWOW/monitoring/volunteer/stream/vms511.html last accessed 19 June 2009).

Bacteria level limits established by the U.S. Environmental Protection Agency provide context to the above. For water contact recreation, the total coliform limit is 10,000 MPN per 100 ml of water in a single sample or an average of less than 1,000 MPN per 100 ml, depending on the sampling method. For fecal coliform the limit is 400 (or 200 depending on sampling method) MPN per 100 ml. For *E. coli* the average limit is 126 MPN per 100 ml. If sampled differently, the limit for *E. coli* varies between 235 and 576 MPN per 100 ml depending on intensity of beach use. (http://www.swrcb.ca.gov/water_issues/programs/swamp/docs/bacteria_monitoring/bacteria_monitoring_inventory_report.pdf last accessed 10 October 2009) (http://www.swrcb.ca.gov/rwqcb2/water_issues/programs/planningtm-dls/basinplan/web/tab/tab_3-02.pdf last accessed 10 October 2009).

Lobos Creek itself may not be as vulnerable to disturbance and pollutants by dogs and other animals due to fencing that prevents access to a significant portion. Furthermore, its relatively remote location in the southwest corner of the Presidio and its *aegis* under the mantle of the U.S. government until 1994 has kept it off the radar of many San Francisco residents and tourists. Nonetheless, coliform bacteria have been a concern of Presidio Treatment Plant personnel over the years and are routinely monitored and treated (Scott Sacks, Presidio Trust, 23 April 2009, personal communication).

CHAPTER 4: Lobos Creek Watershed

The Presidio

The Presidio encompasses 603 hectares (1,491 acres) in northwest San Francisco (Figure 8). Approximately 65 percent is open space. Owing to its strategic location overlooking the San Francisco Bay and Pacific Ocean, the Presidio was the site of a military base from 1776 until its transfer to the National Park Service in 1994. The Presidio is currently an amalgam of natural areas, designed landscapes, and historic structures. It was designated a National Historic Landmark in 1962 and joined the federally-protected 30,350-hectare (75,000-acre) Golden Gate National Recreation Area in 1994.

Features such as coastal bluffs, open shore, and eucalyptus, pine and cypress groves are the backdrop for Civil War-era homes, historic defense structures such as underground bunkers, batteries, and airplane hangars, military buildings converted to schools and businesses, visitor centers, libraries, restaurants, cemeteries, a golf course, museums, and residential neighborhoods.

The Presidio is managed by the Presidio Trust and the National Park Service. The Presidio Trust is a federal agency established by Congress in 1996. It manages the interior 80 percent of the park while the National Park Service manages the coastal areas includ-

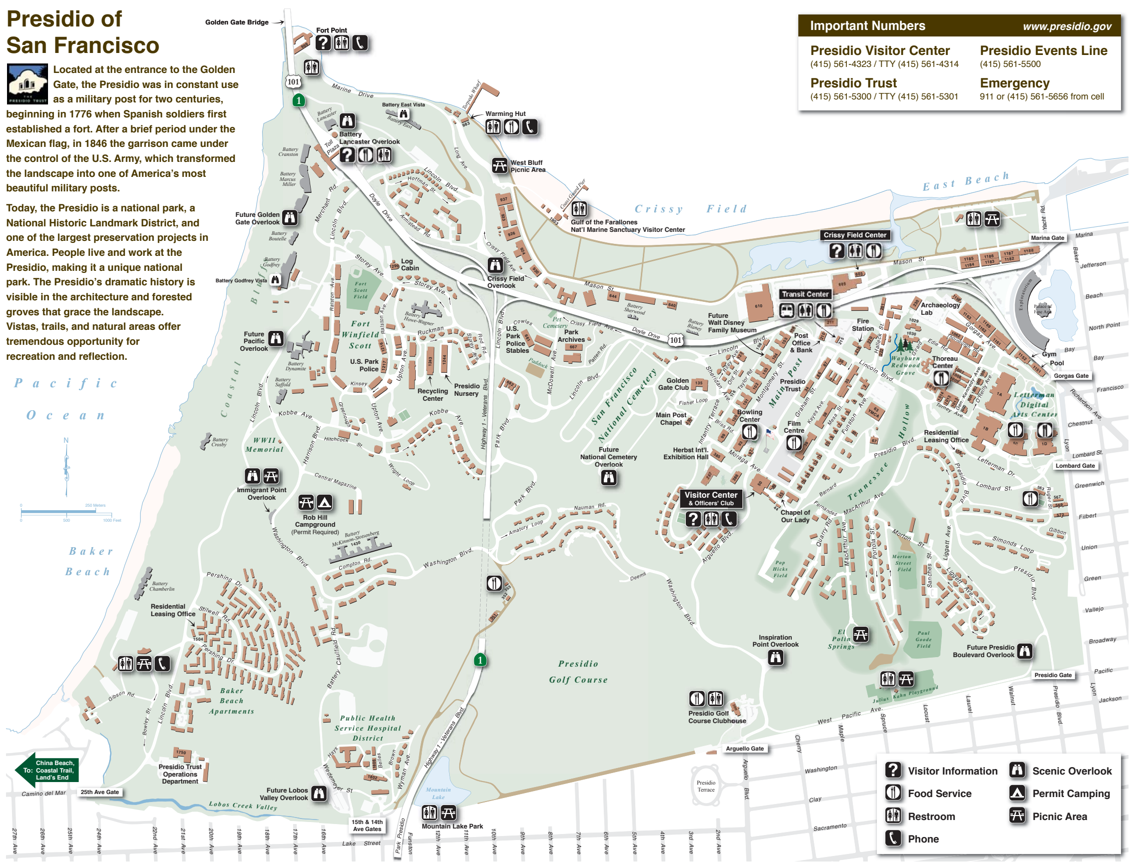

Presidio of San Francisco
Located at the entrance to the Golden Gate, the Presidio was in constant use as a military post for two centuries, beginning in 1776 when Spanish soldiers first established a fort. After a brief period under the Mexican flag, in 1846 the garrison came under the control of the U.S. Army, which transformed the landscape into one of America's most beautiful military posts.
Today, the Presidio is a national park, a National Historic Landmark District, and one of the largest preservation projects in America. People live and work at the Presidio, making it a unique national park. The Presidio's dramatic history is visible in the architecture and forested groves that grace the landscape. Vistas, trails, and natural areas offer tremendous opportunity for recreation and reflection.
Important Numbers
www.presidio.gov
Presidio Visitor Center
(415) 561-4323 / TTY (415) 561-4314
Presidio Events Line
(415) 561-5500
Presidio Trust
(415) 561-5300 / TTY (415) 561-5301
Emergency
911 or (415) 561-5656 from cell
Golden Gate Bridge
Fort Point
Crissy Field
East Beach
Crissy Field Center
Transit Center
Pacific Ocean
Baker Beach
Presidio Golf Course
San Francisco National Cemetery
Visitor Center & Officers' Club
Public Health Service Hospital District
Baker Beach Apartments
Lobos Creek Valley
Mountain Lake Park
Visitor Information
Food Service
Restroom
Phone
Scenic Overlook
Permit Camping
Picnic Area

Figure 8

ing Lobos Creek. The Presidio Trust manages the water treatment plant for Lobos Creek. When the Presidio was turned over to the National Park Service in 1994, annual federal appropriations in the range of $16 million to $25 million were authorized to subsidize annual operating expenses of $38 million to $40 million. Federal appropriations will cease in 2013, by which time the Presidio Trust must generate sufficient revenues to support its operations, capital improvements, natural environments, built spaces, and infrastructure. This is being accomplished primarily through commercial and residential leasing. There are approximately 225 businesses currently operating in the Presidio. Renovation now underway of the Public Health Hospital into an apartment complex will bring the number of residential housing units to 1,300+ (Jody Sanford, Presidio Trust, 21 April 2009, personal communication).

The Richmond District

Most of the watershed lies to the south of the Presidio encompassing much of the Richmond District. Population of this area, based on the 2000 census, is 74,679. Land use is a combination of housing units, commercial establishments, sidewalks, driveways, parking lots, streets, and major transportation corridors such as Geary Boulevard, Clement Street, and California Street. Areal extent of this densely developed district is 692 hectares (1,709 acres), much of it impervious surface cover (Teresa Ojeda, San Francisco Planning Department, 23 April 2009, personal communication).

Hydrologic System

Lobos Creek is a perennial, first-order creek and flows from its headwaters near 16th Avenue approximately 1.6 kilometers in a west/northwesterly direction along the southwestern border of the Presidio. Seeps and springs, which feed the creek, are hydrogeologic features of groundwater outflow into the stream channel. The primary difference between seeps and springs is flow. Groundwater issuing from seeps is typically slower and smaller in volume than groundwater from springs (http://water.nv.gov/WaterPlanning/dict-1/PDFs/wwords-s.pdf last accessed 15 May 2009).

Field investigation in 1998 by the Urban Watershed Project identified seeps and springs along the banks of the channel over a reach of approximately 0.8 kilometers between 17th Avenue and 22nd Avenue (Figure 9). Seventeen seeps and two springs along the south bank, and six seeps and one spring along the north bank were identified. The south bank seeps between 18th Avenue and 21st Avenue provide the majority of water to the creek.

Similar observations were first recorded in historic reports. G.A. Elliott remarked, “As might be expected from the relative areas of the watershed on either side of the creek, the greater number of the springs feeding Lobos Creek are on the South bank owned by the Spring Valley Water Company” (Elliott 1911, 2). Hydraulic Engineer, M.J. Bartell, noted the following in his 1913 report, “From a superficial examination, it appears that 90 per cent of the flow of Lobos Creek comes from the South or Richmond District side, most of it be-

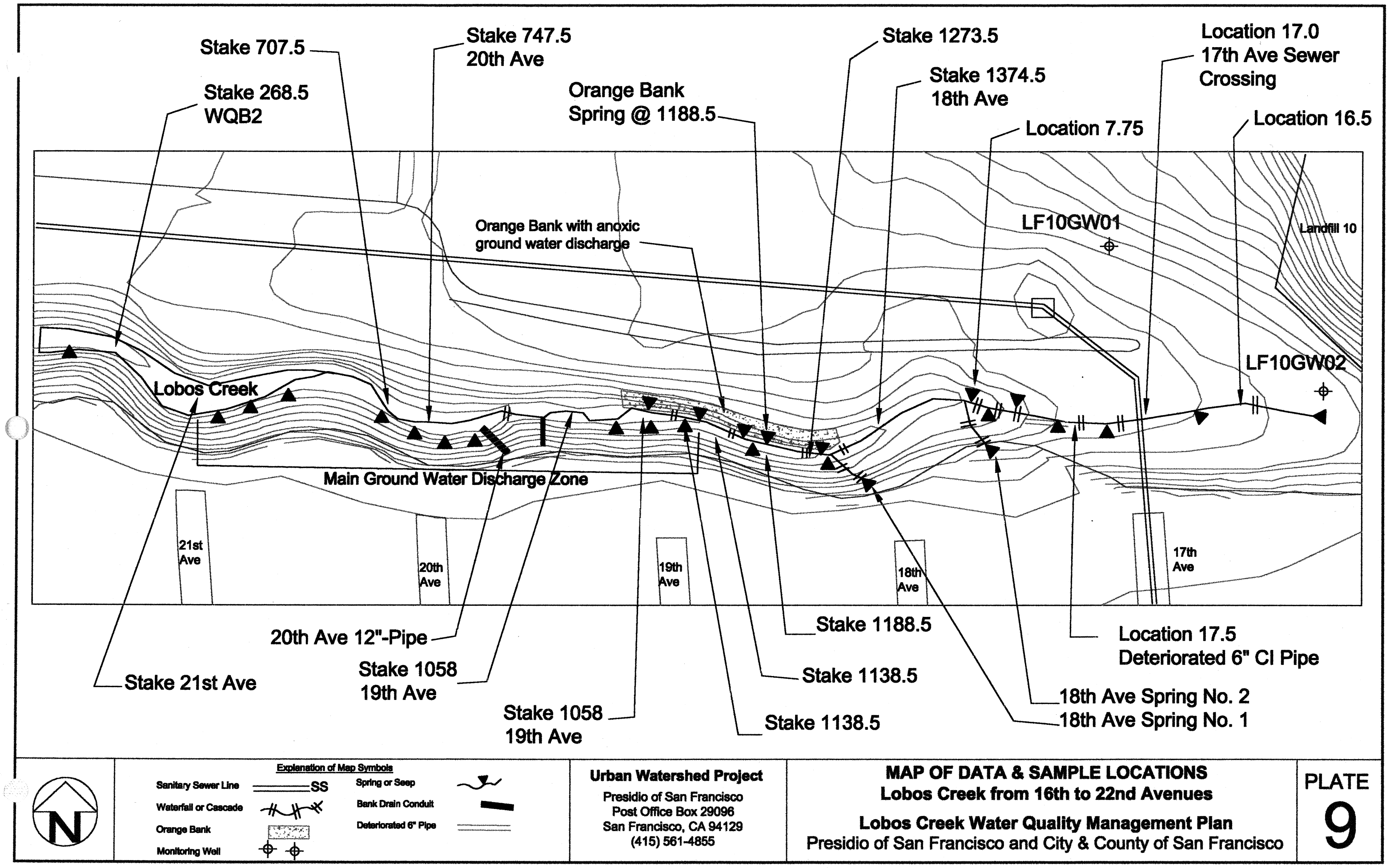

Stake 707.5
Stake 268.5
WQB2
Stake 747.5
20th Ave
Orange Bank
Spring @ 1188.5
Stake 1273.5
Stake 1374.5
18th Ave
Location 7.75
Location 17.0
17th Ave Sewer
Crossing
Location 16.5
Orange Bank with anoxic
ground water discharge
LF10GW01
Landfill 10
LF10GW02
Lobos Creek
Main Ground Water Discharge Zone
21st
Ave
20th
Ave
19th
Ave
18th
Ave
17th
Ave
20th Ave 12"-Pipe
Stake 21st Ave
Stake 1058
19th Ave
Stake 1058
19th Ave
Stake 1188.5
Stake 1138.5
Stake 1138.5
Location 17.5
Deteriorated 6" CI Pipe
18th Ave Spring No. 2
18th Ave Spring No. 1
N
Explanation of Map Symbols
Sanitary Sewer Line
SS
Waterfall or Cascade
Orange Bank
Monitoring Well
Spring or Seep
Bank Drain Conduit
Deteriorated 6" Pipe
Urban Watershed Project
Presidio of San Francisco
Post Office Box 29096
San Francisco, CA 94129
(415) 561-4855
MAP OF DATA & SAMPLE LOCATIONS
Lobos Creek from 16th to 22nd Avenues
Lobos Creek Water Quality Management Plan
Presidio of San Francisco and City & County of San Francisco
PLATE
9

Figure 9

tween 19th and 21st Avenues" (San Francisco Bureau of Engineering 1913, 101). Hermann Schussler, Chief Engineer of Spring Valley Water Works from 1866 to 1915, conducted investigations on the creek's source and determined that 75% of the total discharge of 2.25 million gallons per day (MGD) (8,517 cubic meters per day) occurred in the stretch between 18th and 22nd Avenues, from "underneath its high south bank" (Schussler 1915, 26).

Estimated creek volume has ranged from three MGD (11,356 m3/day), according to historic reports, to 0.77 MGD (2,915 m3/day) at the end of the 1987-1992 drought. For perspective, the volume of three Olympic-size swimming pools is slightly less than two million gallons (7,571 m3).

Studies on flow when Lobos Creek was first tapped as a drinking water supply in 1858 by the Bensley Water Company were limited. A quotation in the *Alta California* newspaper, 15 February 1860, offers some indication of discharge. "The Lobos Creek runs summer and winter about two millions of gallons (8,000 m3) each twenty-four hours, which is estimated will supply a population of 150,000 persons with fifteen gallons (57 liters) per day each, or 200,000 with ten gallons (38 liters) each" (Behan 1922, 9). The population of San Francisco in 1860 was just under 57,000. Today, according to the San Francisco Public Utilities Commission, the average San Franciscan uses about 72 gallons (272 liters) of water per day (http://sfwater.org/mto_main.cfm/MC_ID/13/MSC_ID/168/MTO_ID/355 last accessed 2 February 2009).

An earlier quote in the *Alta California*, 3 August 1857, is more general. "From a conversation with the Engineer of the projected works, we understand that the stream of water from whence the supply is to be derived is never failing, and though not large, it flows the entire year in near the same volume, which he estimates will over-supply the city at present and for a long time to come" (Behan 1922, 8).

An historic resource study examines the importance of the water supply of "about 3,000,000 gallons per day" (11,356 m3/day) during the Civil War (Thompson 1997, 41).

A report by Charles Gilman Hyde (1911) notes a maximum yield of three MGD (11,356 m3/day). In this same report he references T.R. Scowden's 1875 report explaining the delivery process (by flume and pumps) of 2.25 MGD (8,517 m3/day) to three reservoirs on and near Russian Hill. Both Mountain Lake and Lobos Creek are the sources but a quantity breakdown per source is not provided. Hyde also references Colonel G.H. Mendell's 1877 report wherein it is noted, "two millions (7,571 m3) as coming from Lobos Creek" (Hyde 1911, 5). G.A. Elliott's report of 1911 includes a table of rate-of-flow in MGD, averaged per month, for the years 1870-1888. The range is 1.55 MGD to 2.55 MGD (5,867 m3/day - 9,653 m3/day). The report also shows a figure of 2.99 million gallons (11,318 m3) measured on 12 November 1908 (Elliott 1911, 5).

In 1986, Clyde Wahrhaftig, Professor of Geology and Geophysics at University of California, Berkeley, was told by Peter Straub, Director of Engineering and Housing at the Presidio, that the Army draws an average of 1.95 MGD (7,382 m3/day) from Lobos Creek (Wahrhaftig 1986).

In October 1991, engineering firm, Nolte and Associates, measured flow of 1.65 MGD (6,246 m3/day) between 20th Avenue and 21st Avenue. Interestingly, two months later, flow was 0.77 MGD (2,915 m3/day). Explanation for the 53 percent decrease was a drop in groundwater levels in response to a continuing dry weather cycle (Nolte and Associates 1993).

