



Freshwater Quality Monitoring in the San Francisco Bay Area Network

2013-2014 Biennial Report

Natural Resource Report NPS/SFAN/NRR—2016/1188



ON THE COVER

Photograph of Redwood Creek in Golden Gate National Recreation Area.
Photo by Katie Wallitner

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Executive Summary

The National Park Service (NPS) San Francisco Bay Area Network (SFAN) Inventory and Monitoring Program monitors freshwater streams in John Muir National Historic Site (JOMU), the Presidio of San Francisco (PRSF), Muir Woods National Monument (MUWO), Pinnacles National Park (PINN), Point Reyes National Seashore (PORE), and Golden Gate National Recreation Area (GOGA). SFAN vital signs, or indicators of ecosystem health, represent a suite of ecological phenomena operating at a range of temporal and spatial scales. SFAN managers and specialists ranked freshwater quality as one of the most important vital signs. SFAN units support highly-valued aquatic resources that are significant in an ecological and economic context, including many federally protected species.

Water years (WYs) run from October 1st to September 30th of each year. This report summarizes water quality data from 25 SFAN sites monitored during WYs 2013 and 2014 (10/1/2012 – 9/30/2014), including 11 sites in the Redwood Creek watershed (GOGA/MUWO), nine sites in the Lagunitas Creek watershed (PORE/GOGA), and five sites in the San Francisquito Creek watershed (GOGA). During WYs 2013-2014, NPS staff made a total of 550 site visits; visits occurred monthly and additionally during storm events. During these visits staff collected data for select water quality parameters, employing the methods set forth in the peer-reviewed SFAN Freshwater Quality Monitoring Protocol (Coopridge and Carson 2006). Core parameters measured in the field included temperature (air and water), dissolved oxygen, pH, specific conductance, and turbidity. Samples collected in the field were tested for pathogenic indicator bacteria (*Escherichia coli* [*E. coli*] and total coliform) and nutrient parameters (nitrate as nitrogen and total Kjeldahl nitrogen [TKN]). Staff conducted fecal coliform sampling at the Olema Creek watershed sites as well, following a schedule set by the San Francisco Bay Regional Water Quality Control Board's (RWQCB) Tomales Bay Pathogen Total Maximum Daily Load (TMDL) program.

Only half of the SFAN freshwater quality parameters have established objectives put in place by the RWQCBs or the United States Environmental Protection Agency (EPA); other parameters (temperature, specific conductance, turbidity, and nitrate) do not have established water quality objectives, and are compared to ecological objectives drawn from scientific literature. In this report, the percentage of results that fail to meet any type of objective will be referred to as the *failure rate*.

When grouping SFAN water quality results from all WY 2013-2014 site visits, the pH, specific conductance, turbidity, and fecal coliform results most frequently met the objectives: only two percent of pH results failed to fall within the objective range; six percent of specific conductance results exceeded the ecological objective maximum of 500 $\mu\text{S}/\text{cm}$; seven percent of turbidity results exceeded the ecological objective maximum; and only seven percent of fecal coliform results exceeded the contact recreation maximum of 400 MPN/100mL.

Overall, the nitrate (as nitrogen) and the dissolved oxygen datasets had the highest failure rates (21 and 20 %, respectively). However, due to the variability between watersheds, much higher failure rates were revealed when grouping results by watershed. The Lagunitas Creek watershed exhibited the highest failure rate for nitrate (31% exceeded the ecological objective maximum of 0.30 mg/L)

while the San Francisquito Creek watershed exhibited the highest failure rate for dissolved oxygen (39% fell below the dissolved oxygen minimum objective of 7 mg/L). Of the three watersheds, the Redwood Creek sites most frequently met the water quality objectives.

Monitoring efforts during WYs 2013 and 2014 produced a snapshot of water quality conditions in three SFAN watersheds. Due to the two-year rotating basin design of the SFAN Freshwater Quality Monitoring Protocol, this specific set of 25 sites will not be monitored again until WYs 2017-2018 (Coopridier and Carson 2006). The only exception to the rotating basin design is the set of six Olema Creek watershed sites, which require year-round monitoring under the Tomales Bay Pathogen TMDL Program. During WYs 2015-2016, this freshwater quality monitoring program will continue at 30 sites within PORE, JOMU, PINN, and GOGA.

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List of Terms

CFS	Cubic Feet per Second
EPA	(United States) Environmental Protection Agency
GOGA	Golden Gate National Recreation Area
JOMU	John Muir National Historic Site
MPN	Most Probable Number (of colony-forming units per 100 mL)
MUWO	Muir Woods National Monument
MQO	Measurement Quality Objectives
NPS	National Park Service
NPSTORET	National Park Service's version of the EPA STORET database
PINN	Pinnacles National Park
PORE	Point Reyes National Seashore
PRSF	The Presidio of San Francisco
QC	Quality Control
RDL	Reporting Detection Limit
RPD	Relative Percent Difference
RWQCB	Regional Water Quality Control Board
SFAN	San Francisco Bay Area Network (of the National Park Service)
STORET	Storage and Retrieval (EPA's water quality database)
TC/EC	Total coliform and <i>E. coli</i>
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WY	Water Year

Introduction

Background

The National Park Service (NPS) *Management Policies* (NPS 2006) state that NPS managers will “use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals.” The NPS Inventory and Monitoring (I&M) program was established to help accomplish that mandate. Under the I&M program, San Francisco Bay Area Network (SFAN) staff monitor freshwater quality in five NPS units: John Muir National Historic Site (JOMU), Muir Woods National Monument (MUWO), Point Reyes National Seashore (PORE), Golden Gate National Recreation Area (GOGA), and Pinnacles National Park (PINN) (Figure 1). SFAN staff conduct freshwater quality monitoring under the SFAN Freshwater Quality Monitoring Protocol, which contains a thorough narrative and twelve standard operating procedures (SOPs) describing sampling locations, quality assurance procedures, field and laboratory methods, and data management procedures (Coopridge and Carson 2006).

Freshwater streams within the SFAN support a range of federally protected and culturally important species including the California freshwater shrimp (*Syncaris pacifica*) [FE¹], coho salmon (*Oncorhynchus kisutch*) [FE¹/SE²], steelhead (*Oncorhynchus mykiss*) [FT³], and California red-legged frog (*Rana draytonii*) [FT³]. Also, streams in the network provide beneficial uses including contact and non-contact recreation, fish spawning and migration, cold freshwater habitat, and terrestrial wildlife habitat. Water quality in these streams has a direct impact on associated resources including marine waters, riparian habitat, wetlands, and the aquatic and terrestrial species dependent on these habitats.

The California Environmental Protection Agency regulates water quality through the State Water Resources Control Board which is divided into nine Regional Water Quality Control Boards (RWQCBs). Through Basin Plans, the RWQCBs have identified “beneficial uses” for water bodies, and numerical and narrative water quality objectives (also referred to as standards) to meet the uses. In each Basin Plan there are specific numerical objectives for pH, dissolved oxygen, and pathogenic indicator bacteria, while there are no established objectives for nitrates, temperature, specific conductance, or turbidity. All SFAN park units fall under the regulation of the San Francisco Bay RWQCB, except for PINN (which is within the Central Coast RWQCB area).

¹ FE – federally endangered

² SE – state endangered

³ FT – federally threatened

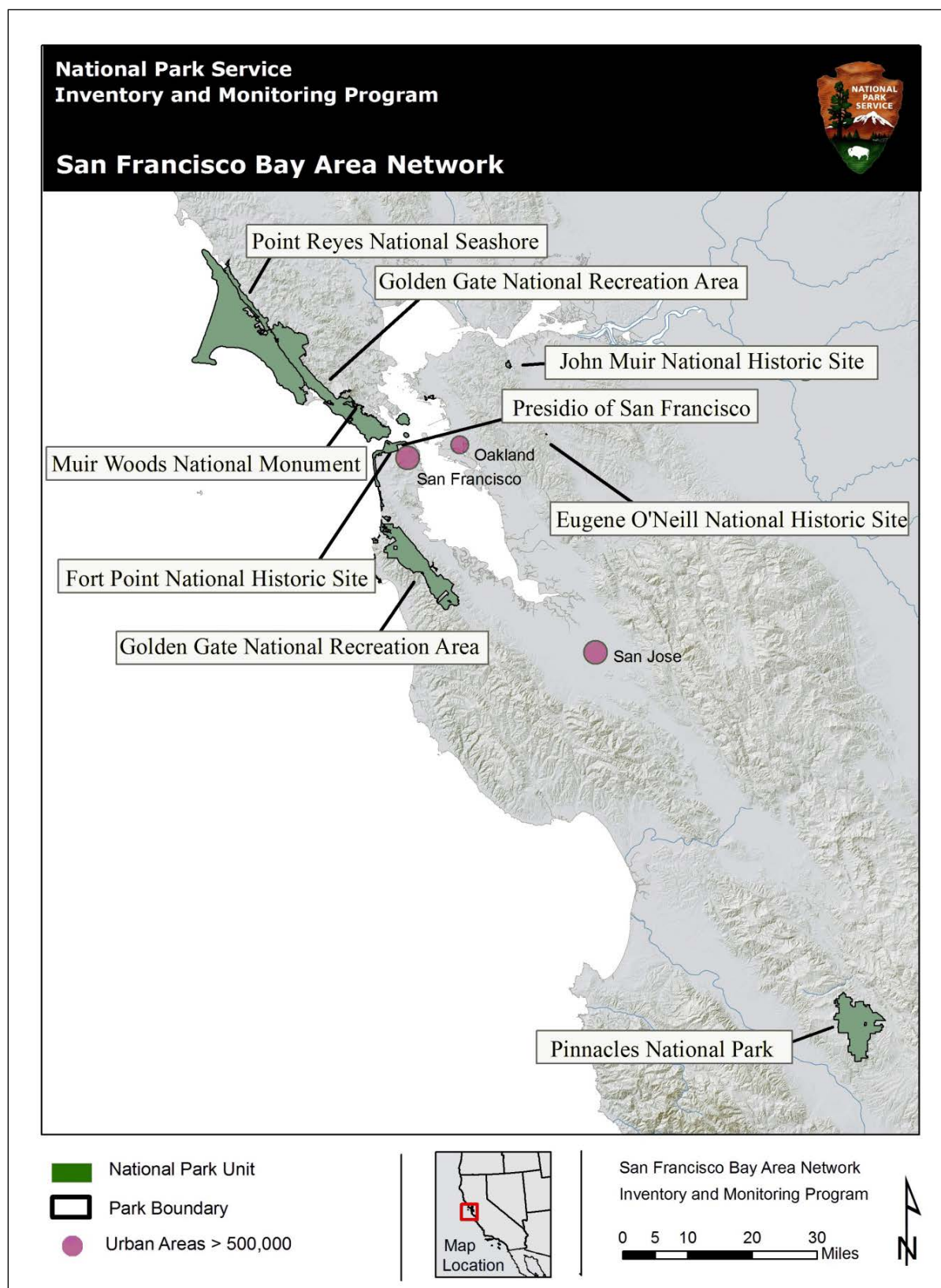


Figure 1. Map of the San Francisco Bay Area Inventory and Monitoring Network.

Objectives

Monitoring objectives as stated in the SFAN Freshwater Quality Monitoring Protocol are:

- Determine variability and long-term trends in water quality through monthly summaries of select parameters (water temperature, pH, conductivity, dissolved oxygen, total nitrogen, nitrate, ammonia, discharge, fecal and total coliform) at selected sites in priority freshwater streams within SFAN.
- Determine the existing ranges and diel variability of water temperature, pH, conductivity, and dissolved oxygen at selected sites in priority streams within SFAN.
- Determine the extent that selected sites in priority streams within SFAN meet federal and state water quality standards for fecal indicator bacteria, un-ionized ammonia, dissolved oxygen, and pH through monthly sampling.
- Determine the annual, seasonal, and 30-day mean fecal coliform load to Tomales Bay (an impaired water body) from Olema Creek as required by the San Francisco Bay RWQCB's Tomales Bay Pathogen Total Maximum Daily Load (TMDL) Program.

The goal of this report is to present data collected from the SFAN water quality sites during two consecutive water years (WYs) of monitoring. This report presents ranges and summary statistics of physical, chemical, and biological parameters measured at the SFAN water quality sites during WYs 2013-2014 (October 1, 2012 – September 30, 2014). Some of the monitoring questions and program objectives set forth in the protocol are not addressed in this report. SFAN staff have not measured diel variability because of significant needs for additional funding, staff time, and continuous monitoring equipment. Additionally, The RWQCB has not calculated loading as part of their TMDL program, and have not studied long-term trends for these data. WY 2014 marks the eighth year of protocol implementation (and fourth year of data from each watershed) and the dataset will soon be evaluated in order to determine the feasibility of trends analysis.

Overview of Aquatic Resources

Land uses in and around SFAN park units are various and represent a range of anthropogenic modification. These lands include both coastal wilderness and watersheds surrounded by urban development. Land uses within the rural watersheds include agriculture, ranching, and commercial recreation operations (e.g., equestrian operations) as well as protected wilderness areas.

The Mediterranean climate of the San Francisco Bay Region typically exhibits wet winters and dry summer months, however, both winter seasons of WY 2013 and 2014 were mild due to a statewide drought. Local streams are generally flashy, with high runoff during storm events and very low to intermittent flow during summer and early fall. In response to flashy hydrologic conditions and the active geologic processes in the area, stream channel morphology is highly dynamic. Chalone Creek in PINN includes a mobile sand bed that is typically dry at the surface in the summer months. Watersheds in JOMU and portions of GOGA are greatly altered by development and urbanization, with some natural processes engineered out of their stream systems. Watersheds within PORE and the Marin and San Mateo County portions of GOGA are less altered, and most of the smaller watersheds support anadromous steelhead trout. The larger PORE and northern GOGA watersheds, including Lagunitas, Olema, Redwood, and Pine Gulch, support both coho salmon and steelhead.

Stream systems in these areas have been degraded by historic and current agricultural activities, as well as low-intensity residential development.

Several NPS efforts to improve ecological function of aquatic habitat within SFAN watersheds are underway. The Redwood Creek watershed (MUWO/GOGA) is currently the focus of a variety of projects including watershed planning, transportation planning, water quality investigations, sensitive species monitoring, riparian habitat improvement projects, invasive/non-native plant removal, and fish habitat improvement. Current projects at PORE include the implementation of rangeland water quality best management practices and fish habitat improvement projects. Recent land management efforts in PINN include yellow star thistle removal, pig exclusion, and the relocation of various structures to enhance stream function.

Study Areas

Due to the rotating basin design of the SFAN Freshwater Quality Monitoring Protocol, the type of sites and number of watersheds monitored alternate during each two-year rotation. During the first two years of protocol implementation (WYs 2007-2008) SFAN staff monitored 30 sites in eight different watersheds within four SFAN parks (PORE, PINN, GOGA, and JOMU). During the subsequent two years (WYs 2009-2010) the rotation included 25 monitoring sites in three different watersheds, within GOGA, MUWO, and PORE. The watersheds monitored during WYs 2013-2014 are those that SFAN staff first monitored in WYs 2007-2008 and are introduced briefly below. More background information on site selection criteria, rationale, and sampling design can be found in the SFAN Freshwater Quality Monitoring Protocol (Coopridier and Carson 2006). The 2006 protocol identifies sites as *proposed* or *alternate*, but in the current program and in this report they will be referred to as *primary* and *secondary* sites, respectively. Primary and secondary sites are monitored at the same frequency, but involve slightly different parameters (see Methods section for more information).

Redwood Creek Watershed

The Redwood Creek watershed extends over approximately seven and a half square miles. Its headwaters originate on the south side of Mount Tamalpais, where the creek flows through Mount Tamalpais State Park, through MUWO, under Highway 1, and eventually into the Pacific Ocean at Muir Beach. The largest tributary of upper Redwood Creek is the Bootjack Branch (1.96 mi² watershed), followed by Fern Creek (1.11 mi² watershed) and Kent Creek (0.99 mi² watershed) (Coopridier 2004). There are seven other minor tributaries (including Spike Buck Creek, Rattlesnake Creek, and Camino del Canyon) in what is considered the upper Redwood Creek area (Coopridier 2004). Green Gulch (1.26 mi² watershed) is the largest tributary of the lower Redwood Creek area (Lehre and Wahrhaftig 1974). Green Gulch and another tributary (often referred to as the Golden Gate Dairy tributary) join Redwood Creek less than half of a mile upstream of the mouth. The area near the mouth of the creek is known historically as Big Lagoon, and has been the focus of extensive restoration efforts. The beneficial uses for Redwood Creek (defined by the San Francisco Bay RWQCB) include agricultural supply, coldwater habitat, freshwater replenishment, municipal supply, contact and non-contact recreation, fish spawning, and wildlife habitat.

Hydrologic monitoring of Redwood Creek began in 1997 with the installation of a streamgage at the Highway 1 Bridge. Water quality monitoring within the Redwood Creek watershed had been conducted sporadically since the mid-1980s and was mainly short-term and project-based. NPS staff have conducted fisheries monitoring (focused on coho salmon and steelhead) in the watershed since the early 1990s. In WYs 2009-2010 SFAN staff initiated long-term water quality monitoring in the Redwood Creek watershed and the second rotation continued during WYs 2013-2014.

SFAN and GOGA staff selected eleven sites within the Redwood Creek watershed for monitoring as part of the SFAN Freshwater Quality Monitoring Program (Table 1). Two of the monitoring sites are in the upper watershed area, and nine are scattered around the lower Redwood Creek area (Figures 2 and 3). Out of these eleven sites, three are located on the mainstem of Redwood Creek. The

remaining eight sights are located on tributaries of Redwood Creek, and they all exhibit low or intermittent flows in the summer and early fall.

Table 1. Redwood Creek watershed monitoring site locations, approximately in order from upstream to downstream.

Site	Site Type	Flow Regime	Location	Site Description
BJC1	Primary	Intermittent	Tributary	Bootjack Creek: in Bootjack picnic area, Mt. Tamalpais State Park
FC2	Secondary	Intermittent	Tributary	Fern Creek: upstream of Panoramic Hwy (near milepost 3.22) in Mt. Tamalpais State Park
FC1	Primary	Intermittent	Tributary	Fern Creek: off of Fern Creek Trail in MUWO, above confluence with Redwood Creek
CDC2	Primary	Intermittent	Tributary	Camino del Canyon Creek: off of Frank Valley Road, above confluence with Redwood Creek
RDW1	Primary	Perennial	Mainstem	Redwood Creek mainstem: downstream of MUWO entrance, under the Frank Valley Road concrete bridge
KC1	Primary	Intermittent	Tributary	Kent Creek: upstream of Kent Creek culvert (milepost 2.67), approximately 50 ft from confluence with Redwood Creek
RDW2	Primary	Perennial	Mainstem	Redwood Creek mainstem: at stream gaging station under Hwy 1 Bridge
GGD	Primary	Intermittent	Tributary	Golden Gate Dairy tributary: upstream of the Hwy 1 culvert at intersection with Pacific Way
GG2	Secondary	Intermittent	Tributary	Green Gulch: in Green Gulch Zen Center, upstream site next to guest parking lot
GG1	Primary	Intermittent	Tributary	Green Gulch: in Green Gulch Zen Center, downstream site near horse pasture
RDW3	Primary	Perennial	Mainstem	Redwood Creek mainstem: upstream of Muir Beach Pedestrian bridge