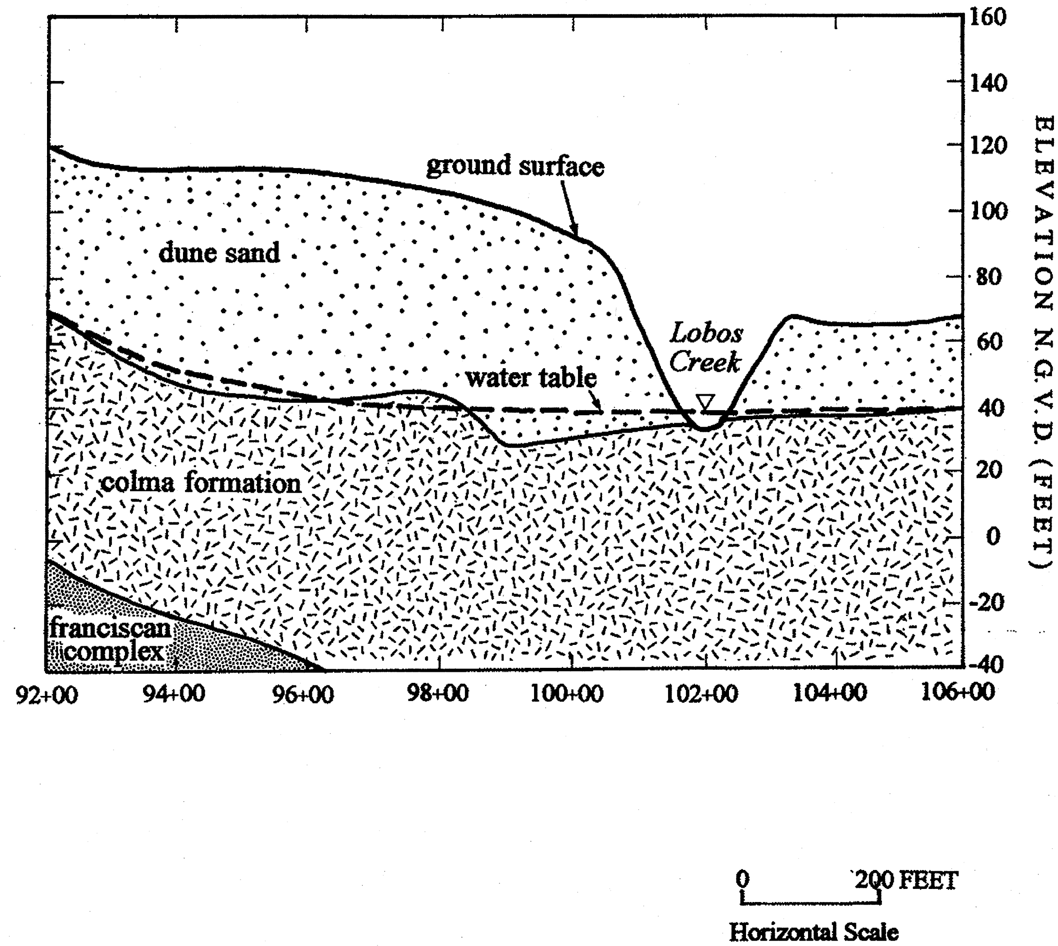
Current flow averages 1.4 MGD (5,300 m3/day). The Presidio water treatment plant draws approximately 0.8-0.9 MGD (3,000 m3/day - 3,400 m3/day). Average daily demand for year 2008 was 0.86 MGD (3,255 m3/day). More than 50 percent of this was used for irrigation. Supplemental water is purchased from the San Francisco Public Utilities Commission when demand exceeds production (Scott Sacks, Presidio Trust, 18 May 2009, personal communication).

Geomorphic Evolution

The natural landscape of nearly 78 square kilometers of the San Francisco peninsula was dune ecosystems until development in the second half of the 19th century. Dune sands underlie more than half of San Francisco and can be up to 45 meters thick (San Francisco Department of City Planning 1996). A brief explanation of Lobos Creek through geologic time provides an understanding of its evolution. The geologic assemblage of Lobos Basin and the watershed is Franciscan Complex overlain by Colma Formation overlain by dune sands (Figure 10).

The Franciscan Complex (200 million to 80 million years old; Late Jurassic and Cretaceous periods) is a bedrock mélange of ocean floor material consisting of graywacke sandstone and argillite, and lesser amounts of greenstone (altered basalt), radiolarian ribbon chert, limestone, and serpentinite (Elder 2001). In the San Francisco North Quadrangle, the Franciscan Complex may be up to 10,000 feet (3,048 meters) thick. At Baker Beach, near Lobos Creek, it is about 2,350 feet (716 meters) thick with outcrops visible at the north end (Schlocker 1974; Elder 2001). Approximately 70 meters beneath the Presidio water treatment plant is Franciscan Complex bedrock (Kern and Youngkin 1999).

The Colma Formation (80,000 to 125,000 years old; Pleistocene epoch), overlaying the Franciscan Complex, is a relatively thin layer of unconsolidated estuarine/coastal deposits of fine-grained sand, silty sand, and beds of clay as thick as 1.5 meters. These materials



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Consultants in Hydrology

Typical Geologic Cross-Section of Lobos Creek Valley

Figure 10

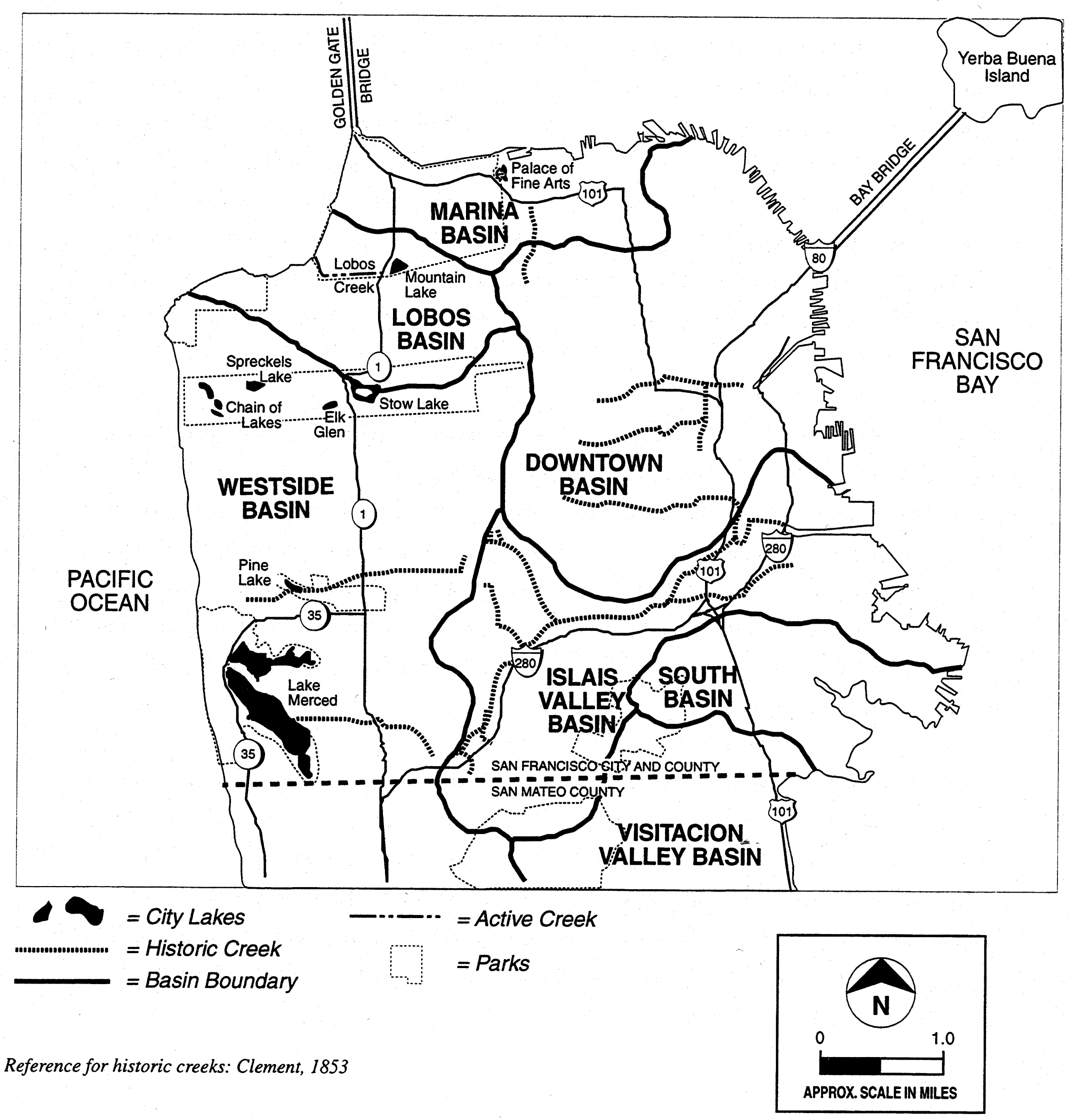
were deposited during an interglacial period when sea level was slightly higher than today. The Colma Formation has a maximum thickness of approximately 300 feet (91 meters) (Schlocker 1974) and locally forms a thin veneer over rocks stretching from the Golden Gate Headlands to Angel Island and south to the peninsula (Elder 2001). The Colma Formation controls the gradient and outlet elevation of Lobos Creek (Kern and Youngkin 1999). It is the primary water-bearing unit of the aquifer. Before dune fields were established, the Colma Formation was a surface deposit and the watershed generated more runoff than infiltration. A stream channel was likely initiated and flowed as an ephemeral stream (Philip Williams & Associates 1995).

Approximately 5,000–6,000 years ago Holocene dune sands from beaches along the coastline were deposited by strong westerly winds. Dune sands overlaying the Colma Formation range in thickness up to 150 feet (46 meters) (Schlocker 1974). Consequently, the watershed surface shifted from Colma deposits to permeable sands. Precipitation infiltrated the sands and the water table built up beneath. Groundwater emerged as surface flow as the stream channel incised to the less permeable Colma Formation. The hydrology of the creek then shifted from an ephemeral to a perennial spring-fed stream. The constant flow prevented the channel from filling in with wind-blown sands while dunes formed around the creek. Along Lobos Creek the contact between the Colma Formation and dune sands is no deeper than about 35 feet (11 meters) below ground surface (Kern and Youngkin 1999).

Lobos Basin

Lobos Creek is a surface expression of the groundwater table of Lobos Basin, one of seven groundwater basins in San Francisco (Figures 10 and 11). Surface water and groundwater are two manifestations of a single integrated resource (Winter et al. 1998). A groundwater basin, also called an aquifer, is an area underlain by permeable materials capable of furnishing a significant supply of groundwater to wells or storing a significant amount of water (State of California Department of Water Resources 2009, http://www.groundwater.water.ca.gov/bulletin118/basin_maps/definition.cfm last accessed 15 March 2009). Groundwater basins are defined by flow-system divides similar to watersheds which are separated on the basis of topographic divides such as bedrock ridges. Groundwater divides commonly do not underlay surface divides due to depth of flow, hydraulic conductivity, and dynamic recharge and discharge conditions related to climate and precipitation (Winter, Rosenberry and LaBaugh 2003).

Since the land surface is its upper boundary, Lobos Basin is an unconfined aquifer. Areal extent of the basin is approximately 963 hectares (2,379 acres) and discharge is into the Pacific Ocean via Baker Beach (Phillips, Hamlin, and Yates 1993). A trough of Franciscan Complex bedrock whose axis dips to the north-northwest defines the horizontal and vertical limits of the basin. The marine and terrestrial sediments deposited in this trough contain water-bearing units of the aquifer (Nolte and Associates 1993). The amount of groundwater stored in the aquifer is estimated to be between 25 million and 41 million m3



Reference for historic creeks: Clement, 1853

SF RWMP/GWMP Program EIR ■

Figure 51
Location of Lakes and Creeks in San Francisco

Figure 11

(6.7 billion-10.8 billion gallons), with a mean residence time of 4.7 to 15 years. Sources of recharge are precipitation, surplus irrigation water, and leaking water and sewer/storm mains (Wahrhaftig 1986). Annual recharge is estimated as 511 million gallons (1.9 million m3), with leaking pipes accounting for about 40 percent of this (Phillips, Hamlin and Yates 1993; http://www.dpla2.water.ca.gov/publications/groundwater/bulletin118/basins/pdfs_desc/2-38.pdf last accessed 30 April 2009).

Based on his investigations, Hermann Schussler (1915) produced a watershed map of Lobos Creek and the subterranean flow of water that feeds it. Later studies of well water level measurements also conclude that principal groundwater flow direction is northwest (Philip Williams & Associates, Harding-Lawson and Associates, and KCA Engineers 1995) (Figure 12). At elevations above the channel bottom, the bank intercepts groundwater flow. Therefore, the groundwater table is higher than the channel elevation, resulting in Lobos Creek as a surface expression of it (Kern and Youngkin 1999). Yet the water table is generally below the level of stormwater/sewer lines which, when leaks in the lines occur, results in exfiltration of sewage to the groundwater system (Phillips, Hamlin and Yates 1993).

Geophysical investigation indicates a north-south bedrock ridge slightly east of 20th Avenue which may exert a controlling influence on the discharge of groundwater to the creek (Nolte and Associates 1993). Because the water surface elevation in the creek remains relatively constant through time, Lobos Creek also acts as a constant head boundary that is

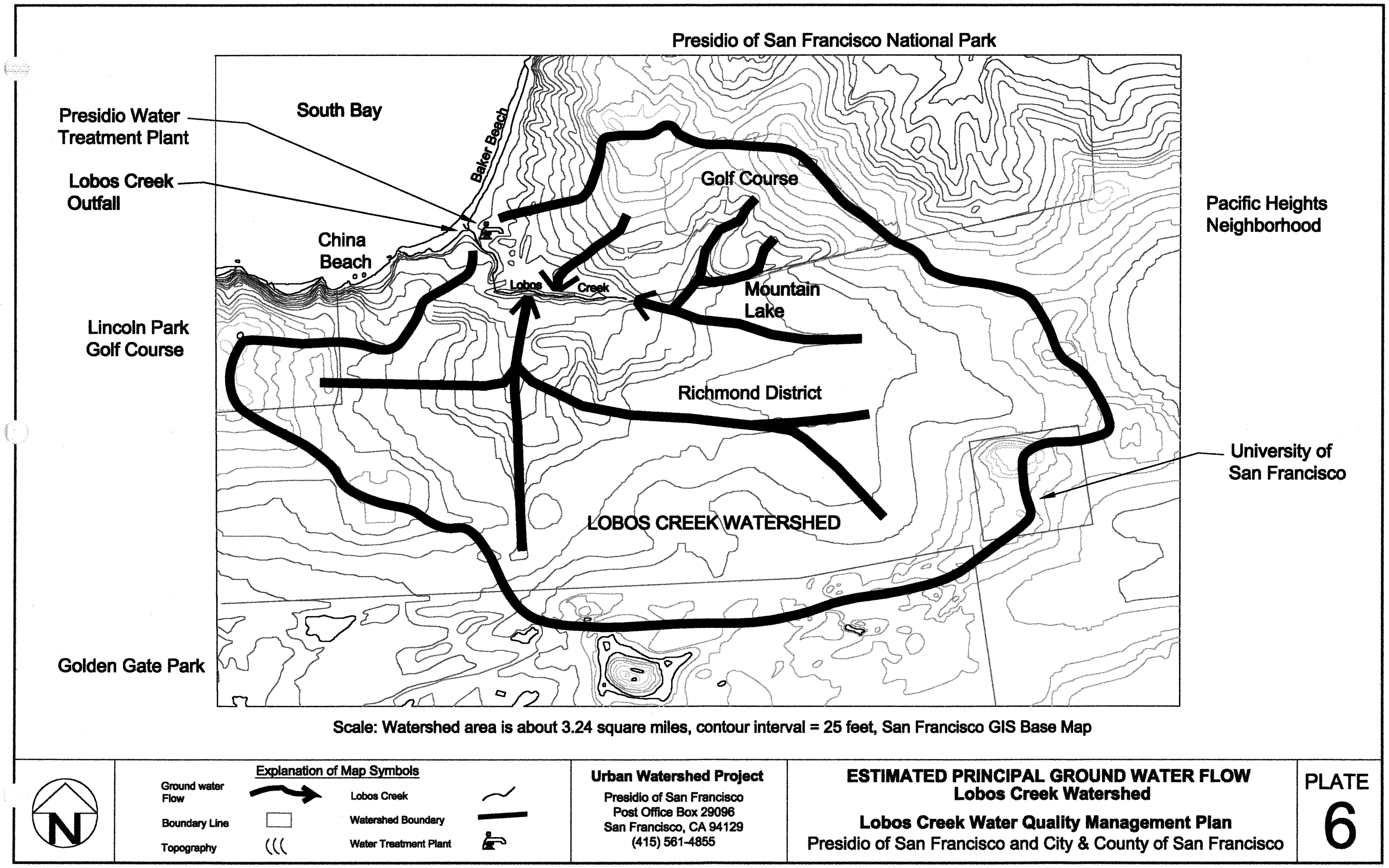

Presidio of San Francisco National Park
South Bay
Presidio Water Treatment Plant
Lobos Creek Outfall
Baker Beach
China Beach
Lincoln Park Golf Course
Golf Course
Lobos Creek
Mountain Lake
Pacific Heights Neighborhood
Richmond District
University of San Francisco
LOBOS CREEK WATERSHED
Golden Gate Park
Scale: Watershed area is about 3.24 square miles, contour interval = 25 feet, San Francisco GIS Base Map
N
Explanation of Map Symbols
Ground water Flow
Boundary Line
Topography
Lobos Creek
Watershed Boundary
Water Treatment Plant
Urban Watershed Project
Presidio of San Francisco
Post Office Box 29096
San Francisco, CA 94129
(415) 561-4855
ESTIMATED PRINCIPAL GROUND WATER FLOW
Lobos Creek Watershed
Lobos Creek Water Quality Management Plan
Presidio of San Francisco and City & County of San Francisco
PLATE
6

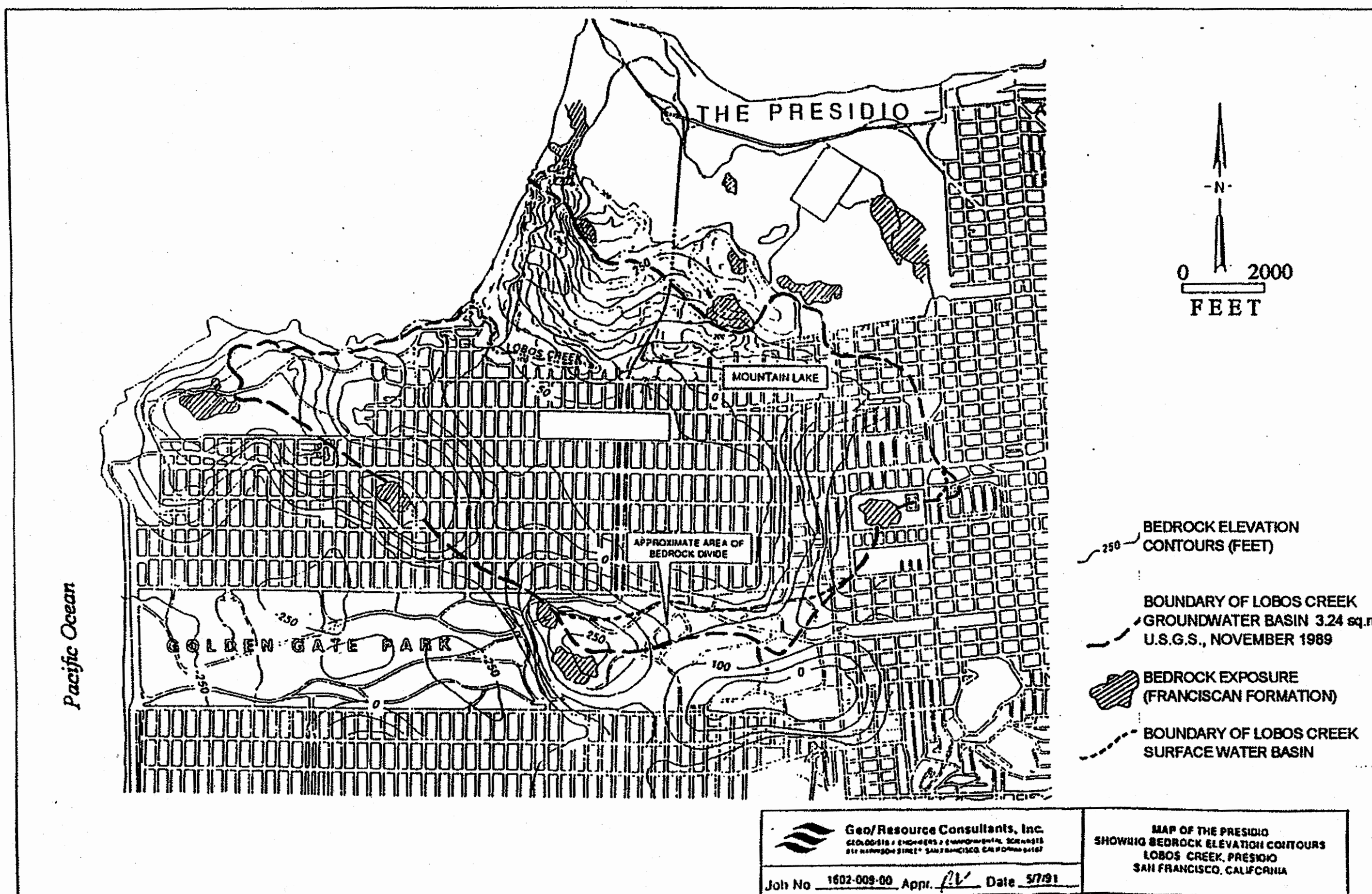
Figure 12

a primary controlling factor on the groundwater gradient between the creek and the Pacific coast (Nolte and Associates 1993).