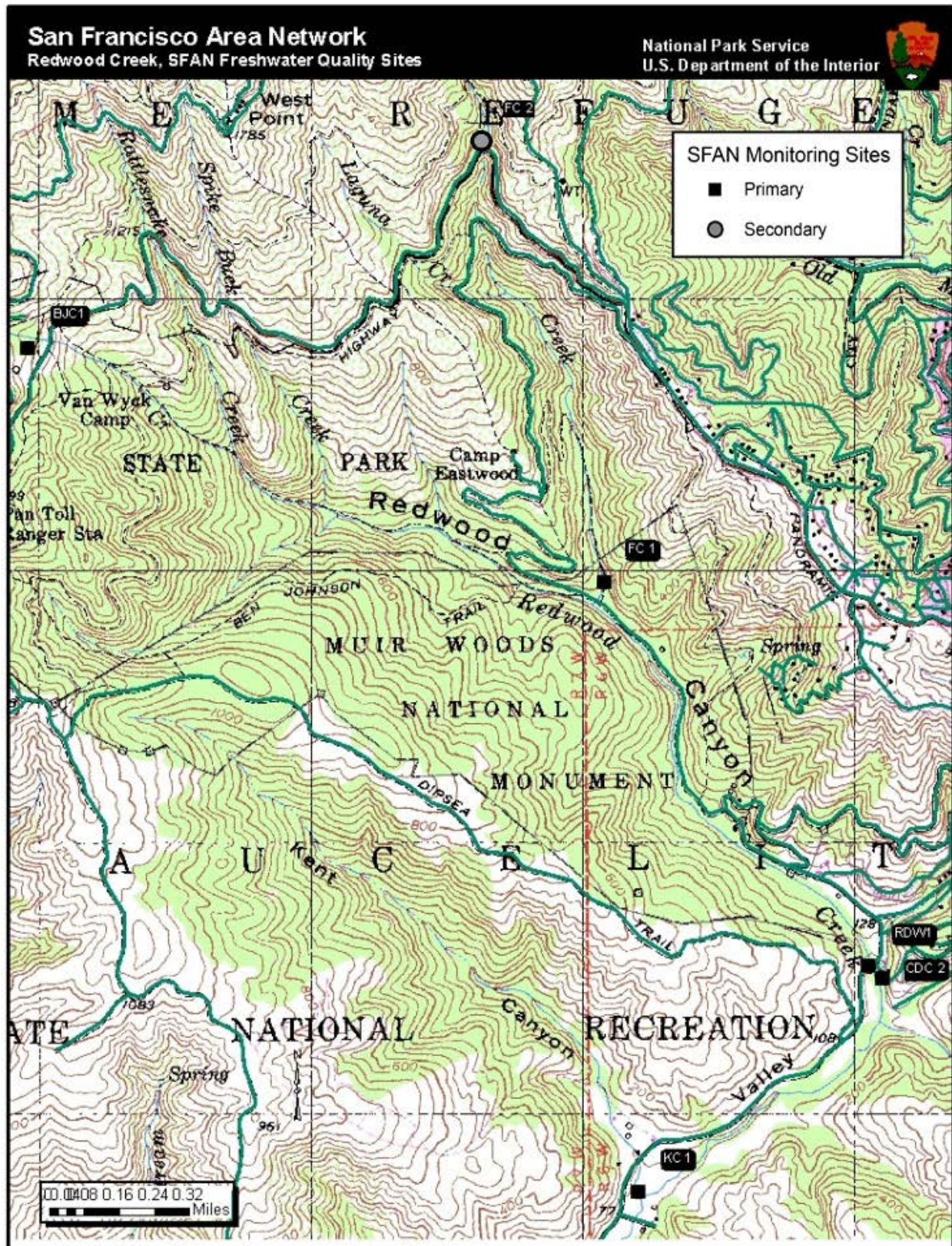


Figure 2. Six (of eleven) of the Redwood Creek watershed sites.

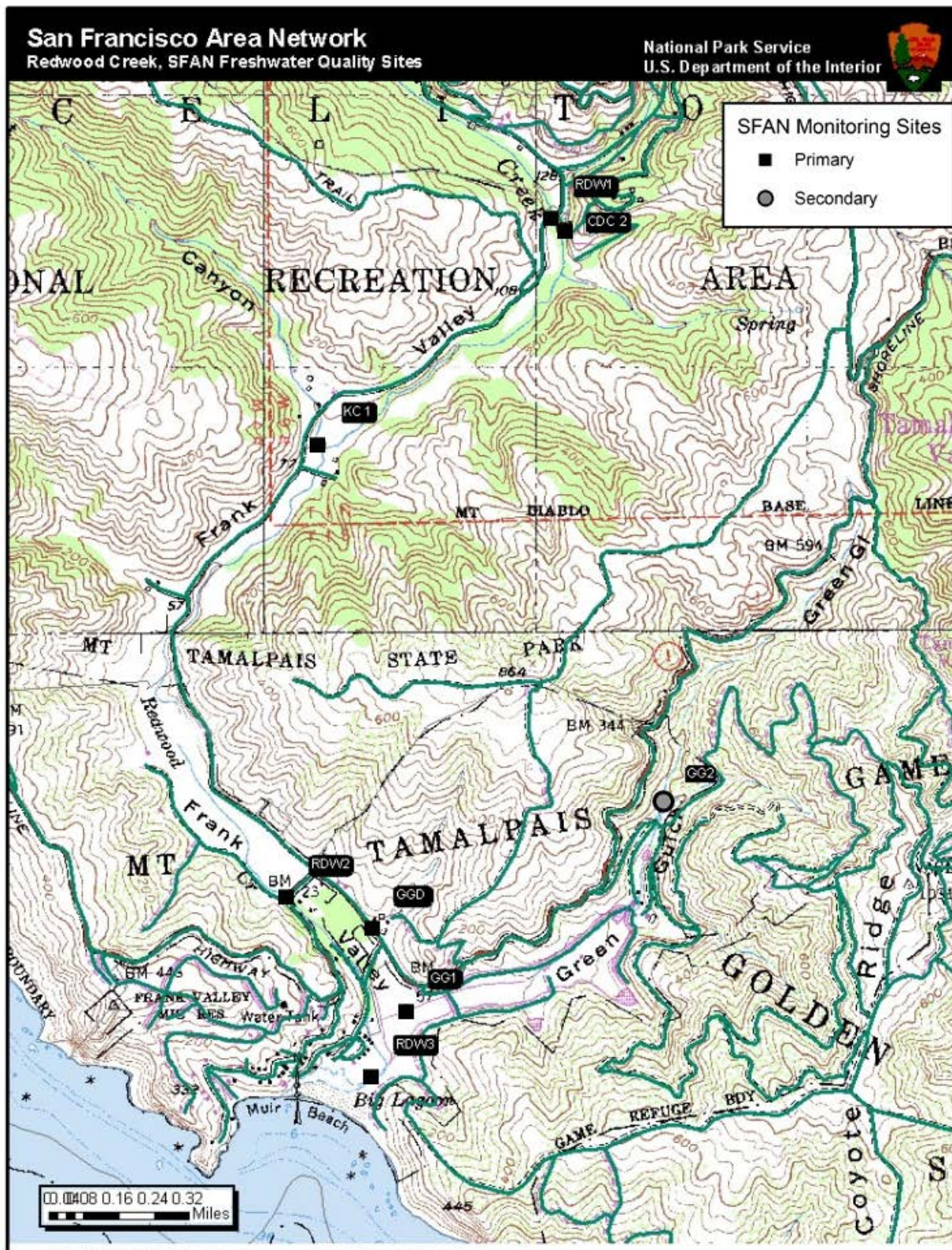


Figure 3. Eight (of eleven) of the lower Redwood Creek watershed sites. This map overlaps with Figure 2.

Lagunitas Creek Watershed

The 88 mi² Lagunitas Creek watershed is the largest within the SFAN, flowing north from Mount Tamalpais, through a series of lakes and dams, and eventually passing through NPS lands (PORE/GOGA) before reaching the head of Tomales Bay near the town of Point Reyes Station. Stream discharge records range from 22,100 cfs, in the floods of January 1982, to 0.01 cfs during the drought of 1977 (Freeman et al., 2003). Within NPS lands there are several tributaries of Lagunitas Creek, including Olema Creek, Bear Valley Creek, Haggerty Gulch, and Tomasini Creek. The San Francisco Bay RWQCB has identified Lagunitas and Olema Creeks as impaired by pathogens, sediment, and nutrients.

Olema Creek is the largest tributary of Lagunitas Creek, with stream discharge records up to approximately 3,000 cfs (Coopridier 2004). Olema Creek flows north through the Olema Valley to its confluence with Lagunitas Creek near Tomales Bay. About 55 to 60 percent of the Olema Creek watershed supports cattle grazing. Two horse concessions operations, Stewart Horse Stable and Five Brooks Horse Stable, are located in the central portion of the watershed.

The NPS initiated hydrologic monitoring in Olema Creek in 1997 with the installation of a streamgauge at the Bear Valley Road bridge. SFAN and PORE staff have conducted water quality monitoring within the Olema Creek watershed since 1999 and fisheries monitoring (focused on coho salmon and steelhead) has been conducted in the Olema Creek watershed since 1994. Water quality monitoring under the SFAN Freshwater Quality Monitoring Protocol began in the fall of 2006.

Lagunitas and Olema Creeks support viable populations of coho salmon, steelhead, and California red-legged frogs. Lagunitas Creek also supports a well-established population of California freshwater shrimp; over 5,000 individuals were recorded during a 2011 survey (Serpa 2011). Because of its significance as habitat for threatened and endangered species, and as a source of pollutant loading to Tomales Bay, the Lagunitas Creek watershed is the subject of extensive monitoring through the SFAN Freshwater Quality Monitoring Program as well as the SFAN Coho and Steelhead Monitoring Program, the Salmon Protection and Watershed Network, and Marin Municipal Water District's Lagunitas Creek Fisheries Program.

NPS staff originally selected nine primary (and two secondary) sampling sites within the Lagunitas Creek watershed for inclusion in the SFAN Freshwater Quality Monitoring Program (Table 2 and Figure 4). The PORE Pastoral Water Quality Program adopted the secondary sites for eight years of monitoring, collecting only core parameter and pathogenic bacteria data. This program ended in July 2014 and these two sites are no longer monitored. Data from these two secondary sites are not included in this report because they are not part of the SFAN I&M Program.

Table 2. Lagunitas Creek watershed monitoring site locations, approximately in order from upstream to downstream.

Site	Site Type	Flow Regime	Location	Site Description
OLM18	Primary	Intermittent	Mainstem Olema	Olema Creek: upstream of Randall Gulch (near Hwy 1 milepost 21.06)
OLM1	Primary	Intermittent	Tributary of Olema	John West Fork: upstream of Highway 1 culvert (near milepost 22.67)
OLM2	Secondary	Intermittent	Tributary of Olema	Giacomini Gulch: downstream of Highway 1 culvert (near milepost 22.78)
OLM14	Primary	Perennial	Mainstem Olema	Olema Creek: access just downstream of the northernmost Five Brooks Bridge
OLM6A	Primary	Perennial	Tributary of Olema	Davis Boucher Creek: approximately 165 ft upstream of footbridge, above confluence with Olema Creek
OLM4	Secondary	Intermittent	Tributary of Olema	Quarry Gulch: at staff plate upstream of confluence with Olema Creek (near Hwy 1 milepost 26.0)
OLM11	Primary	Perennial	Mainstem	Olema Creek: at Bear Valley Road Bridge
LAG1	Primary	Perennial	Tributary of Olema	Bear Valley Creek: upstream of first bridge in Bear Valley Headquarters area
OLM10B	Primary	Perennial	Mainstem Olema	Olema Creek: adjacent to Olema Marsh, below residence #530
LAG3	Primary	Perennial	Tributary of Lagunitas	Devil's Gulch: upstream of Sir Francis Drake Boulevard in Samuel P. Taylor State Park
LAG2	Primary	Perennial	Tributary of Lagunitas	Cheda Creek: upstream of Sir Francis Drake Boulevard (near milepost 19.17)

San Francisco Area Network Lagunitas & Olema Creek, Freshwater Quality Sites

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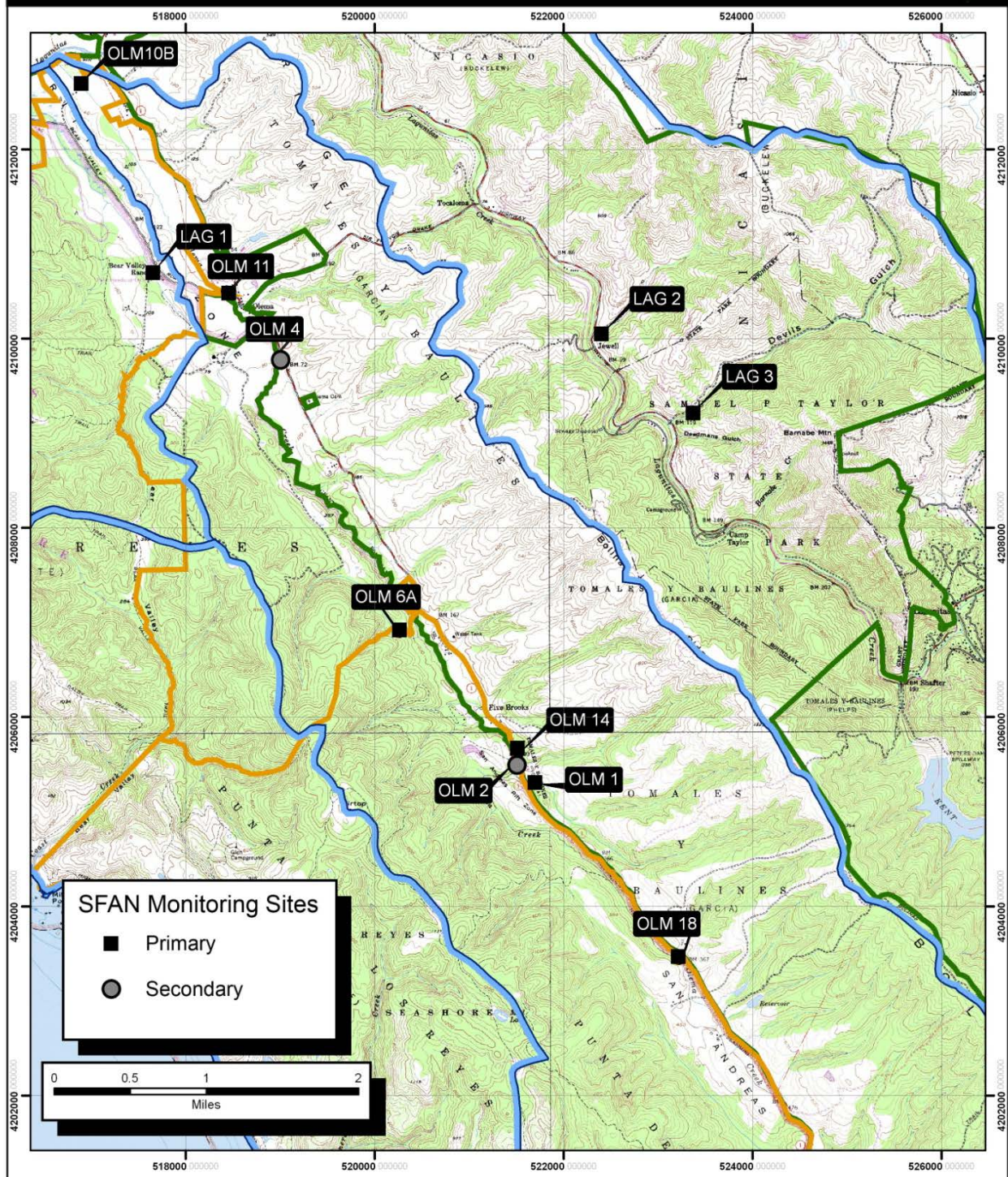


Figure 4. Map of the Lagunitas Creek watershed sites.

San Francisquito Creek Watershed

In 1992 GOGA acquired the Phleger Estate, located adjacent to Huddart County Park in the town of Woodside in central San Mateo County. The headwaters of West Union Creek are located within the 1,000-acre Phleger Estate, where the creek flows south through NPS lands into Huddart County Park. There are two minor (unnamed) tributaries of West Union Creek within the Phleger Estate, and another larger tributary, McGarvey Gulch, which flows into West Union near the Phleger/Huddart boundary. West Union Creek drains approximately five square miles of land before flowing into Bear Creek, a tributary of San Francisquito Creek, which eventually empties into the San Francisco Bay, northeast of Palo Alto and Stanford University. San Francisquito Creek is listed under Section 303(d) of the Clean Water Act for impairment by sedimentation/siltation, as well as the pesticide diazinon.

Until January 2004 the NPS had not conducted any monitoring of surface water in the southern GOGA lands. Some limited water quality monitoring had been conducted within the San Francisquito Creek Watershed, but not on NPS lands. Water quality concerns for West Union Creek include increased sediment from erosion and runoff from trails, since landslides and significant bank erosion have been observed in the past (Coopridge 2004). Equestrian recreation in the Phleger Estate may also contribute to runoff of bacteria and nutrients.

NPS staff selected two primary and three secondary sampling sites within the West Union Creek watershed to be monitored as part of the SFAN Freshwater Quality Monitoring Program (Table 3). Two sites are located on the mainstem of West Union Creek, and the remaining three sites are located on tributaries of West Union Creek. In this report, these will be referred to as the San Francisquito Creek watershed sites (Figure 5).

Table 3. San Francisquito Creek watershed monitoring site locations, in order from upstream to downstream.

Site	Site Type	Flow Regime	Location	Site Description
WU4	Secondary	Perennial	Mainstem	West Union Creek: upstream of tributary #2
WU3	Secondary	Intermittent	Tributary	Tributary #2 (second tributary upstream of McGarvey Gulch): upstream of Raymundo Bridge Trail
WU2	Secondary	Intermittent	Tributary	Tributary #1 (first tributary upstream of McGarvey Gulch): above the Miramontes trail crossing
WU1	Primary	Perennial	Mainstem	West Union Creek: ¼ mile down the trail from the Huddart County Park boundary
MGG1	Primary	Perennial	Tributary	McGarvey Gulch: between trail crossing and confluence with West Union Creek (above large boulders)

San Francisco Area Network West Union Creek, Freshwater Quality Sites

National Park Service
U.S. Department of the Interior

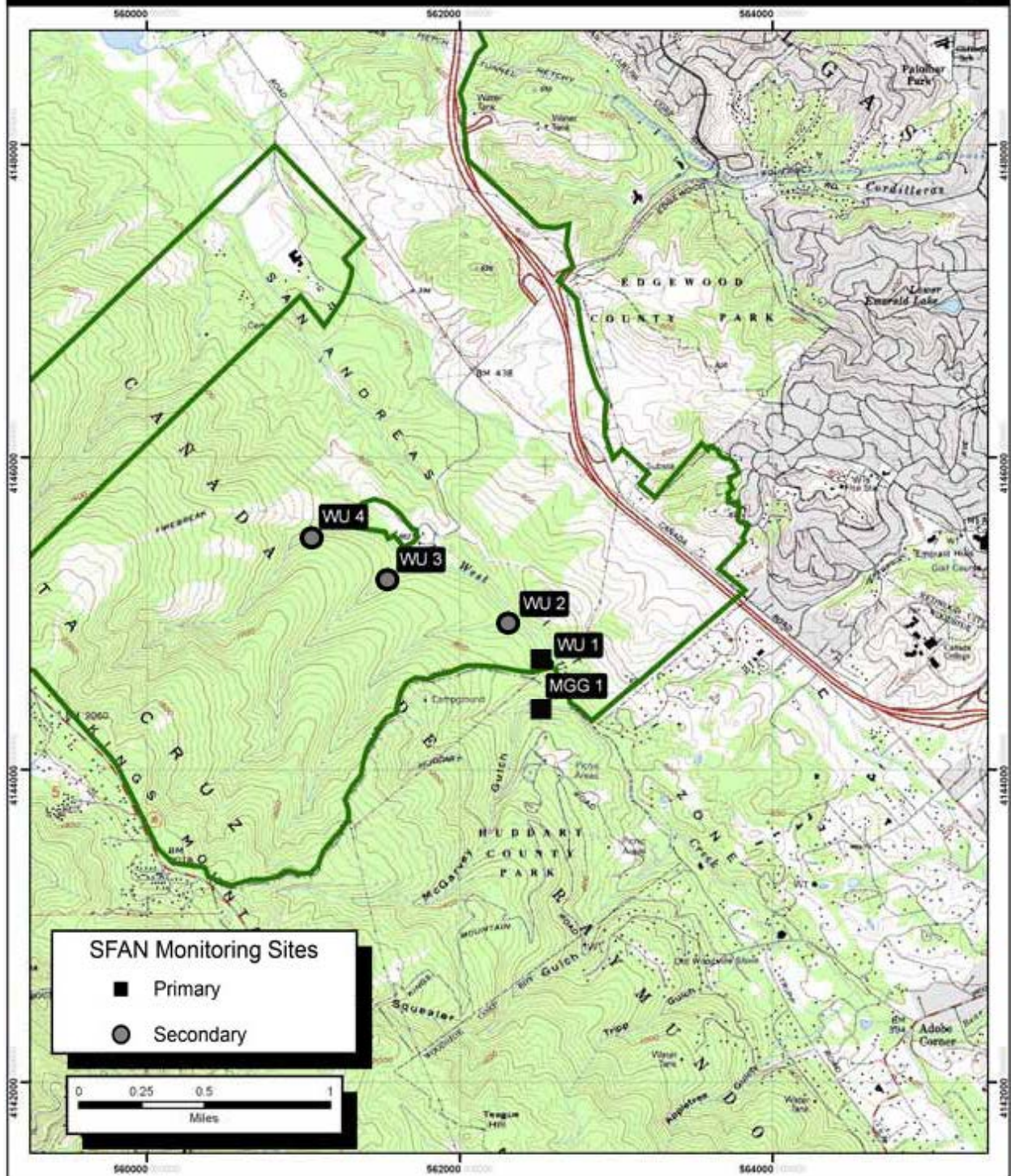


Figure 5. Map of the San Francisco Creek watershed sites.