The (surface) watershed drains an area approximately 842 hectares (2,080 acres) or 8.4 square kilometers (3.25 square miles), much of it encompassing the Richmond District. Less than 1.3 square kilometers (0.5 square miles) lies within the Presidio (Figure 13).

The watershed is defined largely by bedrock outcrops of the Franciscan Complex (Figure 14). From the west and moving in a counterclockwise direction, following are the hills that comprise the basin. Lincoln Heights (115 meters elevation), near the Palace of the Legion of Honor, is the western boundary. Southeast of this is Washington Heights (79 meters), in the heart of the Richmond District. The southern boundary is Strawberry Hill (125.5 meters) in Golden Gate Park. Northeast from the park, Lone Mountain (136.5 meters) and Laurel Hill (106.7 meters) are the eastern boundary. Northwest of the eastern boundary, within the Presidio, are Presidio Hill (112.7 meters) and Rob Hill (114 meters) which define the northern boundary (Graham 2004).

In an undeveloped landscape, precipitation that falls within these boundaries would eventually flow through Lobos Creek. However, the city of San Francisco has a combined sewer/stormwater collection system. Precipitation that falls on the western side of the city is diverted to the combined city system, drains to the Oceanside treatment plant, is



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Historic Groundwater and Surface Water Basins for Lobos Creek

Figure 13

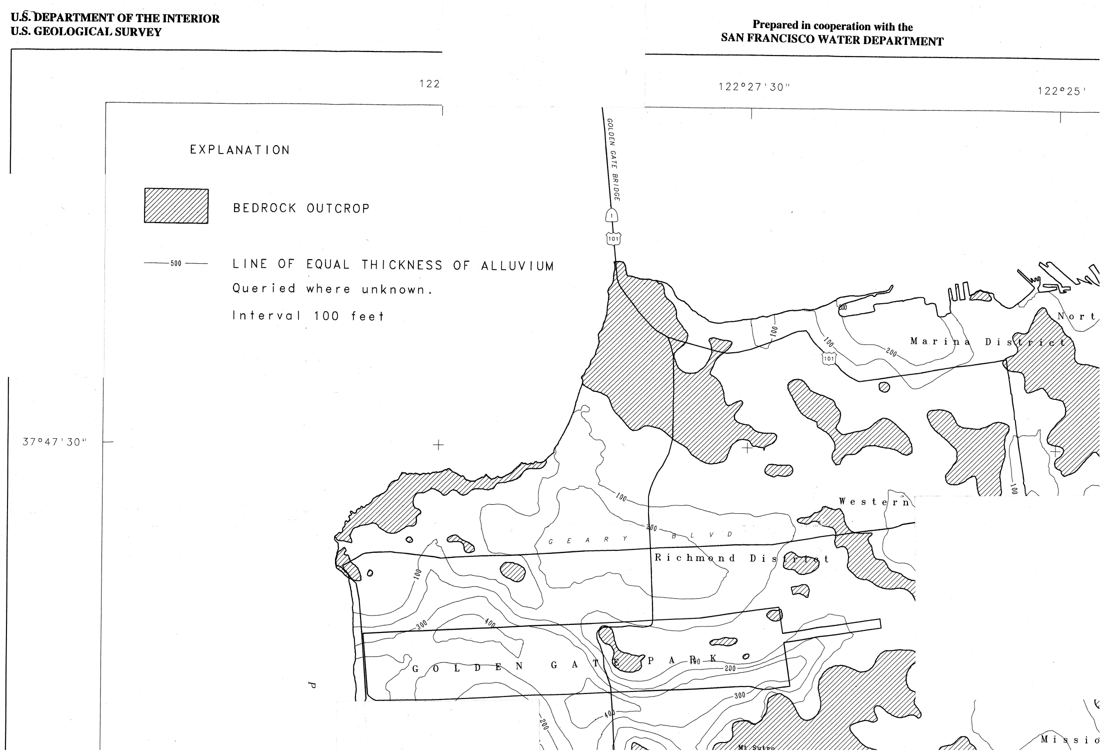

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
Prepared in cooperation with the
SAN FRANCISCO WATER DEPARTMENT
122°27'30"
122°25'
37°47'30"
EXPLANATION
BEDROCK OUTCROP
LINE OF EQUAL THICKNESS OF ALLUVIUM
Queried where unknown.
Interval 100 feet
GOLDEN GATE BRIDGE
Marina District
Western
GEARY BLVD
Richmond District
GOLDEN GATE PARK

Figure 14

treated and released into the Pacific Ocean. The reason for the combined system dates to the early days of San Francisco development. Cities built prior to 1900 did not treat sewage. It simply flowed in to local water bodies. When public health protection became a greater concern, sewage treatment became necessary. Separate systems were built to avoid the cost of treating stormwater too. By 1900 San Francisco had become a relatively dense, urban environment. The population was approximately 342,000. Separating the system would have been too costly and disruptive so it remained a combined system (Ramirez-Herrera, Sowers, and Richard 2006). The Presidio has a separate system from the City and County of San Francisco (CCSF). Stormwater mains are separate from sewer mains. However, much of the Lobos Creek watershed encompasses the Richmond District which is connected to the CCSF combined sewer/stormwater system.

Surface water runoff to Lobos Creek is volumetrically insignificant compared to groundwater contribution. Since 85 percent of the watershed encompasses the developed Richmond District, most surface water runoff drains to the city's combined sewer/stormwater system. Surface water runoff accounts for just five percent of flow in the creek, or 0.08 MGD (303 m3/day). Considering seasonal variations in rainfall, an average daily runoff is approximately 0.14 MGD (530 m3/day) from November through April, and 0.02 MGD (76 m3/day) from May through October (Dames & Moore 1994).

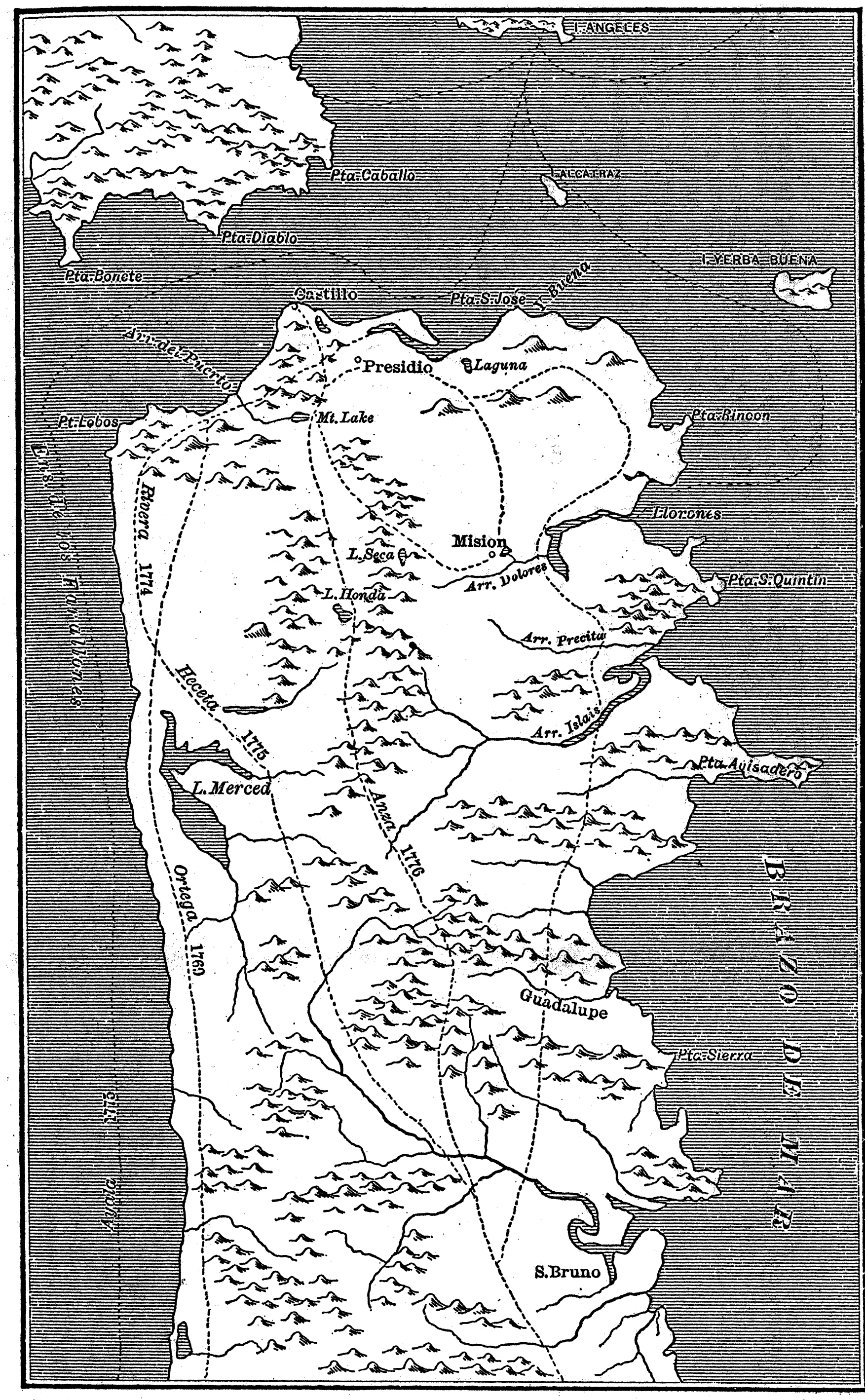
Mountain Lake

The proximity of Lobos Creek to Mountain Lake, within 400 meters, would imply a hydrologic connection. A map of Juan Bautista de Anza's 1776 Monterey to San Francisco expedition shows a surface connection between the lake and the creek (Figure 15). Reference is made to a lake on which the party camped and a stream flowing from it called Arroyo del Puerto (Bancroft 1884). Translated as 'valley or stream of the port', this is Lobos Creek.

In 1858 engineers from the Mountain Lake Water Company sank shafts between the lake and the head of Lobos Creek and determined there was no flow between the two bodies of water (Elliott 1911).

In his report of 1915, Hermann Schussler states, "I have been intimately acquainted with the entire locality surrounding Lobos Creek and Mountain Lake, ever since the spring of 1866, and at no time during this long period, has there been, nor could there ever have been a surface outlet from Mountain Lake in a westwardly direction over the divide between it and Lobos Creek" (Schussler 1915, 27).

The divide he refers to is a bedrock ridge underneath the Public Health Hospital. United States Geological Survey bedrock mapping shows a boring that encountered bedrock at an elevation of 137 feet (41.7 meters) at the hospital. This is higher than the elevation of



PENINSULA OF SAN FRANCISCO.

Figure 15

Mountain Lake at 129 feet (39.3 meters) (Nolte and Associates 1993). However, south of the lake, bedrock conditions probably do not preclude a groundwater connection in the Mountain Lake area and the Lobos Basin.

A report by engineering firm, Geo/Resource Consultants (1991), supports the evidence of a hydrologic connection between Mountain Lake and Lobos Creek. However, it is noted, recharge to the creek is predominantly from the south, whereas recharge from the lake to the creek is around five percent.

Present Setting

From its headwaters, Lobos Creek flows west towards Lincoln Boulevard. It is culverted at approximately 24th Avenue for approximately 50 meters and emerges on the north side of Lincoln Boulevard where it flows north to a diversion structure. It is here where up to 64 percent of the flow is diverted to the Presidio water treatment plant. One-thousand-eight-hundred-ninety-three m3/day (0.5 MGD) has been estimated to be the basic in-stream flow necessary to ensure resource preservation (Presidio Trust 2002). Non-diverted water is considered bypass and flows into another culvert for approximately 150 meters to an outfall structure at Baker Beach where it empties into the Pacific Ocean (Figures 16a and b). Upstream of Lincoln Boulevard, north of the creek, a locked gate and chain-link fencing prevent people from entering. Residential homes line the south side approximately 20 meters above the creek. Thick vegetation is substantial on the south slope beneath the

Figure 16. Outfall structure at Baker Beach, 12 March 2009. Photo by J. Depman

Figure 16. Flow from outfall structure at Baker Beach to Pacific Ocean, 12 March 2009. Photo by J. Depman

homes, and remnants of chain-link fencing and its concrete foundation appear on the slope and in the creek.

Elevation at the headwaters of Lobos Creek is approximately 38 meters and the outfall structure is at sea level. This results in an average slope of about 0.4 percent (Kern and Youngkin 1999). There is a two percent slope at the outfall structure which precludes tidal influence (Philip Williams & Associates 1995).

In the immediate vicinity of one of this study's sites, called 18th Avenue, an orange gel-like substance appears at the north bank / surface water interface. It is also present on the south bank though in lesser amounts. It likely represents what the U.S. Geological Survey refers to as red flocs, bacteria reacting to the presence of iron where anoxic groundwater discharges into oxygenated water or air (Robbins et al. 1997). Dissolved oxygen measurements in the area by the Urban Watershed Project confirm anoxic groundwater coming from the north bank (Kern and Youngkin 1999).

The consortium of bacteria is likely *Siderocapsa sp*., *Gallionella ferruginea*, and *Leptothrix ochracea* (Eleanora Robbins, formerly with U.S. Geological Survey, 6 May 2009, personal communication). The bacteria actively oxidize iron for energy or passively precipitate iron oxide. The result is orange-colored slime and iridescent, oily-appearing films on the surface of the water. To test whether it was bacteria or oil at the 18th Avenue site, I broke the film with my hand. The 'platelets' remained separate which indicated bacteria. If they had reformed, it would likely indicate oil.

An orange residue built up on the housing and an instrument (water temperature/EC data logger) installed for this study. It was likely a result of red flocs in the water. The residue strongly bonded to surfaces since attempts to wipe it from the logger and housing were unsuccessful.

Associated with these bacteria is manganese. However, there doesn't appear to be a manganese cycle in the vicinity since rocks in the creek do not have a black coating (Eleanora Robbins, formerly with U.S. Geological Survey, 7 May 2009, personal communication). The Presidio water treatment plant treats water for iron and manganese to ensure maximum contaminant levels are not exceeded.

The Colma Formation, containing magnetite and other iron-bearing minerals, is likely the source of the iron (Will Elder, Geologist, National Park Service, 25 June 2009, personal communication). Serpentinite, a rock of the Franciscan Complex, contains largely magnesium with small amounts of iron. Other iron-bearing rocks include chert and greenstone. A large band of serpentinite exists in the Hunters Point mélange, which underlies the west/southwest region of the Presidio (Figure 7) (Will Elder, Geologist, National Park Service, 15 May 2009, personal communication). Serpentinite is exposed on the coastal bluffs

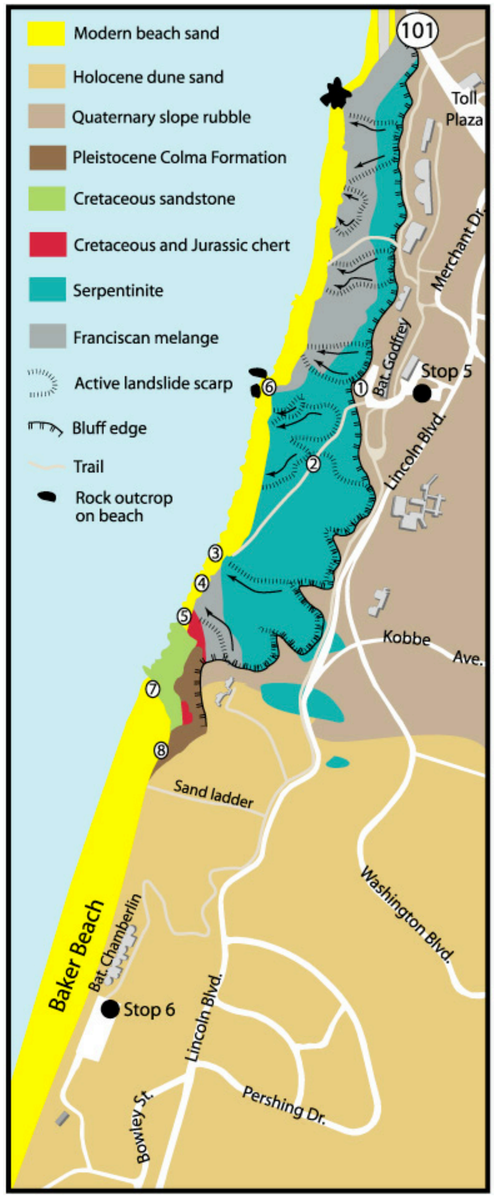


Figure 17. Geologic map of coastal bluffs in the Presidio of San Francisco
Source: Elder 2001

above Baker Beach. Chert underlies a part of the Presidio and is also exposed on the bluffs above Baker Beach (Figure 17). About 20 to 25 percent of the Marin Headlands terrane is basalt which has been subjected to some level of alteration into greenstone.