Methods

Water Quality Objectives

In California, the RWQCBs established Basin Plans, which set “numerical and narrative objectives for surface waters” (Tables 4 and 5). The numerical objectives for bacteria are based on the national criteria established by the United States Environmental Protection Agency (EPA) (U.S. EPA 1986). In this report we refer to failures to meet water quality objectives (surpassing objective maximums) as *exceedances*. The Basin Plans also outline the beneficial uses assigned to each stream that is a significant surface water feature. Although the San Francisco Bay RWQCB has identified some nutrients as impairments to Tomales Bay and is developing nutrient objectives for the region, the Basin Plans have not currently established objectives for any nutrients except un-ionized ammonia. Only half of the SFAN freshwater quality parameters have established objectives put in place by the RWQCBs or the EPA; other parameters (temperature, specific conductance, turbidity, and nitrate) do not have established objectives. In this report we compare these to ecological objectives drawn from scientific literature.

Table 4. Numerical objectives for surface waters in PORE and GOGA - from the San Francisco Bay Regional Water Quality Control Board's Basin Plan (CA RWQCB 2010).

Parameter	Water Quality Objective
Dissolved oxygen (non-tidal waters, cold water habitat)	7.0 mg/L minimum
pH	Less than 8.5 and greater than 6.5 pH units

Table 5. Pathogenic indicator bacteria objectives for freshwater contact recreation use - from the San Francisco Bay Regional Water Quality Control Board's Basin Plan (CA RWQCB 2010).

Parameter	Timeline	Objective Maximum (MPN/100mL)
Total coliform	Single-day sample	10,000
	30-day average	1,000
Escherichia coli	Single-day sample	235
	30-day average	126
Fecal coliform	Single-day sample	400
	30-day average	200

In order to assist states with the development of nutrient standards, the EPA undertook nationwide sampling of nutrients in rivers and streams, and developed regional reference values (U.S. EPA 2000). The regional reference values can be used to assess whether nutrients in the SFAN are

exceeding expected conditions. The EPA regional reference values for the sub-ecoregion encompassing the SFAN are 0.36 mg/L for total Kjeldahl nitrogen (TKN) and 0.16 mg/L for nitrate and nitrite (Table 6). Previous monitoring in the SFAN has shown nitrite values to be insignificant, thus the SFAN only samples nitrate (Coopridge 2004).

Table 6. Ecoregion III reference values for nutrients (U.S. EPA 2000).

Parameter	Regional Reference Value
Nitrate as nitrogen	0.16 mg/L
Total Kjeldahl nitrogen	0.36 mg/L

Clean Water Act Section 303(d) Listed Waters

Under Section 303(d) of the federal Clean Water Act, numerous water bodies within and adjacent to NPS lands are listed as impaired by pathogens, sediment, and nutrients. With the state as the lead in development of TMDLs, the NPS has participated as an active stakeholder, along with other partners, to support development and implementation of water quality monitoring and enhancement efforts in order to address water quality pollution issues.

In 2007 the San Francisco Bay RWQCB completed a TMDL project plan for pathogens in the Tomales Bay Watershed, which set forth water quality targets for Tomales Bay and its tributaries (CA RWQCB 2011). Part of this monitoring regime is conducted through the SFAN program in conjunction with the RWQCB and other stakeholders. This includes monthly monitoring of six SFAN sites along Olema Creek, in addition to intensive weekly monitoring for five consecutive weeks during both the winter and summer. Additional information about TMDLs in the SFAN can be found in the Freshwater Quality Monitoring Protocol (Coopridge and Carson 2006) and on the San Francisco Bay RWQCB website (<http://www.waterboards.ca.gov/sanfranciscobay/>).

Site Selection

Detailed information about the process used to select SFAN monitoring locations is documented in the SFAN Freshwater Quality Monitoring Protocol (Coopridge and Carson 2006).

Sampling Regime

The sampling design for the SFAN Freshwater Quality Monitoring Program involves a rotating basin approach in which each watershed is monitored monthly for a two-year period (Table 7). This approach allows the SFAN to collect enough samples from each site and watershed in order to perform statistical analyses, while allowing for sufficient funds to perform laboratory analyses. There are two groups of basins in this design, meaning that every four years, each site and each watershed group will have two additional years of data available for analysis. This design is intended to allow for the detection of both short-term and long-term trends in all monitored watersheds. The only exception to the rotating basin approach is the Olema Creek watershed, which is monitored continuously (every water year) because sampling is mandated by a TMDL project. An effort is

made to visit each site at approximately the same time of day, once per month (except for Strentzel Creek), and to attempt to capture at least one storm event per year.

Table 7. SFAN water quality monitoring schedule. (WY = water year, M = visited monthly, S = visited during at least one storm event, W = visited 5 consecutive weeks in the winter and summer as required by the Tomales Bay Pathogen TMDL Project.)

Watershed/Stream	Park Unit	WYs 2007-2008 & 2011-2012	WYs 2009-2010 & 2013-2014	Number of Monitoring Sites
Olema Creek	PORE	M, S, W	M, S, W	6 Primary
Pine Gulch	PORE	M		3 Primary
Franklin Creek	JOMU	M		1 Primary
Strentzel Creek	JOMU	S		0 Primary / 5 Secondary
Chalone Creek	PINN	M, S		5 Primary / 3 Secondary
Rodeo Creek	GOGA	M, S		2 Primary
Tennessee Creek	GOGA	M, S		2 Primary / 1 Secondary
Nyhan Creek	GOGA	M, S		1 Primary
Oakwood Creek	GOGA	M, S		0 Primary / 1 Secondary
West Union Creek	GOGA		M	2 Primary / 3 Secondary
Lagunitas Creek	PORE/GOGA		M, S	3 Primary
Redwood Creek	GOGA/MUWO		M, S	9 Primary / 2 Secondary

Primary sites ranked as a higher priority during site selection in the protocol development process, while secondary sites were identified to be of a slightly lower priority and could be integrated into the sampling regime only if funding and time allowed. Many of the secondary sampling sites are in close proximity to primary sites, and it became apparent during the first year of monitoring that the sampling of core parameters and bacteria from the secondary sites could be conducted on each corresponding field day with little additional time. Furthermore, the SFAN acquired the IDEXX Quanti-Tray system for affordable (internal) processing of pathogenic indicator bacteria samples, which keeps costs low for the secondary sites. The processing of nutrient samples (by a contracted laboratory) is one of the largest costs to the SFAN water quality program; therefore, the SFAN monitors nutrient parameters only at primary sites.

Sample Parameters

The NPS I&M Program called for monitoring of all basic level 1 water quality parameters. Level 1 parameters include a qualitative description of flow and core parameters (water temperature, dissolved oxygen, pH, and conductivity) (NPS 2002).

At each site, NPS staff measured core parameters in the field and collected water samples for laboratory processing (Table 8). Staff also documented air temperature, cloud cover, flow severity,

recent precipitation, and conducted photo monitoring. Additionally, staff collected a quantitative discharge measurement at select sites (established stream gaging stations) when site conditions allowed, following methods set forth in the SFAN Streamflow Monitoring Protocol (Fong et al. 2011). All instantaneous measurements and grab samples were collected from the centroid of flow. Samples were analyzed for nutrients (nitrate as N and TKN [at primary sites only]), turbidity, and pathogenic indicator bacteria (total coliform and *Escherichia coli*). Fecal coliform samples were only collected in the Olema Creek watershed. All water quality sampling followed the methods described in the SFAN Freshwater Quality Monitoring Protocol (Coopridge and Carson 2006), manufacturer's equipment manuals, and United States Geological Survey (USGS) guidance.

Table 8. SFAN water quality monitoring parameters.

Parameter Group	Specific Parameters
Core	Water temperature, dissolved oxygen, pH, and conductivity
Bacteria	Total coliform and <i>Escherichia coli</i> at all sites (+ fecal coliform at Olema Creek sites only)
Sediment	Turbidity
Nutrients	Total Kjeldahl nitrogen (TKN) and nitrate (as N)
Discharge	Qualitative flow description only (quantitative stream discharge measurements were collected at select sites under the SFAN Streamflow Monitoring Program)

Table 9 lists the processing methods used for all parameters. NPS staff collected core parameter data in-situ, using a YSI ProPlus (Professional Series) multiparameter instrument. In order to evaluate samples for fecal coliform concentration (at Olema Creek watershed sites only), the RWQCB contracted with CEL Analytical Laboratory in San Francisco and Excelchem Environmental Labs in Rocklin, CA. NPS staff processed all total coliform, *E. coli*, and turbidity samples at PORE's Pacific Coast Science and Learning Center Laboratory. Analytical Sciences LLC, in Petaluma, CA processed all nutrient samples.

Table 9. Water quality testing methods used in the SFAN.

Parameter	Method
Core parameters	Instantaneous readings collected in the centroid of flow with a YSI ProPlus multiparameter instrument.
Total coliform bacteria	Enzyme substrate coliform test: standard method 9223B using IDEXX Quanti-Tray 2000 with colilert reagent
<i>E. coli</i> bacteria	Enzyme substrate coliform test: standard method 9223B using IDEXX Quanti-Tray 2000 with colilert reagent
Fecal coliform bacteria	Fecal coliform by multiple tube fermentation: standard method 9221B
Nitrate (as N)	EPA method 300 [detection limit: 0.15 mg/L]

Table 9 (continued). Water quality testing methods used in the SFAN.

Parameter	Method
TKN	Standard method 4500-Norg C [detection limit: 0.25 mg/L]
Turbidity	Hach 2100P turbidimeter
Discharge	Methods from the SFAN Streamflow Monitoring Protocol using a SonTek FlowTracker ADV or Marsh-McBirney Flowmate (Fong et al. 2011)

Data Handling and Analysis

NPS staff entered all data into NPSTORET (housed at PORE), which is the database created and provided by the NPS Water Resources Division. All data entered into NPSTORET were verified by an alternate staff person. Staff routinely upload these data to the EPA STORET database that allows for public access.

Water quality data contain many values that cannot be quantified, but are known to be above or below a certain threshold (e.g., reporting limit, detection limit, quantification limit, etc.); these data are considered *censored* during statistical analysis (Helsel 2005). The SFAN nutrient results are often reported as *non-detect*, meaning that the value is not defined as zero, but is only known to be less than the reportable detection limit of that particular method. The SFAN bacteria results can be censored on either end (producing results above or below the quantifiable range), which further complicates data analysis. A study by the USGS (Antweiler and Taylor 2008) evaluated the main classes of statistical treatment of censored environmental data, and found that the nonparametric Kaplan-Meier method was the most effective technique for overall determination of summary statistics for datasets with less than 70% censoring. For this reason, NPS staff used the Kaplan-Meier statistical method (through the NPSTORET database) to create summary statistics and figures for all censored SFAN data in this report.

Quality Control

NPS staff calibrated field equipment at the beginning of each sampling day, performing a three-point calibration (i.e., utilizing three buffers of different values) for all pH sensors, a one-point calibration for conductivity (specific conductance), and a one-point calibration for dissolved oxygen (utilizing the water-saturated air method). NPS staff performed calibration checks immediately following each calibration, and again at the end of the field day, in order to monitor for fouling and drift, and to ensure that the instruments stayed within the calibration acceptance criteria of each parameter (+/- 0.2 pH units, +/- 10% for dissolved oxygen saturation, and +/- 15% for specific conductance). In past years, if any parameter failed a post-field drift check, staff would flag all corresponding results from that entire field day as rejected. Due to improvements in technology, equipment maintenance, and calibration procedures, WYs 2013 and 2014 marked the first years (in the program's history) that staff detected no failures and there was no loss of core parameter data.

In order to assess precision, field staff collected approximately 10% of all samples in duplicate. Additionally, (for turbidity and bacteria samples only) staff created trip blanks (of distilled water) in order to detect and locate possible sources of contamination. The contracted laboratories conducted

their own internal quality control (QC) practices as well (e.g., matrix spikes, laboratory method blanks, laboratory control spikes, and the use of a variety of calibration standards).

Measurement Quality Objectives

The SFAN has established measurement quality objectives (MQOs) for all monitored parameters. There are MQOs for calibration acceptance, precision, and systematic error (percent recovery). Measurement of systematic error (reported as percent recovery) represents the accuracy of the laboratory procedures and equipment, which is determined by conducting matrix spikes or laboratory control spikes, to test a known value of a particular analyte. The MQO for systematic error (percent recovery) is 70-130% for TKN, and 75-125% for nitrate (as N). During WYs 2013-2014, the professional laboratory contracted by the SFAN did not report any QC results that were outside of these acceptable ranges.

The MQOs for precision are defined in the SFAN Freshwater Quality Monitoring Protocol as the acceptable thresholds of relative percent difference (RPD), calculated from the duplicated QC sample sets. The precision MQO for nitrate (as N) and TKN is +/- 30% (RPD), while the MQO for total coliform and fecal coliform is +/- 60% (RPD). An MQO was not established for *E. coli*, so it is assumed to be 60% as well.

The SFAN collected a total of 228 duplicate QC samples during WYs 2013-2014, and 20% of these (46 of 228) included a censored result which prevented calculation of RPD/precision. Because of this limitation, Table 10 contains the mean RPD values (for each parameter) calculated only from those QC tests that had quantifiable RPD (did not include a censored result). The only parameter that did not produce any precision MQO failures was nitrate (as N): no nitrate duplicate had an RPD above 30%, and the mean RPD of all QC tests was only 1.94%. The TKN results also had a low mean RPD (14.55%) - well below the precision MQO of 30%. The mean RPD values for the total coliform and *E. coli* QC tests were much higher (25.56% and 41.01%, respectively), but were still well below their specific MQO of +/- 60%. The fecal coliform QC tests (all run by a contracted laboratory) produced the highest mean RPD (55.79%), although this mean was still below the acceptable threshold of 60%.

Table 10. Precision of SFAN nutrient and bacteria samples during water years 2013-2014. (QC = quality control; RPD = relative percent difference; MQO = measurement quality objective)

Parameter	Nitrate as Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Coliform (MPN/100mL)	<i>Escherichia coli</i> (MPN/100mL)	Fecal Coliform (MPN/100mL)
Total Number of QC Duplicates	45	45	61	60	17
Number of QC Dups with Measurable RPD ¹	23	37	58	47	17
Number that Failed to Meet MQO for RPD ¹	0	5	5	16	7
Mean RPD ¹ (Precision)	1.94%	14.55%	25.56%	41.01%	55.79%
SFAN MQO for RPD (Precision)	+/- 30%	+/- 30%	+/- 60%	+/- 60%	+/- 60%

¹ Many duplicate QC measurements (20% of 228) did not have measurable RPD because of a censored result; therefore, the calculated mean RPD values and number of failures do not include all duplicate QC measurements collected during WYs 2013-2014.

Results and Discussion

This report includes results collected from October 1, 2012 through September 30, 2014 (WYs 2013-2014), the seventh and eighth years of protocol implementation. Due to the two-year rotating basin design of this protocol, the WY 2013 and 2014 data represent the third and fourth years of monitoring this specific set of sites (11 sites in the Redwood Creek watershed, nine in the Lagunitas Creek watershed, and five in the San Francisquito Creek watershed). While it is not yet possible to observe long-term trends, we can evaluate the data in the context of established water quality objectives, ecological objectives, and regional reference values established by the EPA.

Field staff conducted routine monthly monitoring events at approximately the same time of day, and made an effort to collect storm samples from every site during each water year. However, due to the persistence of drought conditions (and the limited number of storms), staff conducted storm sampling only at the Redwood Creek and Lagunitas Creek watershed sites once during each of these water years. Staff did not conduct storm sampling in the San Francisquito Creek watershed during WY 2013 or 2014. Some sites exhibited intermittent seasonal flow patterns and staff characterized these as “dry” or “no flow” on routine monthly visits during WYs 2013-2014. Five sites in the Redwood Creek watershed (CDC2, KC1, GGD, GG2, and GG1) and four sites in the San Francisquito Creek watershed (MGG1, WU1, WU2, and WU3) were too low for sampling at least once during the dry seasons, so their summary statistics are computed from smaller datasets. During the previous rotation (WYs 2009-2010) the MGG1 and WU1 sites had enough water to be sampled every month. In comparison, these two sites dried up after the July 2013 sampling (for approximately five months), and then again after the June 2014 sampling event, exhibiting the effects of the prolonged drought during each of these years. The six Olema Creek watershed sites (in PORE) have the largest datasets, due to the additional monitoring required by the San Francisco Bay RWQCB’s Tomales Bay Pathogen TMDL Program.

The following sections present summary statistics for WYs 2013-2014, organized by parameter and park. All results and summary statistics discussed in this report refer to this two-year rotation as a whole, not as individual years. All means and standard deviations presented in the tables are rounded to one more decimal place than the least precise value (fewest decimal places) of each corresponding dataset (Sullivan 2011).

Core Parameters

Water temperature, dissolved oxygen, pH, conductivity (specific conductance), and turbidity are called the core parameters; these are all interrelated, and describe the most basic level of water chemistry. Thorough knowledge of core parameters is needed in order to better understand nutrient and bacteria data collected. Staff measure these parameters in-situ during every site visit, alongside each sample collection.

Tables 11, 12, and 13 display summary statistics of all core parameter results from WYs 2013-2014, while box and whiskers plots of these data are displayed separately (sorted by parameter) for simplified viewing. All summary statistics are based on instantaneous measurements routinely

collected at approximately the same time of day on each visit; therefore, the data in the tables and figures presented do not reflect the true minimum and maximum values of diel variation.

Table 11. Core parameter results from the Redwood Creek watershed (water years 2013-2014). All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset. (Std. dev. = standard deviation. N of obs. = number of observations.)

Parameter	Statistic	BJC1	FC1	FC2	CDC2	KC1	RDW1	RDW2	RDW3	GGD	GG1	GG2
Water temperature (°C)	Minimum	9.0	8.2	8.7	8.9	8.5	8.5	8.6	9.1	9.8	8.1	7.0
	Maximum	17.0	15.0	15.2	13.7	13.3	15.7	16.1	17.9	13.8	13.8	13.5
	Mean	12.73	11.72	11.98	11.05	10.91	12.33	12.68	13.83	12.08	12.20	10.80
	Median	12.7	12.1	12.4	11.7	11.1	12.8	13.3	14.0	12.8	13.1	10.9
	Std. dev.	2.21	1.84	1.66	1.74	1.46	2.00	2.02	2.67	1.70	1.66	1.79
	N of obs.	25	25	25	6	10	25	25	25	4	15	9
Dissolved oxygen (mg/L)	Minimum	7.47	9.05	8.96	10.15	7.38	7.53	4.73	4.27	4.51	2.75	10.02
	Maximum	20.21	11.81	11.23	11.43	11.03	11.43	11.36	12.07	9.49	11.58	12.32
	Mean	9.774	10.120	10.120	10.490	9.865	9.310	8.408	8.721	6.568	8.425	10.800
	Median	9.30	10.09	10.05	10.38	10.26	9.18	8.40	9.41	7.25	9.63	10.64
	Std. dev.	2.342	0.737	0.578	0.489	1.178	1.000	1.710	1.946	2.283	2.805	0.813
	N of obs.	25	25	25	6	10	25	25	25	4	15	9
pH (pH units)	Minimum	6.37	7.09	6.87	7.22	7.26	7.30	7.30	7.40	7.00	6.70	7.49
	Maximum	8.18	7.89	8.17	7.82	7.61	8.08	7.89	7.99	7.42	7.73	8.27
	Mean	7.619	7.654	7.791	7.560	7.444	7.611	7.581	7.660	7.210	7.399	7.846
	Median	7.92	7.76	7.97	7.77	7.47	7.61	7.58	7.65	7.29	7.47	7.81
	Std. dev.	0.571	0.227	0.416	0.268	0.120	0.160	0.133	0.163	0.184	0.299	0.267
	N of obs.	25	25	25	6	10	25	25	25	4	15	9
Specific conductance (µS/cm)	Minimum	112.4	88.4	64.2	156.8	193.8	121.3	139.5	100.7	257.0	228.3	189.9
	Maximum	306.5	199.9	200.8	219.9	383.5	264.9	292.2	1607.0	313.2	631.5	337.0
	Mean	248.30	168.90	166.30	190.10	258.60	221.40	232.60	345.80	287.10	397.60	246.40
	Median	266.0	180.6	182.5	209.7	261.6	235.7	241.5	274.7	297.5	381.8	232.7
	Std. dev.	58.65	30.83	38.68	27.01	51.49	40.48	37.83	298.00	24.05	120.00	48.67
	N of obs.	25	25	25	6	10	25	25	25	4	15	9

Table 11 (continued). Core parameter results from the Redwood Creek watershed (water years 2013-2014). All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset. (Std. dev. = standard deviation. N of obs. = number of observations.)