Vegetation

Just north of the creek is restored dune habitat. Lobos valley holds five rare or endangered dune plants among its 130 native species, including San Francisco lessingia (*Lessingia germanorum*) and dune gilia (*Gilia capitata ssp. chamissonis*). Riparian vegetation is a mix of exotic and native species. Approximately 60 percent of the plant species are exotic (National Park Service 1996). Coast live oak (*Quercus agrifolia*), Monterey pine (*Pinus radiata*), Miner's lettuce (*Claytonia perfoliata*), poison oak (*Toxicodendron diversilobum*), arroyo willow (*Salix lasiolepis*), and riparian grasses are prevalent on the north bank. Blue Gum Eucalyptus (*Eucalyptus globulus*) trees are part of the landscape but are not abundant. The south bank is predominantly covered in non-native Cape ivy (*Delairia odorata*), Himalayan blackberry (*Rubus discolor*), and ferns. Mature pine trees on residential properties overlook the south bank. Nasturtium plants (*Tropaeolum majus*) are substantial in size and distribution along the south bank. Watercress (*Rorippa nasturtium-aquaticum*) is abundant in nearly all areas of the creek year round (National Park Service 1996). A photograph from 1915 compared to a current photograph, both taken looking downstream, illustrates the overgrowth of vegetation now present on the south bank (Figures 18 and 19).

Figure 18. Looking downstream (west), 1915.

Figure 19. Looking downstream (west) from 18th Avenue site, 14 December 2008. Photo by S. Heiser

Climate

The Presidio has a temperate maritime climate characterized by cool wet winters and foggy summers. Extreme temperatures are rare due to the marine influence. Annual maximum and minimum temperatures are rarely above 27 ˚C or below 4 ˚C. The annual average high is 19 ˚C. Mean annual precipitation is 22 inches (560 millimeters), most of which occurs during the rainy season from November to April (Kern and Youngkin 1999).

Prevailing wind is generally westerly and in spring and summer the Presidio is frequently exposed to strong winds from the north/northwest through the Golden Gate. Due to the prevailing westerlies from the Pacific Ocean the watershed normally experiences excellent air quality (Dames & Moore 1994).

The waters of San Francisco Bay influence the normal and expected seasonal temperatures by cooling shoreline air masses during the summer and warming them in winter. Fog often blankets the Presidio during the late spring and summer and fog drip is a significant addition to precipitation amounts. Coastal fog causes reduction in rates of evapotranspiration (Kern and Youngkin 1999).

The next chapter addresses methods. To preface this section, a comment is made regarding methodology in physical geography.

A 1999 issue (volume 89, issue 4) of the *Annals of the Association of American Geographers* contains nine essays on methodology in physical geography. The collection represents a forum for authors' responses to questions around topics including key methodologies within the subdisciplines; the influence of these methodologies; and methodological discussion towards an integrated physical geography perspective. The essays are written in the context of hydrology, geomorphology, climatology, biogeography, pedology, and GIS. Bauer (1999) loosely defines methodology as the vehicle by which persuasive arguments are constructed. It is a combination of techniques, observations, concepts, and theories bound by reasoning and logic that collectively function together to meet expected outcomes or explanations.

A couple of points from the hydrology essay which influenced methodological direction of this study were the emphasis on field studies and the importance of understanding processes from a physically-based perspective. Hirschboeck (1999) emphasizes that geographers can provide multiple insights into hydrologic processes through the lenses of place, space and scale. A defining characteristic of hydrology research is mathematical modeling. This inadequate 'blackboard hydrology' rather than observations in nature has created a disconnect between theory and practice. Also, discussion of empirical and causal models provided an explanation of analysis approach. While the former describes observed patterns of data, the latter critically examines the quality and nature of the data and the real-world behavior of the physical processes involved (Hirschboeck 1999).

CHAPTER 5: Methods

This chapter describes site selection, data collection equipment, and the process by which water temperature, specific conductance, and groundwater level were measured. Isotope analysis methodology is also addressed.

Before installing instruments in the creek it was necessary to apply for a Scientific Research and Collecting Permit through the National Park Service. Processing time for the permit was approximately seven weeks. In addition to the authorized permit, a General Conditions document outlined privileges, Investigator Annual Report requirements, and other stipulations.

Site Selection

For this study, site one is called ‘20th Avenue’ and site two is called ‘18th Avenue’. The names are a general reference for the location of the sites. Site one is in the creek north of where 20th Avenue ends. Coordinates for 20th Avenue site are 37° 47’ 13.65”N, 122° 28’ 47.75”W. Site two is in the creek north of where 18th Avenue ends. Coordinates for 18th Avenue site are 37° 47’ 13.33”N, 122° 28’ 41.67”W (Figure 20).

Figure 20. Study sites in the Presidio of San Francisco

At each site, two continuous-monitoring data loggers were installed: Odyssey Water Level Logger and Odyssey Salinity/Temperature Logger. The instruments are manufactured by Odyssey Dataflow Systems in Christchurch, New Zealand.

The selection of two sites was based on several factors. Seeps along the south bank are the primary source of water to Lobos Creek. Therefore, the south bank, rather than the north bank, was considered more appropriate for equipment installation. Additionally, nitrate levels are consistently higher on the south side of the creek, and more specifically, in the area of 20th Avenue compared to 18th Avenue. The 20th Avenue site is approximately 150 meters downstream of the 18th Avenue site.

Multiple visits to Lobos Creek at different times of the year to observe conditions such as vegetation and flow helped determine final site selection. Sites were chosen based on visual observation of flow from seeps on the south bank.

Accessibility to the sites was also considered. Data were downloaded at each site periodically and required connecting each logger to a laptop computer. It was necessary to ensure this could be done efficiently and safely every time.

Figures 21 and 22 are photographs of 18th Avenue site and 20th Avenue site, respectively.

Figure 21. 18th Avenue study site, 12 March 2009. Photo by J. Depman

Figure 22. 20th Avenue site, 5 March 2009. Photo by J. Depman

Data Loggers

Some studies which have utilized data loggers for recording stream water temperature include Story, Moore, and Macdonald (2003); Webb, Clack, and Walling (2003); and Johnson (2004). See Holloway et al. (1998) for data loggers that recorded water level to calculate stream discharge. Keen (1992) used data loggers to document the dynamic characteristics of the water table divide beneath sand dunes between Island and Hackberry Lakes in western Nebraska. See Pellerin et al. (2007) for data loggers that recorded water level and specific conductance in an urban watershed. See Schoellhamer and Buchanan (2008) for continuous monitoring in the San Francisco Bay and Delta. The U.S. Geological Survey's Pacific Islands Water Science Center used Odyssey water level loggers in Northern Guam in 2004-2005 (http://hi.water.usgs.gov/studies/guamlens/datacollection.html last accessed 28 May 2009). See Davis and Davis (2001) for a data logger design to continuously monitor electrical conductivity, temperature, and water level in remote regions.

The battery-operated data loggers for this study are relatively compact: length 19 centimeters, width 4 centimeters. Each recorder contains (2) 3.6 volt Lithium cells. Sensors, which measure water level, water temperature, and electrical conductivity are contained inside each instrument casing. Each recorder has 64k bytes memory. Based on a 30-minute scan time, the water level data loggers store about 22 months of readings, and the water temperature/EC data loggers store about 11 months of readings.

Figure 23. Locations of precipitation and air temperature data collection sites

The water level data logger has a 1.5 meter Teflon sensor element which extends from the base of the recorder. A brass counterweight, 14 centimeters in length, extends from the bottom of the Teflon element. The water level data loggers measure water level as it rises and falls along the Teflon element. Measurements are in millimeters from the bottom of the counterweight. Resolution is 0.8 mm.

Depending on the environment in which electrical conductivity data loggers are used (i.e., estuary, freshwater stream), a measurement range is determined in order to provide as much precision in the readings as possible. Resolution and accuracy improve as the range decreases. The range of the data loggers for this study is 0-20 mS/cm. It is within the range for freshwater systems. The range, on Odyssey data loggers, for marine environments is 0-80 mS/cm. Ranges vary somewhat by manufacturer. For example, Hach ranges are 0-19.99 mS/cm, 0-120 mS/cm, and 0-200 mS/cm for brackish and saline water. Testo ranges are 0-200 mS/cm and 0-300 mS/cm. Fisher Scientific range is 0.1-20 mS/cm. Microdaq ranges are 0-37 mS/cm and 10-50 mS/cm.

The conductivity sensor operates by inducing an alternating current in a closed loop and measures the magnitude of current to determine the conductivity of the water. Electrical conductivity, the raw measurement from which specific conductance is derived, is temperature-dependent. At higher temperatures water becomes less viscous and ions can move more easily. Temperature compensation distinguishes conductivity readings due to solutes from those due to temperature. These loggers are standardized to a reference temperature of 20 ˚C with a temperature coefficient of 1.8 percent per degree Celsius. Therefore, the electrical conductivity measurement is increased by 1.8 percent per degree when the temperature is below 20 ˚C, and decreased by 1.8 percent per degree when the temperature is above 20 ˚C. Resolution is +/- 0.05 mS/cm; accuracy is +/- 5 percent full scale (+/- 1 mS/cm). The temperature range is 0-70 ˚C; resolution is +/- 0.1 ˚C; accuracy is +/- 1 ˚C.

All instruments were programmed to scan at 30-minute intervals. Since the creek receives minimal surface runoff and there is little change in flow during rain events, as indicated by lack of floodplain development, readings of less than 30-minute increments were not warranted.

Water level loggers were housed in PVC pipe, 2.3 meters in length and five centimeters in diameter. Holes drilled in the PVC pipe along the mid-section were covered with nylon to act as a filter, allowing water into the pipe yet keeping sediment out. A cap was fitted to the bottom of the pipe to prevent sand from filling the pipe. A removable cap was fitted to the top of the pipe to prevent debris from falling into the pipe.

Approximately two meters distance from each water level data logger is the water temperature/electrical conductivity logger. The logger is mounted in separate housing which sits in the creek bed at the seep outflow. The housing is PVC pipe measuring 0.7 meters in length and 10 centimeters in diameter. Holes drilled in the PVC pipe along the mid-section were covered with nylon to act as a filter, allowing water into the pipe yet keeping sediment out. The logger is suspended in the PVC pipe and entirely submerged in creek water. A cap was fitted to the bottom of the pipe to prevent sand from filling the pipe. A removable cap was fitted to the top of the pipe to prevent debris from falling into the pipe.

Data Collection

The data loggers and housing were installed in July 2008 and recordings started on 24 July 2008. Data were downloaded and loggers restarted on 17 October, 11 and 18 December, 2008; 8 and 22 January, 18 February, 12 March, and 17 April, 2009. Data collection for this study covered (266) 24-hour periods from 25 July 2008 to 16 April 2009.

For each data logger, a site profile was created on a laptop computer using Odyssey Dataflow Systems software. Site profiles contain information unique to each data logger such as serial number, site name, calibration data, and scan time. Site profiles were accessed for download purposes. The data loggers convert raw values to measurements based on calibration data entered into the respective site profile.

Odyssey Dataflow Systems provided calibration data for the water temperature/electrical conductivity loggers. For temperature, two calibration points (unique to each logger: 459 and 3394 for 18th Avenue logger; 369 and 3306 for 20th Avenue logger) corresponded to two measured values in degrees Celsius (4.2 and 34.3). For specific conductance, six calibration points (unique to each logger: 1215, 1620, 2670, 4805, 7170, 9385 for 18th Avenue logger; 1390, 2195, 3770, 5945, 8300, 9945 for 20th Avenue logger) corresponded to six measured values in millisiemens per centimeter (0.12, 4, 8, 12.1, 16.3, 20.2).

Calibration data for the water level loggers was based on values obtained by immersing the Teflon element in water to two points (200 mm from the bottom of the counterweight and 1,500 mm from the bottom of the counterweight) and running TRACE mode on Odyssey software. Values stabilized at 1653 and 3941, respectively, for 18th Avenue data logger; and 1656 and 3898, respectively, for 20th Avenue data logger.

To ensure the loggers were operating at full strength, battery charge was checked periodically in the field with a Fluke 111 multimeter. Odyssey Dataflow Systems recommends battery replacement if voltage is below 6 V. Voltage was 7.3 V when the recorders were installed and never dropped below 7.2 V.

In order to examine links between precipitation in the watershed and the parameters measured, precipitation data were obtained from the San Francisco Public Utilities Commission (SFPUC)'s Seacliff rain gauge (location: 37˚ 47' 21.444"N, 122˚ 29' 12.996"W) located in the neighborhood adjacent to Lobos Creek (Figure 23). Data obtained from SFPUC were 30-minute rainfall totals for the study period.

Hourly average air temperature data from the Bay Area Air Quality Management District (BAAQMD) Fort Funston meteorological tower (location: 37˚ 42’ 53.28”N, 122˚ 30’ 1.80”W) were obtained for the study period (Figure 23). Approximately 8.3 km from Lobos Creek, Fort Funston is a similar coastal exposed location.

Surface water temperature and specific conductivity data collected by the Presidio water treatment plant, as water enters the plant, were obtained for the study period. The plant is located at Baker Beach near the mouth of Lobos Creek (Figure 20).

The isotope analysis for this investigation started with water samples collected on 1 July 2009 between 8:00 and 9:00 during baseflow conditions. Two samples each from 20th Avenue site, 18th Avenue site, and a control location, 17th Avenue, were collected in sterile 20 ml vials. They were kept on ice until delivery at 12:00 noon to the Stable Isotope Facility at University of California, Davis http://stableisotopefacility.ucdavis.edu/.

For assurance of distinct nitrate signals among the sites, a pre-sample was tested in the field at each site using a Hach DR/820 Portable Colorimeter with cadmium reagent. The pre-samples were tested immediately prior to obtaining the submitted samples.

Laboratory testing for NO3-N involved reducing the nitrate to nitrite (NO2) with vanadium chloride. Nitrite was analyzed by diazotizing with sulfanilamide followed by coupling with N-(1-naphthyl) ethylenediamine-dihydrochloride (Doane and Horwath 2003).

In addition to NO3-N, the lab measured ammonium (NH4-N), dissolved organic nitrogen (DON), inorganic nitrogen, phosphate (PO4-P), and dissolved organic phosphate (DOP).

Isotopic analysis of nitrate was conducted over three weeks using a bacterial method. It was based on the analysis of nitrous oxide gas (N2O) that was produced quantitatively from nitrate by denitrifying bacteria, *Pseudomonas chlororaphis*. The process involved growing a culture from the denitrifying bacteria strains for six to ten days; removing N2O from the culture by purging with nitrogen gas; extracting and purifying the sample N2O in preparation for analysis using an isotope ratio mass spectrometer. In the mass spectrometer a beam of charged ions was generated by ionizing the N2O. The ratio of N2O with mass 44, 45, and 46 was measured after separation of the ions by mass due to a magnetic field. From the ratios of N2O with mass 44, 45, and 46, the δ15N of nitrogen in N2O was determined. Samples were referenced against automated injections of N2O from a gas cylinder. The N2O injections were replicates of an internationally recognized nitrate standard (IAEA-N3) that were used to calibrate isotopic ratios to that of air N2. Samples were run with nitrate standards to confirm expected performance of the bacterial conversion. A more complete description of this bacterial method is available in Sigman et al. (2001).

CHAPTER 6: Results and Discussion

Groundwater Level

Groundwater level and precipitation are presented in Figure 24. The hydrograph shows change over nine months (25 July 2008 – 16 April 2009). The 20th Avenue site is approximately 150 meters downstream of 18th Avenue site (Figure 20).

The apparent difference in groundwater levels is due to the positions of the data logger housings in the creek bank relative to natural and differing slope variation at each site. For more meaningful comparison between the two sites, the data are plotted to reflect departure from mean in Figure 25. The difference between the mean groundwater level of the sites is 176 mm. Hydrographs are examined for patterns and relative change over time.

The most apparent general trend at 18th Avenue site is an overall decline in groundwater level. A seasonal pattern of declining water level at the end of the dry season is evident. Typically this would be followed by increasing water level due to recharge during the wet season (Taylor and Alley 2002, de Vries and Simmers 2002, Healy and Cook 2002, Lerner 2002). However, this is not observed in the hydrographs. The most abrupt declines in groundwater level (34 mm over 10.5 hours on 25 December; 25 mm over 2.5 hours on 1-2 January) occur immediately following light rain events around 22 December. An explanation may be local liquefaction causing the housing and data logger to shift or sink in the creek bank. Streambank stability refers to a bank's resistance to change in shape or position (Gordon et al. 2004). Generally, streambeds composed of smaller particles (sand, silt, clay), as is Lobos Creek, are less stable (Gordon et al. 2004). The first relatively substantial rain of the season, 75 mm over 11 days (14-25 December), may have saturated the bank and initiated a shift. Disturbance to the housing and data logger was not observed on a site visit on 8 January. Heavy precipitation events later in the season appear to stall the decline in groundwater level, yet rising groundwater level is not apparent even in mid-April. Groundwater level appears to show no direct link with precipitation as recharge, however it is conceivable that recharge is very slow and occurs after the period of observation. Longer term groundwater level data may provide insight around this effect on the aquifer.

The magnitude of fluctuation is greater at 18th Avenue site than 20th Avenue site. Groundwater level range is 145.5 mm versus 49.3 mm at 20th Avenue site. Most of the variability occurred during the second half of the study period (mid-December to mid-April). A logical reason for this variability would be related to a seasonal shift from baseflow conditions during the dry summer to recharge conditions during the wet winter. However, recharge is not evident.

Some precipitation influence at 18th Avenue site is evident but appears to have a progressively smaller impact on groundwater level. For example, as illustrated in Figure 24, the significant event of 1 November (10:00-18:30, 40.6 mm precipitation) resulted in a groundwater level rise of 40 mm. Subsequent heavy precipitation events (15-16 February and 2-3 March, 73.6 mm and 35 mm, respectively) resulted in a rise of less than 10 mm and less than 20 mm, respectively.

A diurnal cycle at 18th Avenue is illustrated in Figure 26. This pattern could be related to water use in homes and businesses throughout the Richmond District. Typically, most water use, and hence, flow through pipes, occurs during the day. Leaking pipes would therefore lead to increasing groundwater level which is evident from approximately 7:00 to 12:00 noon. Groundwater level declines moderately throughout the afternoon until a steady decline starting around 18:00. Typically, less water use in homes and businesses during the night means less water flowing through and leaking from pipes. Hence, declining or steady groundwater level until 7:00 when people in homes and businesses begin turning on taps and flushing toilets. The rapid response between flow/leaks and rising/declining groundwater level may indicate highly permeable aquifer materials and/or close proximity of leaking pipes. Although the range, 1.25 mm, is nominal, it is greater than the 0.5 mm range at 20th Avenue, as illustrated in Figure 27.

In contrast to 18th Avenue site, there is an overall rise in groundwater level at 20th Avenue site, as illustrated in Figures 24 and 25. The typical seasonal pattern of declining groundwater level at the end of the dry season is not observed. Instead, there is a rise in groundwater level. Rainfall in mid-December coincides with a trend of rising groundwater level.

The range of groundwater level at 20th Avenue site is 49.3 mm, about one-third the range at 18th Avenue site. Similar to 18th Avenue site, most of the variability occurred during the second half of the study period (mid-December to mid-April).

Precipitation influence at 20th Avenue site cannot be adequately deduced from the data. A pattern is not evident. For example, as illustrated in Figures 24 and 25, the first significant event of the season (1 November, 10:00-18:30, 40.6 mm precipitation) resulted in a groundwater level rise of just 5 mm, significantly less than the 40 mm rise at 18th Avenue site. Fifty-six millimeters of precipitation from the events of 5-14 February resulted in a rise of approximately 13 mm. However, the greater amount of rain of 15-17 February (87 mm) appears to have had little influence since groundwater level remained steady, and even declined later in the month on 25 February. Groundwater level remained relatively steady again during the rain of 1-3 March (43 mm precipitation) and again appeared to decline between events of 4-5 March.

The weak diurnal cycle, as illustrated in Figure 27, may indicate a deeper groundwater source, not as influenced by leaking pipes and/or permeable aquifer materials.

In summary, the data suggest that the two sites appear to be dominated by different hydrologic controls. Physical and hydraulic properties of the aquifer could be attributed to the difference. For example, silty clay, which does not easily transmit water, could dominate the aquifer zone around 20th Avenue which exhibits a relatively muted response to precipitation events. More permeable dune sand, which transmits water more easily, could be more in abundance around 18th Avenue, resulting in water flowing to a deeper area of the aquifer. Closer examination of aquifer materials is necessary to test this theory.

Leaking underground sewer/stormwater pipes of the Richmond District contribute to groundwater levels. The data of this study, however, do not indicate the degree of influence of leaking pipes. Tracking groundwater movement by injecting fluorescein dye in pipes could provide insight as to how leakage affects groundwater levels.

It appears that rising and declining groundwater level occurs seemingly without precipitation influence. A few years of data may reveal a relationship or pattern not observed with just nine months of data.

The north-south oriented bedrock ridge 125 meters north of the creek and immediately east of 20th Avenue may exert a controlling influence on groundwater levels.

Water Temperature

Water temperature at both sites and the Presidio Treatment Plant are presented in Figure 28. The graph shows change over nine months (25 July 2008 – 16 April 2009).

Similar to groundwater levels, most of the water temperature variability at 18th and 20th Avenue sites occurred during the second half of the study period (mid-December to mid-April), as depicted at a different scale in Figure 29. This may be related to a seasonal shift from baseflow conditions during the dry summer to recharge conditions during the wet winter. Precipitation is plotted in Figure 29 to illustrate seasonality.

Temperature minimums, maximums, means, and ranges are listed in Table 6. The Presidio Treatment Plant (PTP) measures surface water temperature every two hours as it enters the plant. This location is approximately 350 meters downstream of the 20th Avenue site. During the winter months, PTP does not record temperature on a 24-hour basis. Therefore, while predominantly intact, the data, from November to February as they are shown in Figure 28, do not comprise a complete dataset. The missing data, however, do not compromise comparison and discussion value. The sampling frequency difference between the sites and PTP, 30 minutes and two hours, respectively, does not diminish the data, due to the low temperature variability at the sites.

	Minimum °C	Maximum °C	Mean °C	Range °C	Mean Diurnal Range °C
18th Ave water temperature	16.7	17.9	17.4	1.2	0.2
20th Ave water temperature	16.7	17.4	17	0.7	0.07
PTP water temperature	12.4	18	15.3	5.6	Not available
Air temperature	3.4	28.2	12.1	24.8	4.46

Table 6. Water and air temperatures

Water temperature measured at 18th Avenue and 20th Avenue sites is predominantly based on groundwater as it emanates from seeps. There is some mixing of surface water due to the location of the data loggers at the creek bank. The consistently higher temperatures at both sites compared to PTP surface water temperatures, as illustrated in Figure 28, are unusual. The data loggers are installed in white PVC housing which is shaded by abundant riparian vegetation. The data loggers are not subject to direct sunlight. This generally higher-than-expected temperature behavior at the sites could indicate groundwater mixing with higher-temperature sewage or warm water leaking from pipes.

Air temperature is plotted with water temperatures in Figure 30. As expected, air temperature shows a greater range than water temperature: 24.8 °C compared to 1.2 °C and 0.7 °C at the sites, and 5.6 °C at PTP. The cooler months of November and December are clearly identified. Water temperature at PTP corresponds to the lower air temperature. A brief decline in temperatures is perceptible at 18th Avenue site yet less noticeable at 20th Avenue site. The warm periods around October 23, mid-November and mid-January have little to no influence on water temperatures at the sites and a relatively small influence at PTP.

Figure 31 illustrates daily temperature range at 18th and 20th Avenue sites. The seasonal pattern is evident with winter and spring months showing greater variability on a day-to-day basis. The smaller mean diurnal range of 0.07 °C at 20th Avenue, compared to 0.2 °C at 18th Avenue, is consistent with the smaller mean diurnal range in groundwater level at 20th Avenue compared to 18th Avenue, those being 2.1 mm and 4.6 mm, respectively. Like the less variable groundwater level at 20th Avenue site, the less variable water temperature could indicate a deeper groundwater source.

Average temperatures are plotted in Figure 32 to illustrate diurnal cycles for water and air. Air temperatures show a typical daily curve with the lowest temperature occurring just after sunrise when more solar radiation is received than lost, and the highest temperature occurring mid-afternoon when more solar radiation is lost than received. Across the entire study period the diurnal cycle is weak at both 18th Avenue and 20th Avenue sites. However, when comparing July–mid-December to mid-December–April, the signal is stronger during the latter time period as illustrated in Figures 33 and 34.

Precipitation typically has a cooling effect on ambient water. The data do not suggest this according to Figure 29. Following the late October rain event which resulted in 65 mm precipitation, temperature rose at 20th Avenue site, although nominally, and remained relatively constant at 18th Avenue site. While the temperature at 18th Avenue site fluctuated more than at 20th Avenue site during the winter and spring months, the overall trend was an increase.

In summary, the temperature behavior at the sites is not as strikingly different as groundwater level. The minor seasonal change, the similar means, and the small ranges suggest a constant source of warming. Otherwise, water temperatures would be closer to the annual mean air temperature of 12.1 °C (based on BAAQMD data for July 2008 – June 2009).

Specific Conductance

Specific conductance (SC) for both sites and PTP are presented in Figure 35. Additionally, measurements taken by the National Park Service at 18th and 20th Avenue sites are plotted, along with precipitation.

Similar to water temperature, PTP does not record SC on a 24-hour basis during the winter months. Therefore, while predominantly intact, the data, from November to February as they are shown in Figure 35, do not comprise a complete dataset. The missing data, however, do not compromise comparison and discussion value. The sampling frequency difference between the sites and PTP, 30 minutes and two hours, respectively, does not diminish the data.

Specific conductance minimums, maximums, means, and ranges are listed in Table 7.

	Minimum mS/cm	Maximum mS/cm	Mean mS/cm	Range mS/cm	Mean Diurnal Range mS/cm
18th Ave SC_data logger	-0.25	1.18	0.79	1.43	0.09
20th Ave SC_data logger	-0.29	0.42	0.02	0.70	0.03
18th Ave SC_NPS	0.24	0.64	0.45	0.40	Not available
20th Ave SC_NPS	0.22	0.57	0.41	0.35	Not available
PTP SC	0.58	0.63	0.59	0.05	Not available

Table 7. Specific conductivity in millisiemens per centimeter

The data loggers' measurements are distinctly different from PTP as illustrated in Figure 35. Like water temperature, PTP measures specific conductance as water enters the plant.

The measurements at 20th Avenue site appear to be affected during site visits when the data logger is removed from the water for data download purposes. Although it is out of the water for less than ten minutes, the disruption has a consistent ramping after-effect in the measurements, except 22 January when there is an increase in mS/cm instead of a decrease. It is most likely an artifact of the instrument and not a natural variation. The drop in measurements below zero (November, January, March, April) is confounding, as negative readings are meaningless and do not reflect natural conditions. Consultation with Odyssey Dataflow Systems engineering support on calibration data returned suggestions but no resolution. Consequently, SC measurements recorded by the data logger at 20th Avenue site are questionable. This does not invalidate temperature data for 20th Avenue even though SC and temperature are recorded by the same data logger. Calibration data for temperature is different.

The iron residue build-up on the data logger at 18th Avenue site is likely influencing the measurements and masking actual SC conditions in this area of the creek. The range of 1.43 mS/cm is significantly higher than the 0.04 mS/cm range of discrete measurements taken in July and December 2008 and March 2009 with a handheld Fisher Scientific accumet portable AP50 pH/ion/conductivity meter. Those measurements, 0.48-0.52 mS/cm, are not plotted.

Specific conductance measured once per month from October 2008 – April 2009 by the National Park Service ranged 0.22 to 0.64 mS/cm for both sites. Measurements were taken within one-half meter of the data loggers at 18th Avenue and 20th Avenue sites by personnel using a handheld YSI 556 multiparameter instrument.

A relative spike in measurements is observed on 19 November. This may be attributed to a phenomenon called first flush. This seasonal event occurs after the dry season when a spike in SC results from accumulated residue washed into a system with the season's first significant rainfall (Deletic 1998; Soller et al. 2005). This is not observed, however, in PTP measurements.

Another typical seasonal pattern is a dilution effect. Previous studies have shown that specific conductance typically responds to dilution and is lower during winter periods when flow is higher. Conversely, a concentration effect resulting in higher SC is characteristic of summer months when flow is lower (Caissie, Pollock and Cunjak 1996; Kney and Brandes 2007). Flow data for Lobos Creek were not available to correlate with SC. However, a seasonal pattern is not even observed in PTP data since specific conductance remains relatively constant around 0.6 mS/cm. Precipitation does not appear to strongly influence PTP or NPS measurements. Considering rainwater's lower conductivity relative to rivers and streams, a decrease in mS/cm would be expected in late February. This is observed at 18th Avenue site yet an increase in mS/cm occurs following the early March rain events. This conflicting behavior combined with other irregular periods of precipitation and measurements at 18th Avenue site is confounding.

In summary, SC as measured by the data loggers adds little understanding to the presence of dissolved solids in the water. The masking effect at 18th Avenue site and the ramping effect at 20th Avenue site appear to conceal actual conditions. A common seasonal pattern of higher SC from July-October and lower SC from November-April is not evident. Precipitation appears to have little overall influence. The small range of NPS and PTP measurements are the most consistent and closely related. They predominantly fall within the SC range for drinking water, 0.5-0.8 mS/cm, and may best reflect actual conditions.

Repeating the data collection process with a different set of continuous-monitoring data loggers may yield more realistic results.

NO3-N and E. coli

Nitrate and E. coli are presented in Figure 36 and Tables 1 and 2. Measurements reflect monthly sampling by the National Park Service from October 2008 to May 2009.

Higher concentrations of nitrates at 20th Avenue site, and lower concentrations upstream at 18th Avenue site are consistent with previous studies. Little fluctuation at 20th Avenue site suggests a constant source such as sewage or fertilizer. Nitrate-nitrogen less than 0.2 mg/L is considered a natural background level and concentrations greater than 3.0 mg/L could be attributed to anthropogenic effects (Madison and Brunett 1985). The higher and consistent levels at 20th Avenue site, ranging 5.4-7.3 mg/L NO3-N, suggest the latter.

It is highly unlikely that manure applied as fertilizer to the 16-hectare vegetable garden above Lobos Creek around the turn of the century is still affecting groundwater. Based on crop response studies, about three years is the limit of organic nitrogen mineralized into inorganic forms, i.e., N03-N, after manure is applied. The nitrate that may have entered the Lobos Basin groundwater 100+ years ago would have moved on (Martin Burger, University of California, 21 June 2009, personal communication).

Lower levels of nitrates at 18th Avenue site may be attributed to the red flocs in the area. The consortium of bacteria that comprise red flocs is likely Siderocapsa sp., Gallionella ferruginea, and Leptothrix ochracea. Under anaerobic conditions, Gallionella ferruginea, an iron bacteria, reduces nitrates to nitrites which in turn are reduced to gaseous nitrogen compounds by the ferrous ions present. This autotrophic denitrification could explain a nitrogenous purification in this upstream area of the creek. Gouy, Berge and Labroue (1984) experimented by cultivating strains of Gallionella ferruginea on spring water, in closed tubes, with and without nitrates. Isotopic analysis with 15N, a stable isotope, under a nitrogen atmosphere provided proof of the reduction of nitrates to volatile components. The isotopic level of atmospheric nitrogen is 0.3663 percent of 15N. In the experiment, the isotopic level of nitrogen reached 1.16 percent which represented a 0.79 percent isotopic excess.

E. coli measurements range 20-690 MPN/100 ml among both sites. The maximum contaminant level in drinking water is 0 MPN/100 ml. For perspective, the ‘average’ limit for water contact recreation is 126 MPN/100 ml.

The spike on 19 November at 20th Avenue site is coincident with the spike in SC. With longer term data, statistical tests such as regression and correlation analyses could inform a relationship. The other measurements at 20th Avenue site are consistently lower than measurements at 18th Avenue site. This could suggest that a source of sewage is predominant upstream however, NO3-N data don't strongly support this theory.

E. coli data were not available from PTP but fecal coliform measured on a weekly basis from 2000-2005 where water enters the plant averaged 302 MPN/100 ml. Since the mid-1990's coliform testing has been conducted in conjunction with watershed reports by Dames & Moore (1994) and the Urban Watershed Project (Kern and Youngkin 1999). Testing at locations around 17th and 18th Avenues repeatedly showed elevated counts while testing at locations around 20th Avenue were lower. [Doug, can you help me attach numbers to this? I read this in the Water Quality Mgmt Plan but don't have numbers to support it.]

Measurements at 18th Avenue site show slightly more variability with spikes on 20 October and 13 May. Seasonal patterns and relationships between bacteria and NO3-N are difficult to identify due to limited data. The higher E. coli/lower NO3-N measurements at 18th Avenue site and the lower E. coli/higher NO3-N measurements at 20th Avenue site seem to be a common pattern throughout recent history. The noteworthy point from this data though, is that it led to isotope analysis, a deeper level of investigation around sources of contamination.

Isotope Analysis

Testing of water samples for NO3-N was conducted in the field and in a laboratory at U.C. Davis. Results are presented in Table 8.

Location	Pre-sample NO3-N mg/L at site	Sample #1 NO3-N mg/L in lab	Sample #2 NO3-N mg/L in lab
17th Avenue	3.0	0.55	0.54
18th Avenue	8.0	4.07	4.48
20th Avenue	20.3	13.88	13.44

Table 8. Results of nitrate testing in the field and in the lab

The difference in NO3-N levels between the three locations was compelling. In the context of the maximum contaminant level (MCL) of NO3-N in drinking water (10 mg/L), the locations suggest three locally unique environments. This, combined with one location in excess of the MCL, and a relatively significant overall range between the locations warranted isotope analysis.

Results for laboratory testing of ammonium (NH4-N), dissolved organic nitrogen (DON), inorganic nitrogen, phosphate (PO4-P), and dissolved organic phosphate (DOP) are presented in Table 9. Measurements of ammonium, DON and inorganic nitrogen indicate there are no other forms of nitrogen in the water other than nitrate (Martin Burger, Research Manager, U.C. Davis, 2 August 2009, personal communication). Whereas nitrate is extremely mobile in soil, phosphate is not. It adsorbs to soil particles and moves with soil movement. Like nitrate, phosphate occurs naturally in soil and rocks and is required by all organisms for the basic processes of life. It is present in sewage and wastewater and is one of the main elements of packaged fertilizer. The natural background level of total phosphorus is generally less than 0.03 mg/L (Dunne and Leopold 1978). The U.S. Environmental Protection Agency recommends an upper limit of 0.1 mg/L as the standard for total phosphorus in streams (USEPA 1986). Table 10 shows some common sources of phosphorus and the approximate concentrations delivered to waterbodies. The low levels of phosphate and DOP in the Lobos Creek water samples (Table 9), particularly the below-detection-limit levels at 18th Avenue site, don't necessarily refute its presence in the local environment but rather, suggest that erosion and runoff are not significant contributing factors to these areas of the creek.

Sample # and Location	NH4-N mg/L	DON+inorganic N mg/L	PO4-P mg/L	DOP mg/L
#1, 17th Avenue	0	0.81	0.013	0.052
#2, 17th Avenue	0	0.92	0.049	0.052
#1, 18th Avenue	0	3.95	<0.003	<0.005
#2, 18th Avenue	0	4.14	<0.003	<0.005
#1, 20th Avenue	0.007	13.7	0.012	0.012
#2, 20th Avenue	0	13.7	0.013	0.013

Table 9. Lab results of ammonium, dissolved organic nitrogen, inorganic nitrogen, phosphate, and dissolved organic phosphate

Source	Total Phosphorus (mg/L)
Urban runoff	0.2-1.7
Livestock operations	4-5
Area with 50% forest cover	0.013-0.015
Treated wastewater	10

Table 10. Sources and concentrations of total phosphorus
Source: The Federal Interagency Stream Restoration Working Group, 1998.

The results from isotopic analysis of Lobos Creek samples are presented in Table 11.

Sample # and Location	δ15N (0/00)
#1, 17th Avenue	11.08
#2, 17th Avenue	11.40
#1, 18th Avenue	24.99
#2, 18th Avenue	25.18
#1, 20th Avenue	9.70
#2, 20th Avenue	9.68

Table 11. Lab results of nitrogen isotope analysis

Both NO3-N and δ15N 0/00 for samples #1 and #2 taken from 17th, 18th and 20th Avenue sites are plotted in Figure 37.