Parameter	Statistic	BJC1	FC1	FC2	CDC2	KC1	RDW1	RDW2	RDW3	GGD	GG1	GG2
Turbidity¹ (NTU)	Minimum	0.25	0.25	0.27	5.51	0.39	0.27	0.34	0.56	4.55	0.80	0.84
	Maximum	25.4	35.8	17.4	134	115	41.1	63.7	79.9	41.8	52.5	61.9
	Mean	2.78	2.70	1.71	39.8	17.9	3.76	5.78	6.64	15.66	8.99	15.30
	Median	0.91	0.47	0.53	9.61	5.37	0.46	0.86	1.11	8.62	4.10	12.2
	Std. dev.	5.89	7.70	3.90	52.8	36.0	10.68	15.70	18.04	17.51	12.97	18.48
	N of obs.	25	25	25	6	10	25	25	25	4	15	9

¹ Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

Table 12. Core parameter results from the Lagunitas Creek watershed (water years 2013-2014). All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset. (Std. dev. = standard deviation. N of obs. = number of observations.)

Parameter	Statistic	OLM18	OLM1	OLM14	OLM6A	OLM11	OLM10B	LAG1	LAG2	LAG3
Water temperature (°C)	Minimum	4.4	6.2	5.8	5.6	5.5	6.0	9.8	6.0	4.6
	Maximum	14.7	15.9	15.9	14.7	16.9	16.7	14.5	17.9	17.0
	Mean	11.05	12.05	11.85	11.55	12.51	12.42	12.43	12.05	11.78
	Median	11.9	12.4	12.6	12.1	13.0	13.0	12.6	12.7	12.3
	Std. dev.	2.96	3.11	3.20	2.54	3.34	3.37	1.30	3.23	3.16
	N of obs.	37	37	37	36	37	37	26	26	26
Dissolved oxygen (mg/L)	Minimum	2.94	2.24	4.70	8.87	5.48	0.88	8.33	2.93	8.46
	Maximum	10.46	11.57	12.63	11.94	12.25	12.36	11.21	12.05	12.05
	Mean	7.151	7.797	9.011	10.390	8.782	7.196	9.632	8.447	10.340
	Median	7.32	8.19	8.59	10.42	8.85	7.13	9.61	9.42	10.49
	Std. dev.	2.156	2.656	1.858	0.839	1.881	2.843	0.699	2.567	0.941
	N of obs.	37	37	37	36	37	37	26	26	26

Table 12 (continued). Core parameter results from the Lagunitas Creek watershed (water years 2013-2014). All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset. (Std. dev. = standard deviation. N of obs. = number of observations.)

Parameter	Statistic	OLM18	OLM1	OLM14	OLM6A	OLM11	OLM10B	LAG1	LAG2	LAG3
pH (pH units)	Minimum	6.12	6.30	6.59	7.31	6.86	6.75	6.87	7.15	7.14
	Maximum	7.68	7.57	8.03	8.22	7.84	7.72	7.79	8.19	8.41
	Mean	6.739	7.009	7.441	7.981	7.599	7.443	7.633	7.775	8.125
	Median	6.68	7.04	7.51	8.07	7.67	7.53	7.68	7.83	8.21
	Std. dev.	0.326	0.268	0.360	0.254	0.187	0.247	0.189	0.234	0.273
	N of obs.	37	37	37	36	37	37	26	26	26
Specific conductance (μS/cm)	Minimum	72.3	82.3	84.8	125.8	100.6	112.3	127.0	119.4	127.2
	Maximum	192.0	231.8	344.3	354.5	362.5	380.7	356.2	395.6	377.4
	Mean	139.60	176.00	253.90	291.60	266.50	273.00	298.60	325.10	315.00
	Median	144.5	188.8	284.7	314.5	297.5	288.2	313.3	371.5	350.2
	Std. dev.	26.03	46.19	73.33	49.88	73.71	70.39	56.20	88.50	74.68
	N of obs.	37	37	37	36	37	37	26	26	26
Turbidity¹ (NTU)	Minimum	0.98	0.41	0.22	0.73	1.14	1.27	0.37	0.22	0.22
	Maximum	195	372	502	25.6	721	185	>1000	711	614
	Mean	10.6	14.3	19.5	2.80	28.4	13.3	6.0	34.7	29.1
	Median	2.94	0.82	0.82	1.72	1.85	3.45	0.89	0.63	0.48
	Std. dev.	32.2	61.8	83.7	4.15	121.0	34.9	16.2	142.0	120.7
	N of obs.	37	37	37	36	37	37	26	25	26

¹ Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

Table 13. Core parameter results from the San Francisquito Creek watershed (water years 2013-2014). All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset. (Std. dev. = standard deviation. N of obs. = number of observations.)

Parameter	Statistic	MGG1	WU1	WU2	WU3	WU4
Water temperature (°C)	Minimum	6.7	5.6	6.3	6.1	6.1
	Maximum	15.2	15.6	10.3	11.5	15.6
	Mean	11.17	10.73	8.20	8.88	11.14
	Median	10.9	10.8	8.7	8.8	10.5
	Std. dev.	2.32	2.67	1.71	2.12	2.69
	N of obs.	15	15	4	5	18
Dissolved oxygen (mg/L)	Minimum	1.51	1.08	8.02	4.94	4.84
	Maximum	12.75	11.77	11.34	11.92	12.27
	Mean	6.213	6.233	9.378	9.412	9.104
	Median	5.39	6.15	10.11	10.60	9.35
	Std. dev.	3.449	3.459	1.635	2.713	1.841
	N of obs.	15	15	4	5	18
pH (pH units)	Minimum	6.90	6.27	7.39	6.89	6.70
	Maximum	7.83	7.64	7.51	7.72	8.15
	Mean	7.337	7.057	7.445	7.504	7.741
	Median	7.17	7.05	7.49	7.63	7.84
	Std. dev.	0.339	0.375	0.064	0.345	0.416
	N of obs.	15	15	4	5	18
Specific conductance (µS/cm)	Minimum	283.3	237.7	365.2	294.9	176.7
	Maximum	933.0	563.8	481.9	452.8	573.1
	Mean	601.40	453.60	407.00	376.70	485.70
	Median	605.8	480.1	399.0	393.4	536.5
	Std. dev.	189.90	93.42	51.79	70.14	106.60
	N of obs.	15	15	4	5	18
Turbidity¹ (NTU)	Minimum	0.19	0.28	0.27	0.40	0.19
	Maximum	49.2	11.8	5.95	5.74	11.5
	Mean	4.02	2.13	1.762	1.712	1.07
	Median	0.53	0.53	0.48	0.87	0.38
	Std. dev.	12.52	3.67	2.793	2.262	2.62
	N of obs.	15	15	4	5	18

¹ Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

Water Temperature

There is no established water quality objective for water temperature in SFAN streams, so NPS staff often use criteria for salmonids as ecological objectives. The water temperature range for optimal growth of juvenile coho is 10 to 15.6°C (Armour 1991). Although salmonids have various temperature requirements depending on species, life history stage, and season, this range is used as a general guideline to provide perspective when reviewing the SFAN water temperature results (even though there are no coho in the West Union Creek watershed). During WYs 2013-2014, water temperature was below 10°C at 23% of site visits (128:550) and above 15.6°C at eight percent of site

visits (44:550). All results were below 25°C, a temperature known to be lethal to juvenile coho (Moyle 2002). Even the highest result in the program (17.9°C) was well below this threshold.

The Redwood and Lagunitas Creek watersheds both support populations of coho and steelhead. Ten percent of the Lagunitas results (30:299) and seven percent of the Redwood results (14:194) were above 15.6°C (Figures 6 and 7). The majority of these exceedances were from the farthest downstream sites in each watershed (OLM11, OLM10B, and RDW3). Field staff observed the three highest individual site means at Redwood watershed sites (RDW3, RDW2, and BJC1), while the San Francisquito watershed produced the three lowest means in the program (sites WU3, WU2, and WU1). The San Francisquito sites were too dry to sample in the late summer months, which probably contributed to lower mean values. San Francisquito Creek does not support coho salmon populations, but for perspective relative to other watersheds discussed, none of these results (of 57) were above the 15.6°C ecological objective for coho (Figure 8).

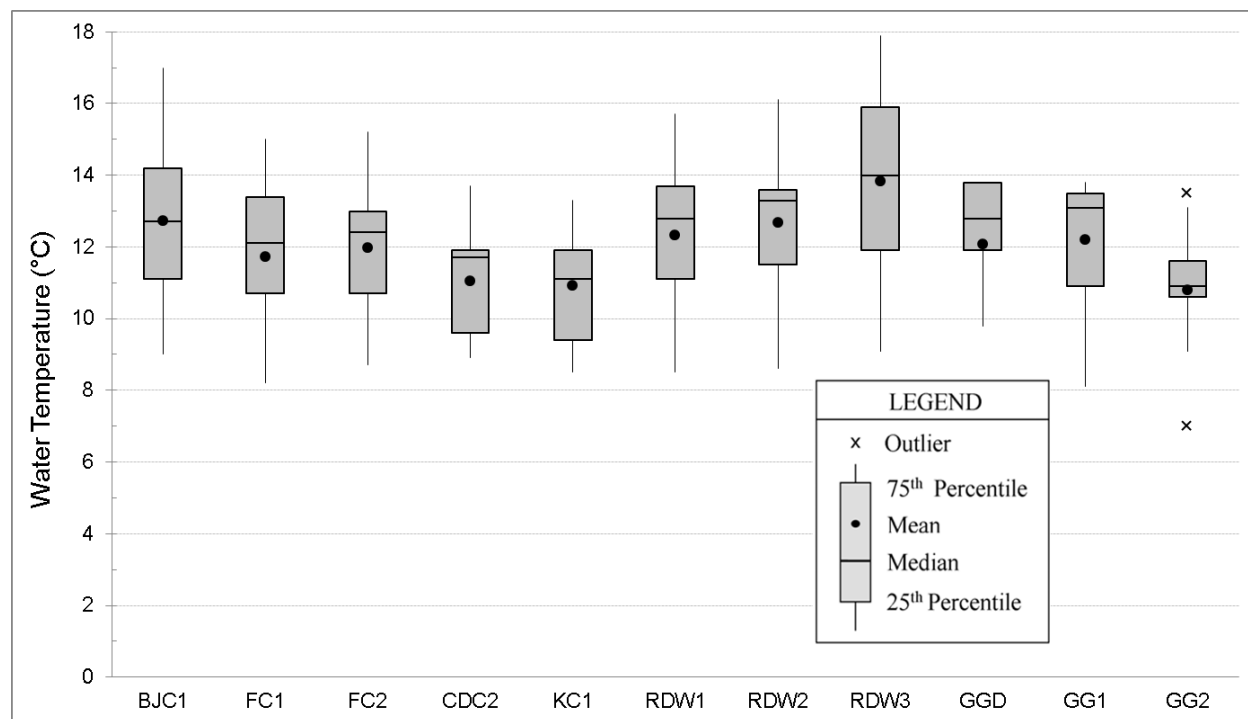


Figure 6. Water temperature results from the Redwood Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