Figure 37 illustrates two noteworthy points from an overall perspective. The samples' values between locations are varied and distinct. This indicates a locally unique environment at each location and allows for more precise interpretation of results. Secondly, for each location the samples' values are relatively close. This consistency validates the method of analysis and substantiates results.

The difference of approximately 15N 14 0/00 between 17th Avenue and 18th Avenue site is compelling and indicates a distinct source entering the creek between 17th and 18th Avenues. The higher value, around +25 0/00 at 18th Avenue site, is consistent with sewage, whereas fertilizer would be around 0 0/00. As the enriched nitrate flowing from 18th Avenue site moves downstream it could be mixing with a lower isotope signature source such as garden fertilizer, or other inorganic source, resulting in a dilution effect and lower values around +10 0/00 at 20th Avenue site. Results of this isotope analysis can only be discussed in general terms until additional data are collected such as flow rates of water at different points; water samples from different locations and times of the year; and potential water sources and their nitrate concentrations.

Explanation for the higher NO3-N values at 20th Avenue site requires additional research. Another physiochemical process may be occurring that contributes to the reduction of coliform yet keeps nitrate levels high and lowers δ15N values.

Studies have shown that low nitrate but enriched δ15N values (Figure 37, 17th Avenue water samples) could be a result of denitrification (Korom 1992; Fukada, Hiscock, and Dennis 2004). It is a process whereby bacteria degrade nitrate to nitrogen gases that are released to the atmosphere, while increasing the δ15N values. Denitrifying bacteria preferentially select 14N leaving the remaining nitrate pool isotopically enriched in 15N. Denitrification occurs when anaerobic conditions exist in a biologically active soil zone, which most likely appears when the water table is within one meter of land surface. When the water table is shallow there is greater likelihood that anaerobic conditions of the saturated zone extend into the biologically active soil zone to derive denitrification (Rolston et al. 1996). Although Lobos Creek lies in a sand dune environment, which lacks the organic matter present in biologically active soil zones, the water table lies close to the surface, as evidenced by the creek as a surface expression of it.

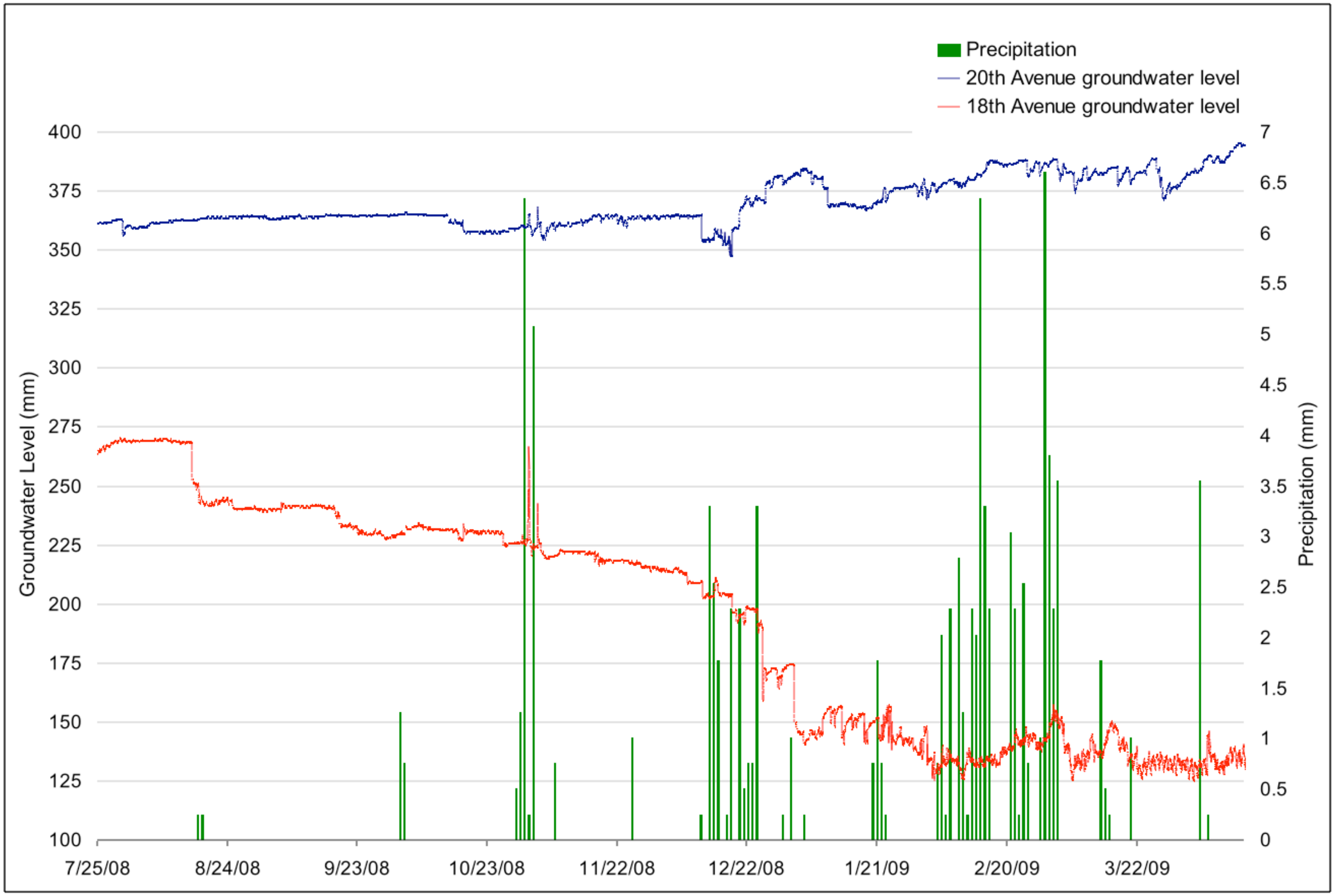


Figure 24. Groundwater level and precipitation

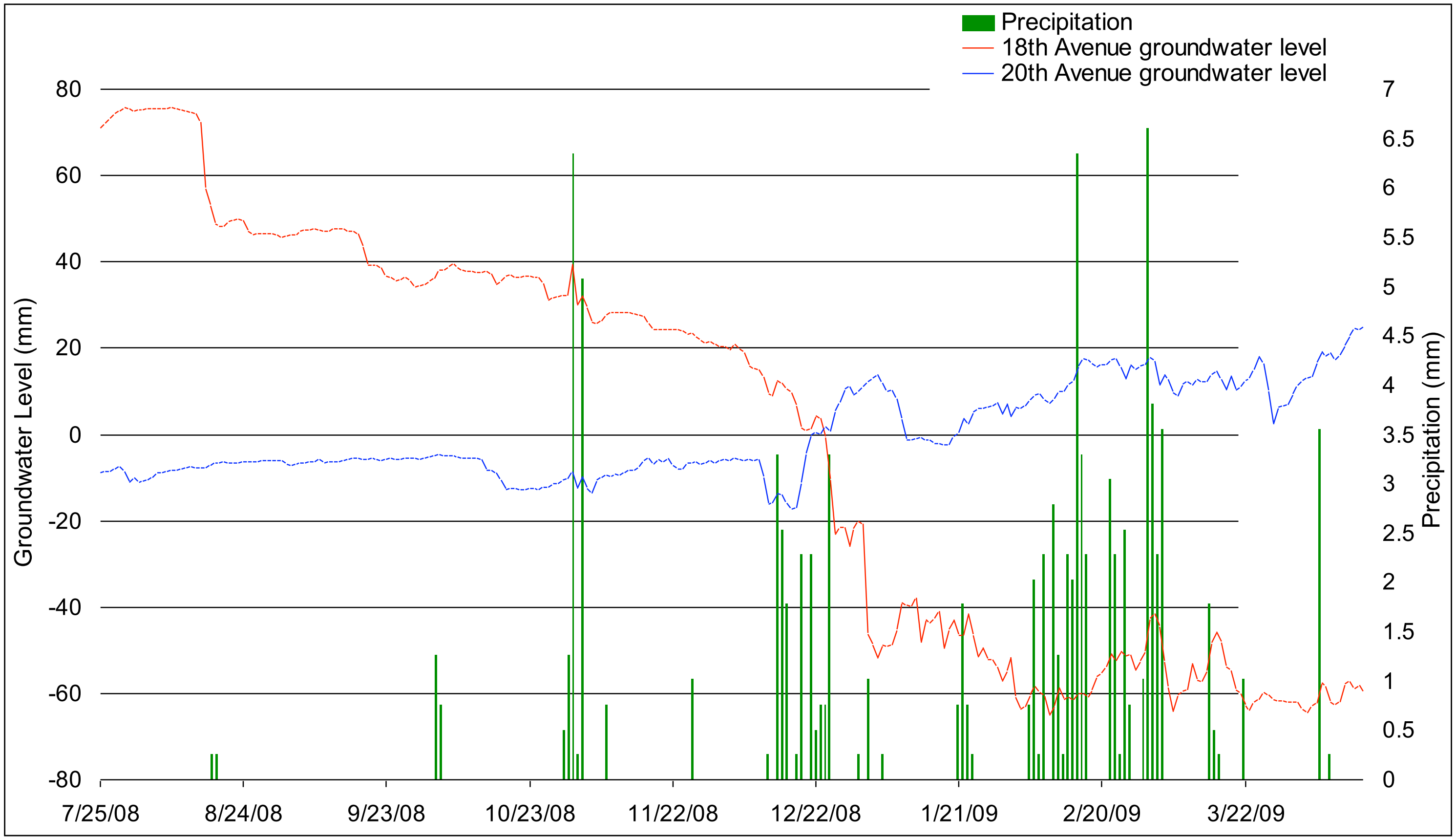


Figure 25. Precipitation and average groundwater level departure from mean

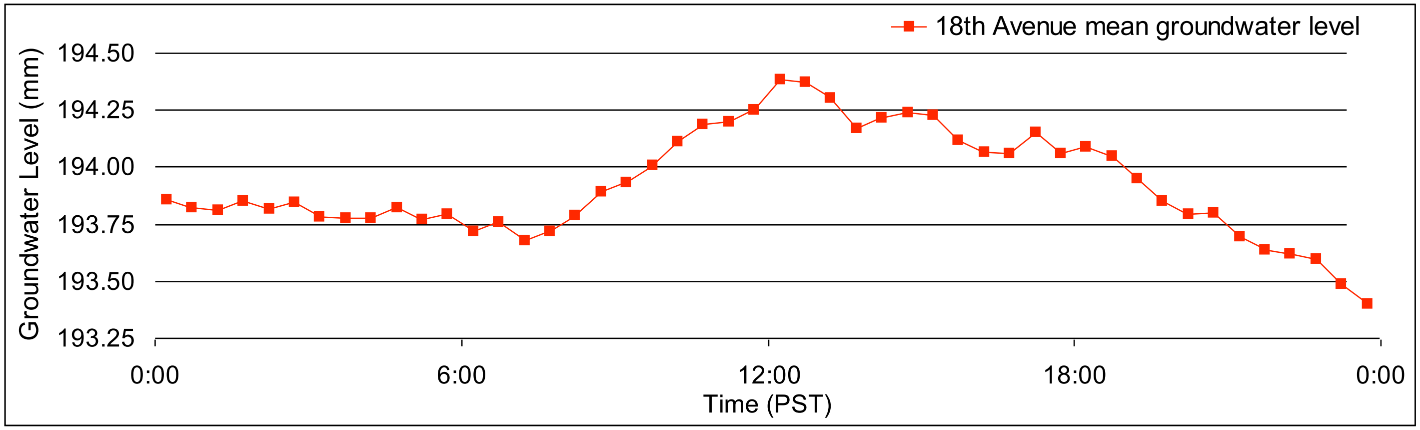


Figure 26. Mean daily groundwater level at 18th Avenue site, 25 July 2008 – 16 April 2009

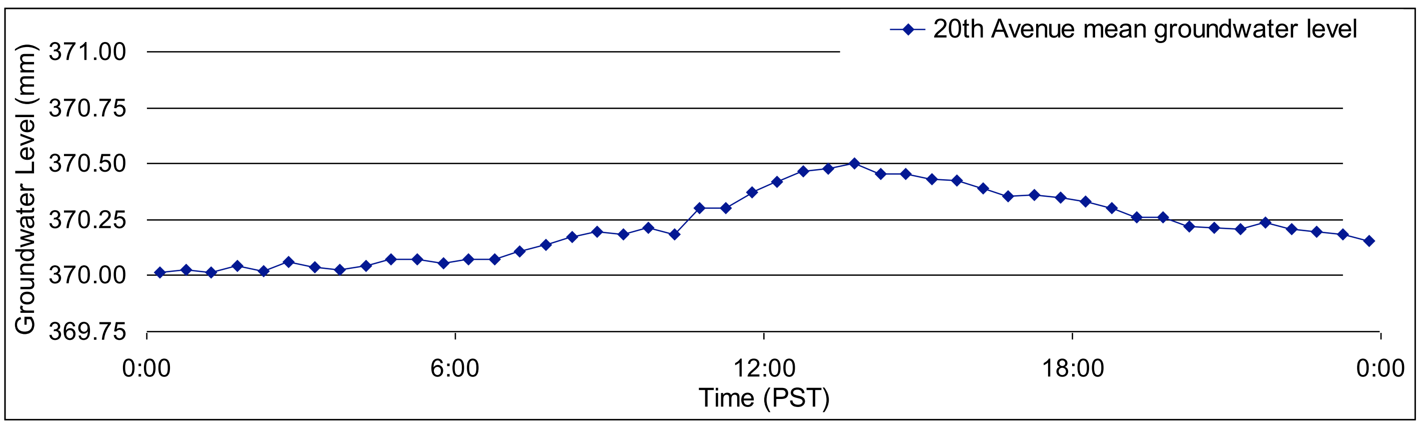


Figure 27. Mean daily groundwater level at 20th Avenue site, 25 July 2008 – 16 April 2009

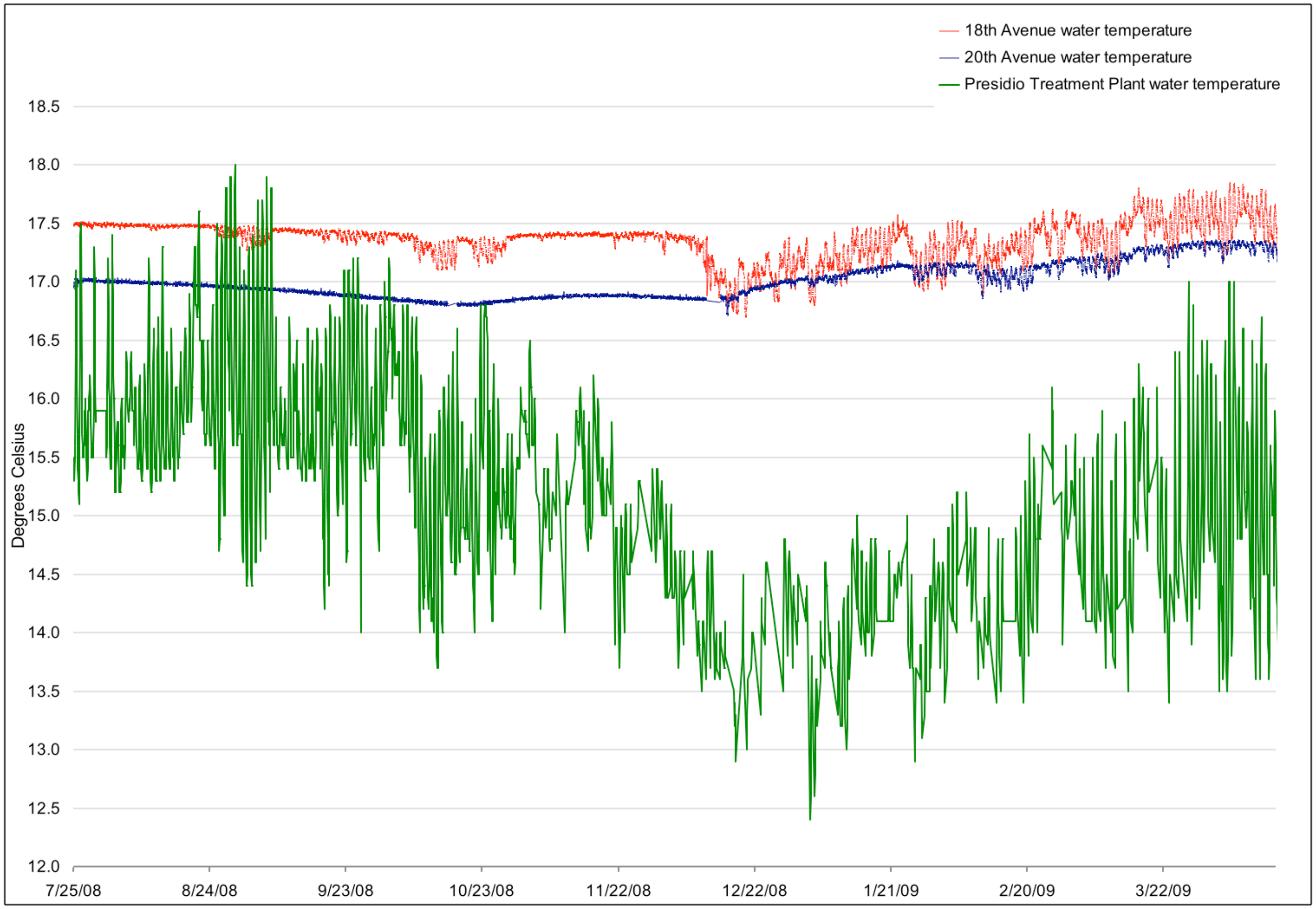


Figure 28. Water temperature at 18th and 20th Avenue sites and Presidio Treatment Plant

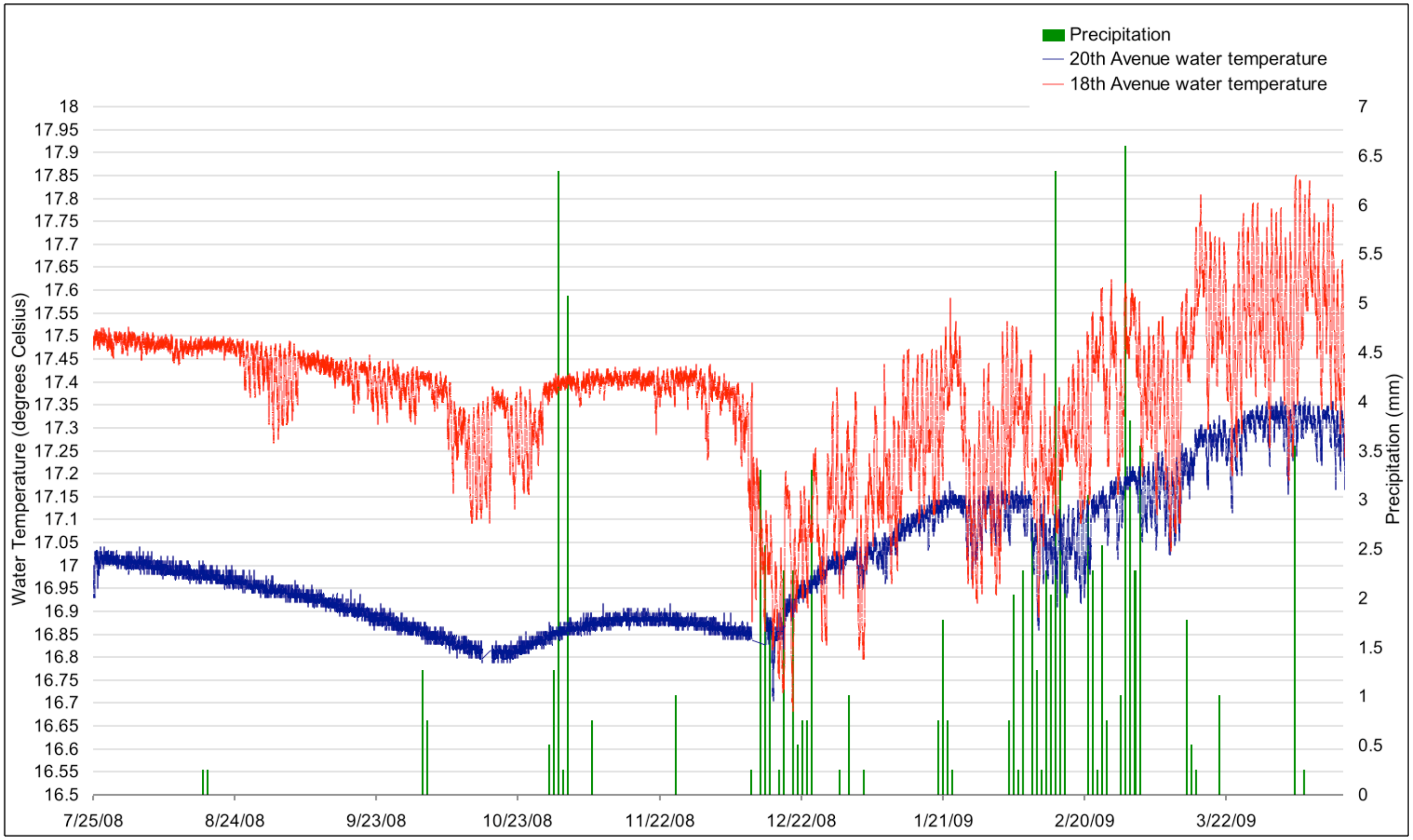


Figure 29. Water temperature at 18th and 20th Avenue sites and precipitation

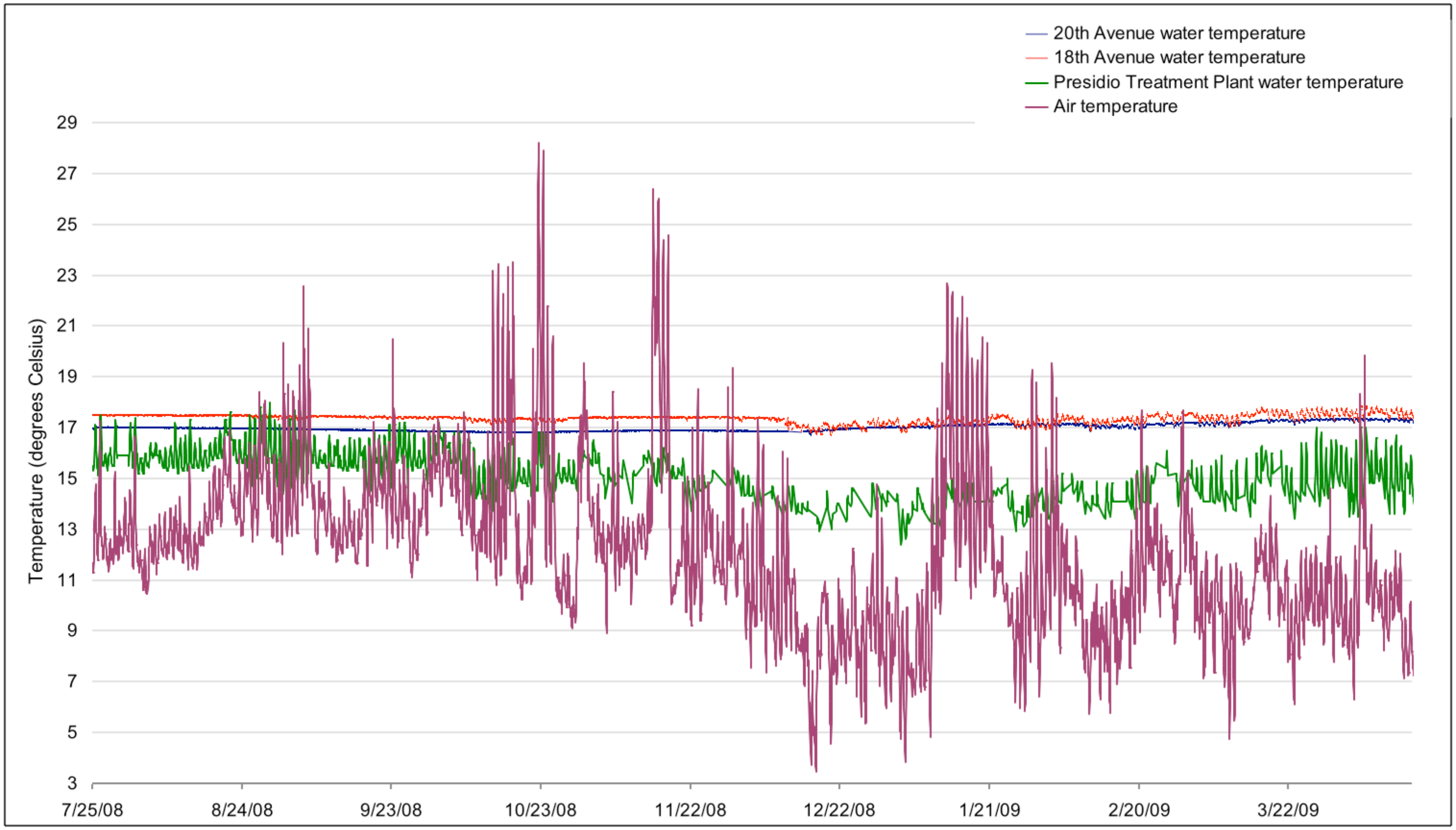


Figure 30. Water temperature at 18th and 20th Avenue sites and Presidio Treatment Plant, and air temperature

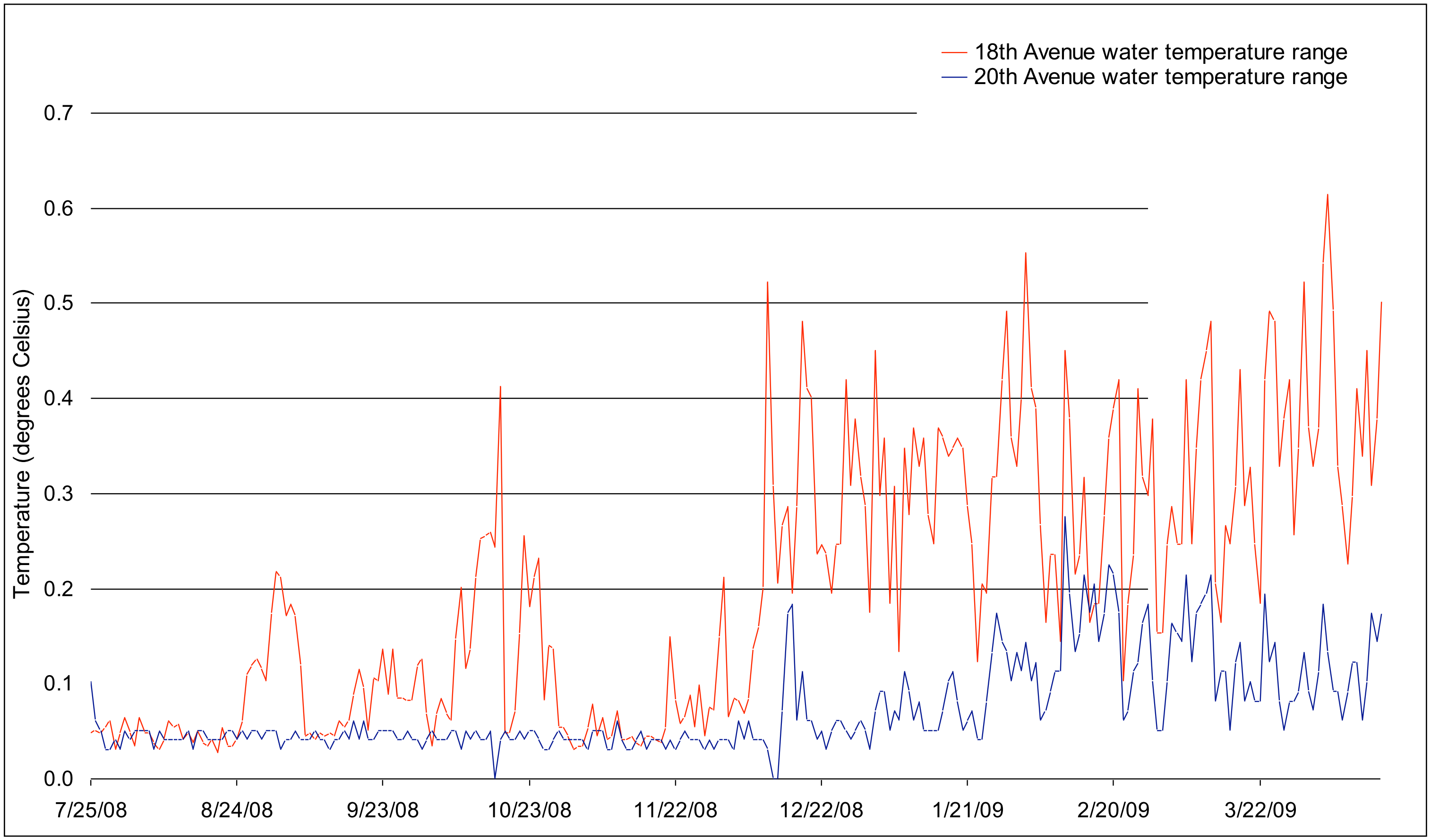


Figure 31. Daily water temperature range at 18th and 20th Avenue sites

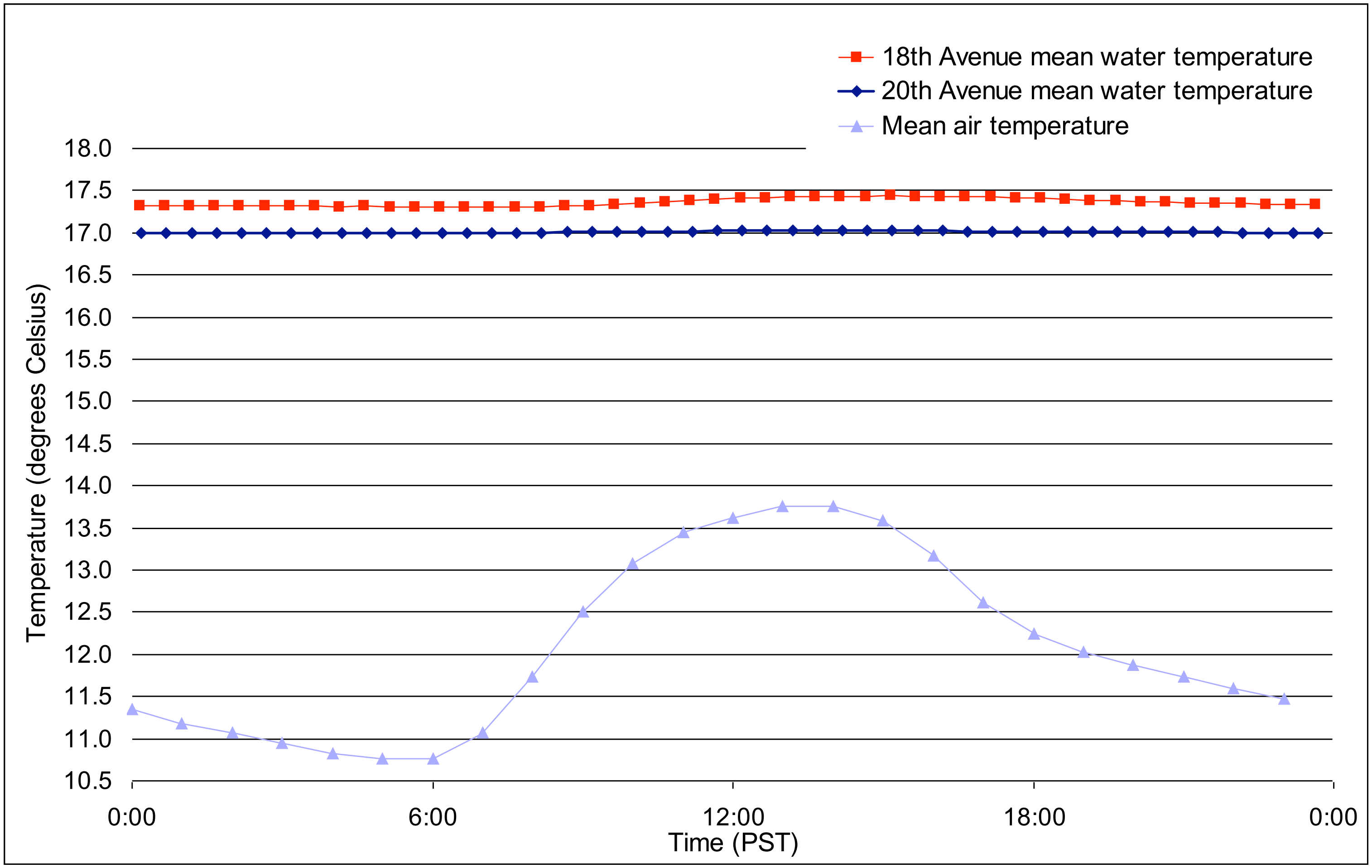


Figure 32. Diurnal cycles, 25 July 2008 – 16 April 2009

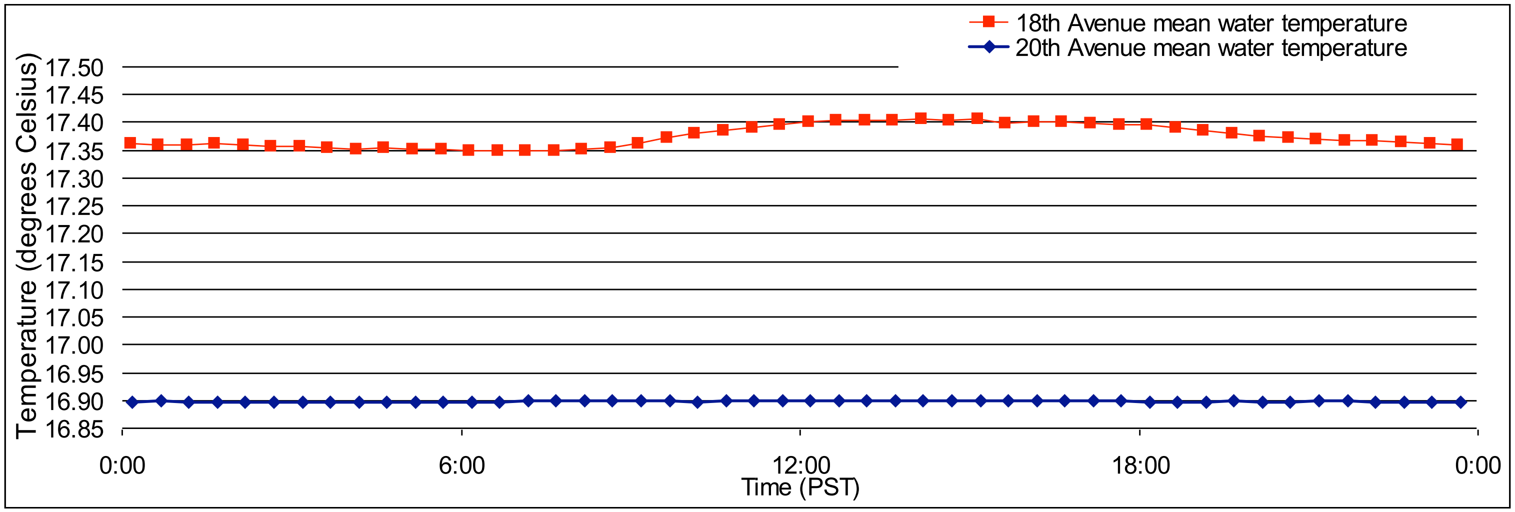


Figure 33. Water temperature diurnal cycles, 25 July – 20 December 2008

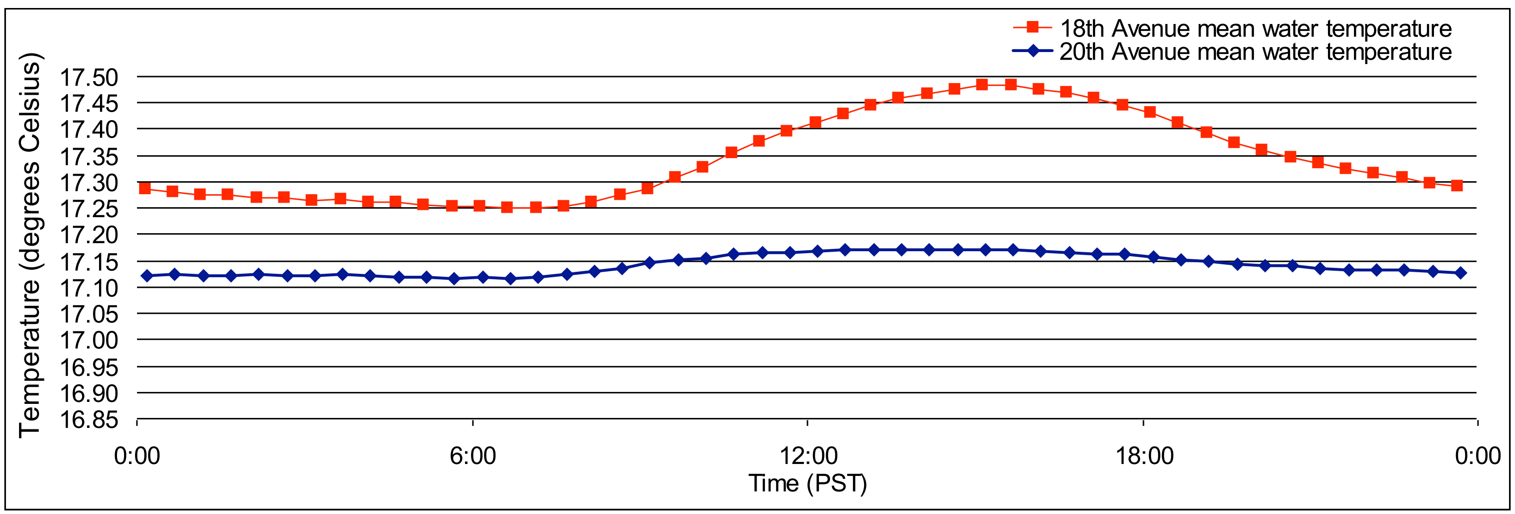


Figure 34. Water temperature diurnal cycles, 21 December 2008 – 16 April 2009

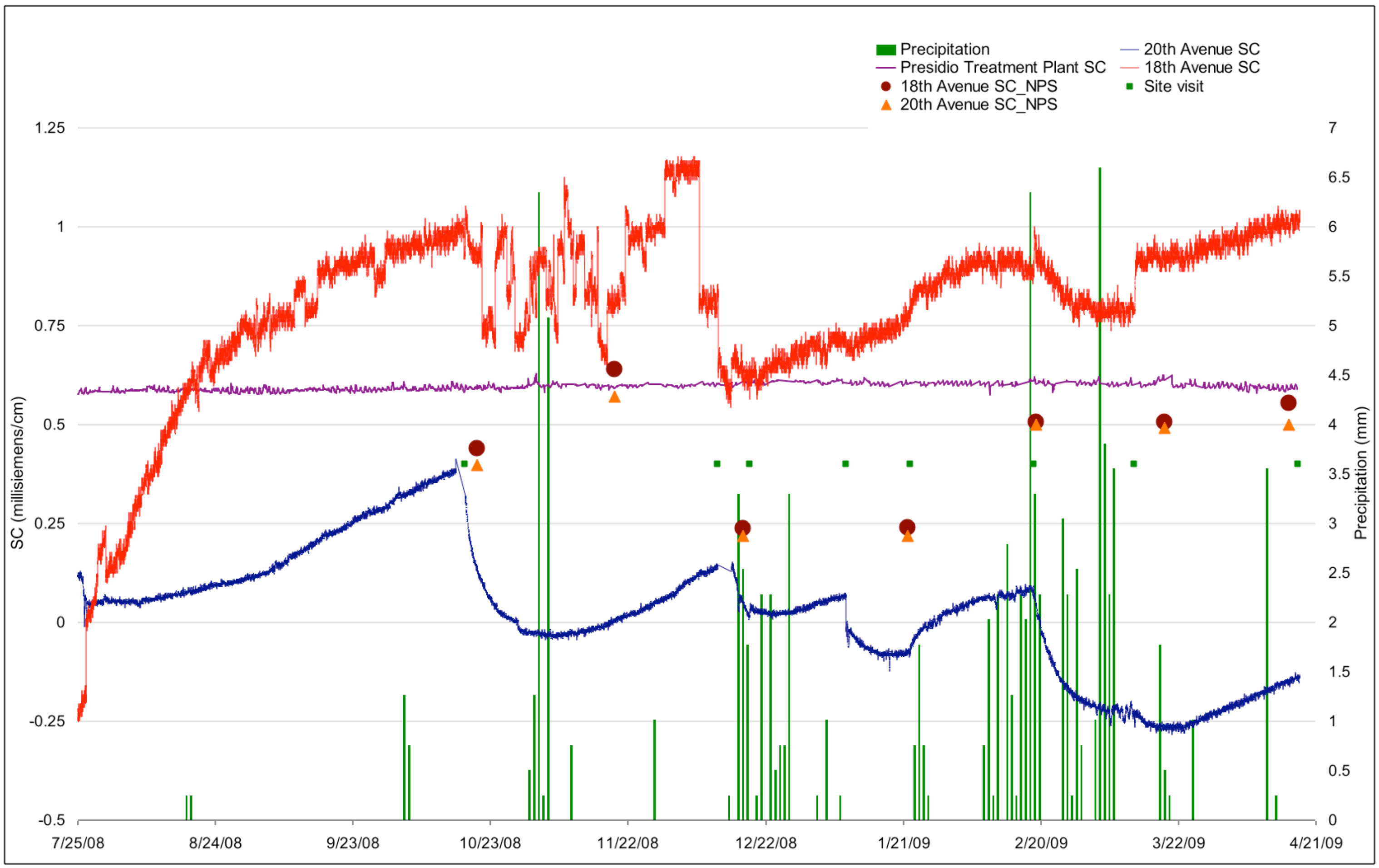


Figure 35. Specific conductance, precipitation, and site visits

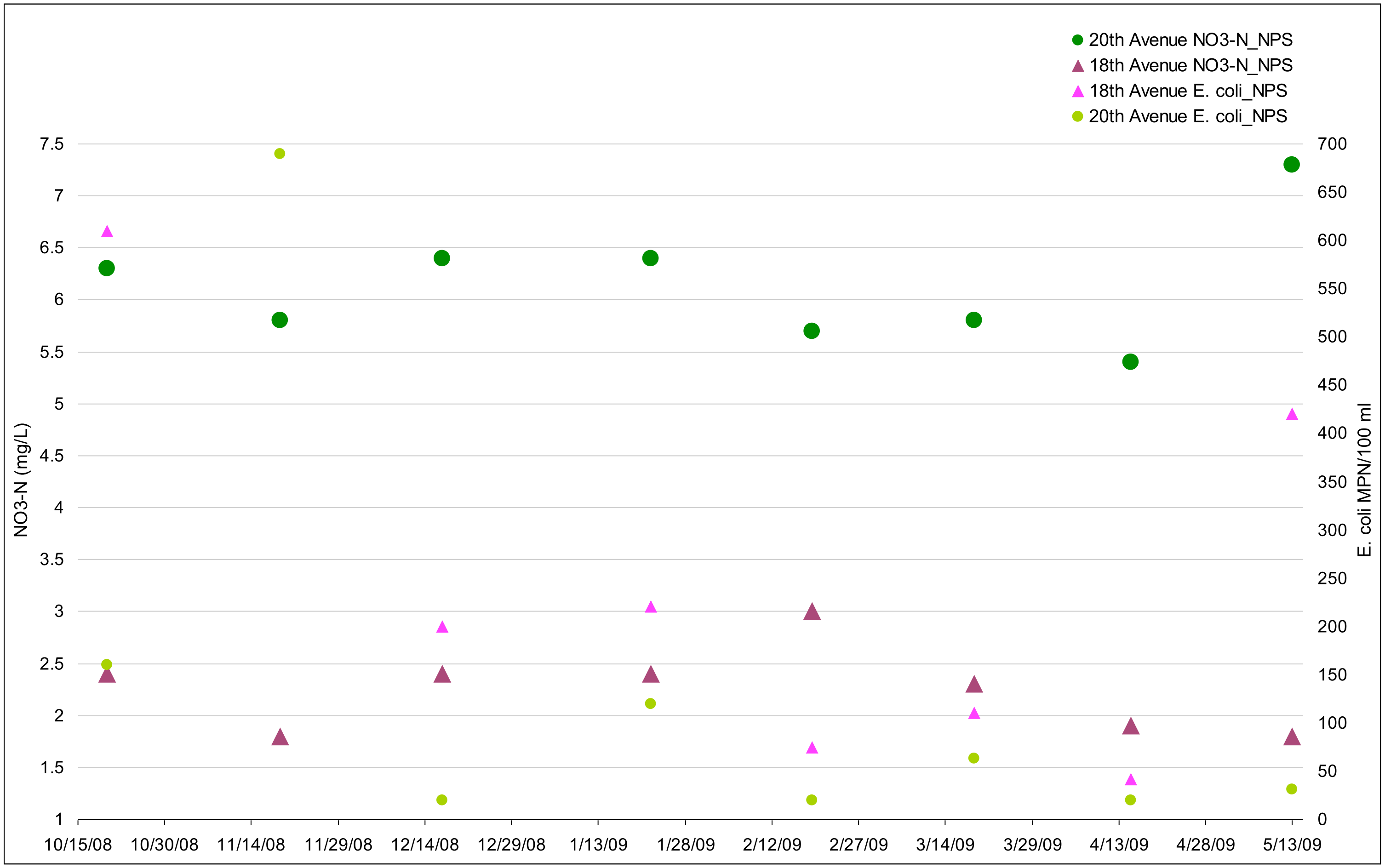


Figure 36. Nitrate-nitrogen (NO_3-N) and *E. coli* measured by the National Park Service

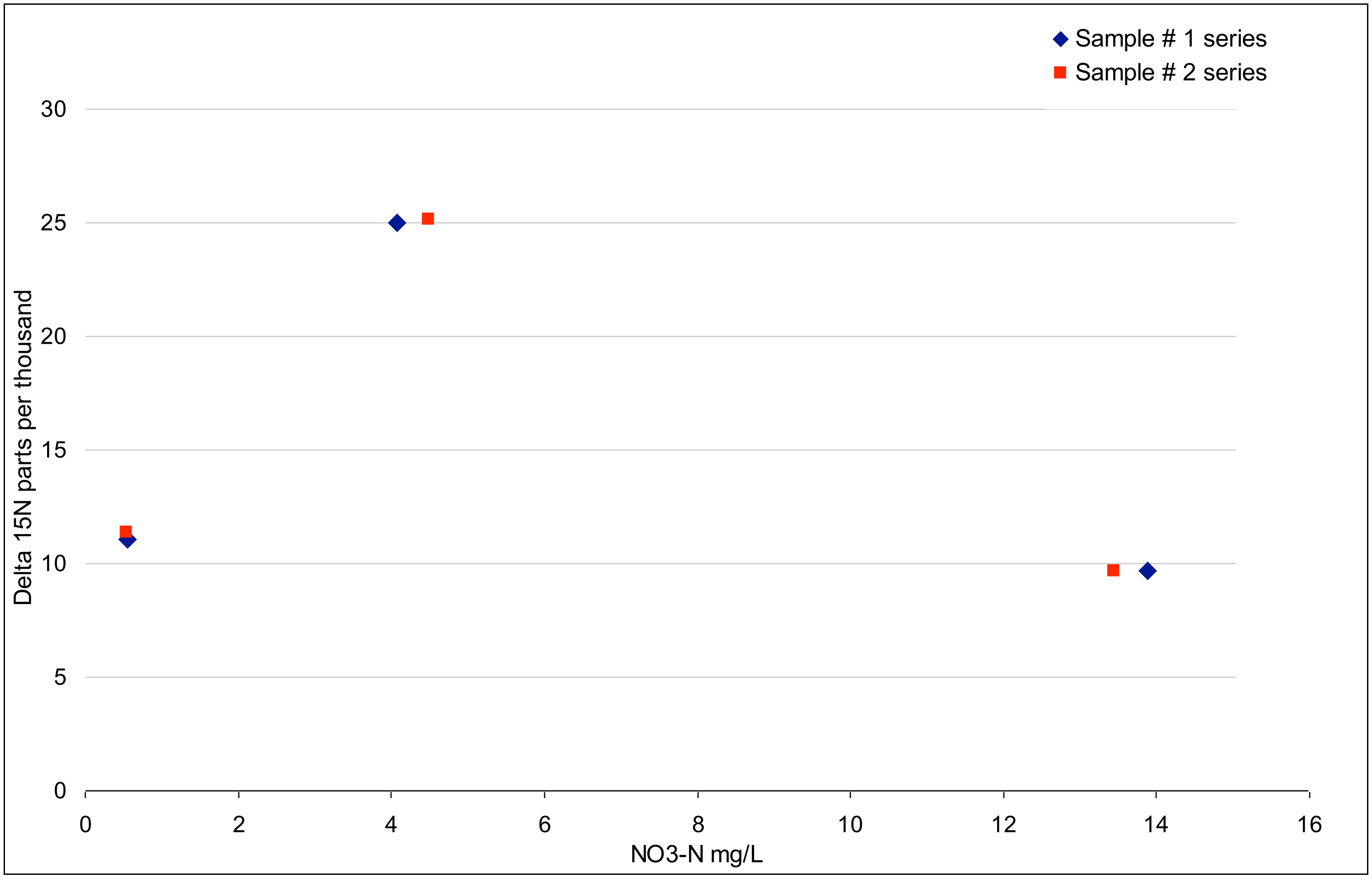


Figure 37. NO_3-N and $\delta^{15}N$ $^{0}/_{00}$ at 17th Avenue and 18th and 20th Avenue sites; from left to right as they appear on the graph are 17th Avenue, 18th Avenue and 20th Avenue testing results.

CHAPTER 7: Conclusion and Recommendations

As a potable water supply for a portion of San Francisco's population, Lobos Creek is a critical resource. Its location and the groundwater basin that feeds it are vulnerable to the disturbances and pollution generated by businesses and residences of the densely developed Richmond District.

This study's examination of groundwater characteristics in two upstream areas of Lobos Creek is believed to be the first to capture continuous water level, temperature, and specific conductance data using data loggers.

Nitrate beyond the maximum contaminant level (10 mg/L NO3-N) in drinking water poses a health risk, primarily to infants and pregnant women. Higher levels of nitrate in some upstream areas of the creek have historically been reported and monitored. The source(s) however, remain undetermined. Although nitrate has not exceeded the maximum contaminant level for drinking water, it is necessary to understand the source and transport of nitrate contamination through a hydrologic system in order to develop an efficient remediation plan.

The data loggers for this study provided a method for capturing daily and seasonal fluctuations of key water quality parameters, which is necessary to characterize a system. Due to the nature of exploratory studies, the investigative process led to isotope analysis which was highly informative and altered initial assumptions about nitrate in the creek.

Following are concluding comments about groundwater level, temperature, specific conductance, E. coli, nitrate, and isotope analysis.

The strikingly different patterns of groundwater level at the sites (increase at 20th Avenue, decrease at 18th Avenue) suggest two different hydrologic systems. The sites are 150 meters apart which raises questions around aquifer materials and composition, and introduces opportunities for hydrogeologic studies. To paraphrase the senior supervisor of the Presidio Treatment Plant, it would be enlightening to remove the invasive vegetation from the south bank in upstream areas of the creek and actually observe flow from springs and seeps. But removal of vegetation opens a political debate between NPS, Presidio Trust, and residents whose homes are perched on the south bank. And this is a debate that no one has wanted to start.

Precipitation does not appear to strongly influence groundwater level at either site. The small diurnal and seasonal variability at 20th Avenue site suggests a deeper groundwater source. Additionally, aquifer materials may be retarding movement here. The 145.5 mm drop in groundwater level at 18th Avenue site between July and April is significant relative to 20th Avenue site, and curious considering the 467 mm of rainfall over this period. The diurnal signal observed at 18th Avenue site could be linked to leaking pipes from the Richmond District.

The higher-than-expected water temperatures at the sites could indicate groundwater mixing with higher-temperature sewage or warm water leaking from pipes. The small range and minimal influence by precipitation and air is curious. Surface water temperature measured by PTP is lower and appears to be influenced somewhat by air. Why there is greater variability at both sites during the second half of the study period requires further data collection and analysis. Despite the inconclusive results, including air and precipitation data in this study were essential.

Specific conductance, as indicated by PTP data, fell within the acceptable drinking water range. Minimal variation across the study period and lack of measurement spikes suggest no pollution events. However, PTP data is not collected through continuous monitoring which would typically reveal such events due to greater sampling frequency. Furthermore, the location where SC is recorded, as water enters the treatment plant, is 350 meters from 20th Avenue site. Nonetheless, the PTP data provided a reference of sorts for recordings by the data loggers. And discrete measurements by NPS were another reference source.

Specific conductance data from the sites were inconclusive due to the presumed red flocs bacteria interference at 18th Avenue site and the instrument artifact at 20th Avenue site. These steady disruptions prevented seasonal and daily analysis and an understanding of the presence of dissolved solids in these areas of the creek.

Results from coliform and nitrate testing by NPS are generally consistent with historic reports. The higher NO3-N levels around 20th Avenue suggest a steady contaminant source, however, the lower E. coli values are not as convincing that it is sewage. In contrast, the lower NO3-N levels and higher E. coli values around 18th Avenue suggest moderate sewage contamination.

The identification of a nitrogen isotope signature strongly suggesting sewage at 18th Avenue site is somewhat surprising. This researcher's assumption was that sewage was more prevalent at 20th Avenue site. This information is important yet should not be considered conclusive. Additional research around flow rates of water at different points; water samples from different locations and times of the year; and potential water sources and their nitrate concentrations is needed.

Following are some recommendations for future research.

Collect data on discharge which are useful in characterizing a groundwater system. Their influence on groundwater level, temperature, and specific conductance can be quantified and analyzed. As the population of the Presidio increases, and demand for water grows, examining flow will contribute knowledge about changes in the aquifer. Resource managers will be better informed when making decisions about conservation.

Collect longer term data for groundwater level, temperature, and specific conductance. Seasonal patterns may be more apparent and interpretive. Perform statistical analyses. Generate more answers and more questions. The groundwater level, temperature, and specific conductance data presented in this study provide a baseline for future research.

Investigate the geologic composition of the watershed in terms of isotope analysis. This may contribute knowledge to the source of nitrates in the creek. However, based on isotope analysis of water samples undertaken for this study, additional work around water sampling should occur before attempting to quantify nitrogen in rock.

Test water for caffeine which would support the leaking pipe theory. A portion of caffeine is not metabolized in human digestive systems and is eliminated with wastewater. Its presence in groundwater is an indicator.

Test water for optical brighteners. These are compounds added to laundry detergents, textiles, plastics, synthetic fibers, and many kinds of paper. Their presence may indicate human origin since household plumbing systems combine wastewater from toilets and washing machines.

Talk to residents that occupy homes along the south bank. It would be informative and perhaps add to the historic chronicle of residential development. This may open the door to dialogue around invasive and overgrown vegetation along the south bank, leading eventually to restoration and greater access to the bank itself.

In closing, an historic reference to Lobos Creek and its modest yet perennial imprint on the landscape is provided. The childhood home of renowned photographer Ansel Adams overlooked Lobos Creek. In his 1985 autobiography Adams provided this description of the creek, which is as fitting today as it was in the early 1900's when he was a child.

"With a resolute whisper, Lobos Creek flowed past our home on its mile-long journey to the ocean. It was bordered, at times covered, with watercress and alive with minnows, tadpoles, and a variety of larvae. Water bugs skimmed the open surfaces and dragonflies darted above the stream bed. In spring, flowers were rampant and fragrant. In heavy fog the creek was eerie, rippling out of nowhere and vanishing into nothingness" (Adams 1985, 11).

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