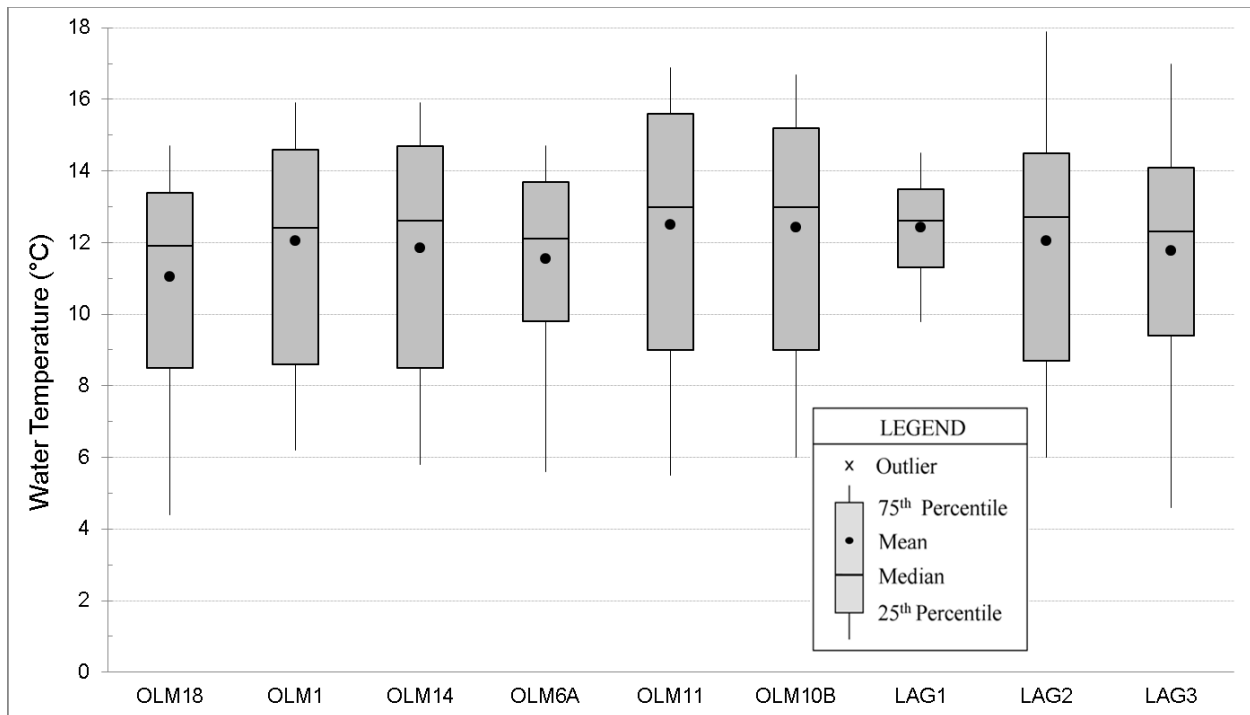


Figure 7. Water temperature results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

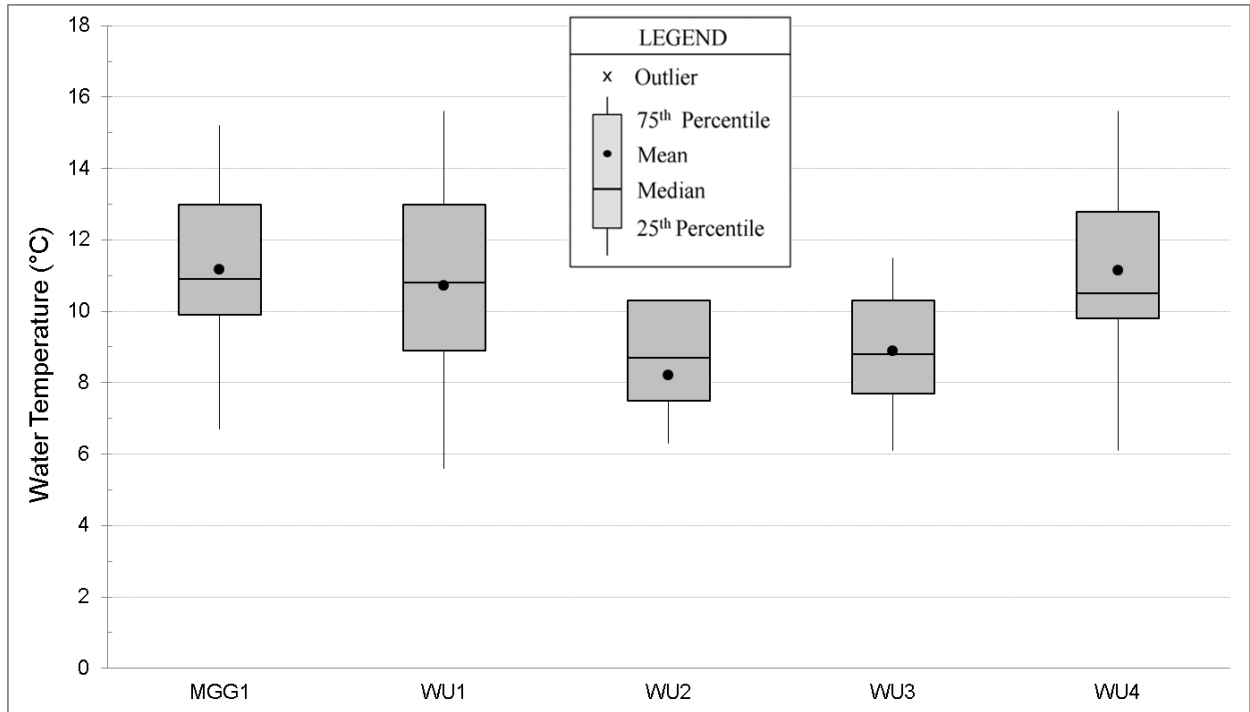


Figure 8. Water temperature results from the San Francisquito Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

Dissolved Oxygen

The San Francisco Bay RWQCB established a dissolved oxygen minimum of 7 mg/L, which applies to all SFAN sites monitored during WYs 2013-2014. This threshold is particularly important to the Redwood and Lagunitas Creek watershed sites, because they support salmonid populations. During WYs 2013-2014 20% of all SFAN dissolved oxygen results (108:550) failed to meet this objective. Dissolved oxygen means were above the water quality objective for every SFAN site, except for GGD in the Redwood watershed and the two downstream sites in the San Francisquito Creek watershed (WU1 and MGG1), all of which exhibit seasonal intermittent flow regimes that can lead to lower dissolved oxygen levels.

Only seven percent of all results from the Redwood Creek watershed (14:194) fell below the dissolved oxygen minimum objective of 7 mg/L. Two of the highest means (program-wide) were from the Redwood tributary sites GG2 and CDC2, and the highest individual result during WYs 2013-2014 was 20.21 mg/L (during a storm) at BJC1, the highest upstream site in the watershed (Figure 9). Measurements from the Lagunitas Creek watershed did not meet the dissolved oxygen objective as often as Redwood: 24% of the Lagunitas results fell below the objective and field staff observed the lowest result of this monitoring period (0.88 mg/L) at site OLM10B (the farthest downstream Olema Creek site) (Figure 10). Staff recorded the highest results in the Lagunitas Creek watershed during the first three months of 2013 and the lowest results between July and September of 2013 and 2014. The only Lagunitas watershed sites that met or surpassed the objective on every visit were OLM6A, LAG1, and LAG3. The San Francisquito watershed had the highest failure rate in the SFAN: 39% of dissolved oxygen results (22:57) fell below 7 mg/L. We recorded these low results at all San Francisquito sites (except for WU2) and at varying times of year (Figure 11).

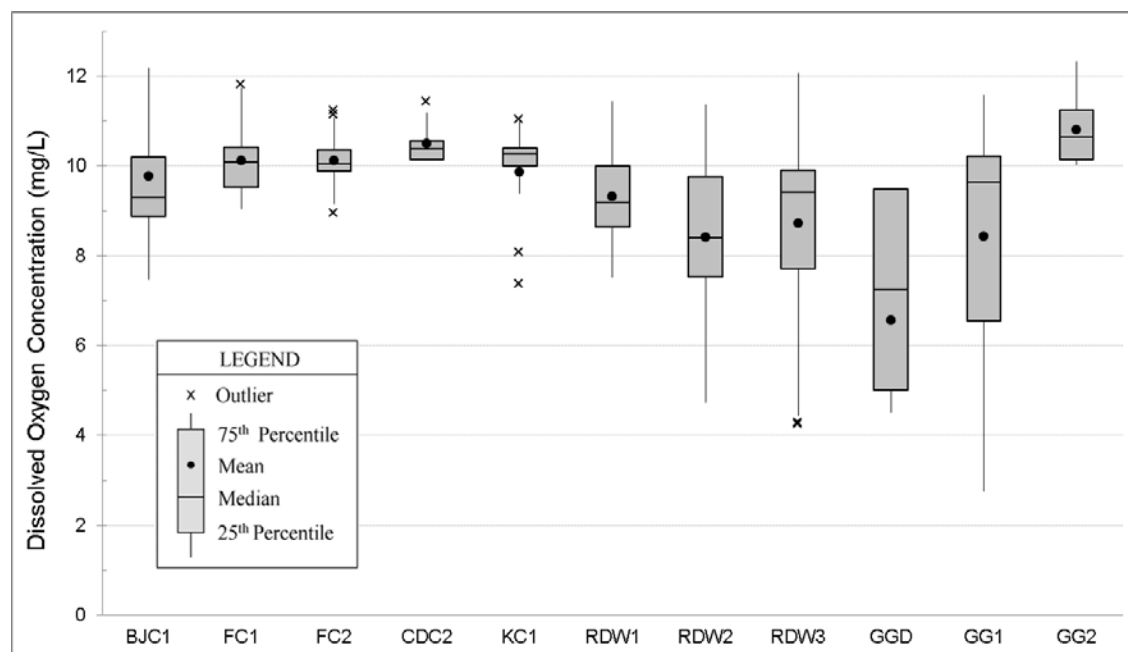


Figure 9. Dissolved oxygen results from the Redwood Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. One outlier is excluded from the figure (20.21 mg/L at site BJC1).

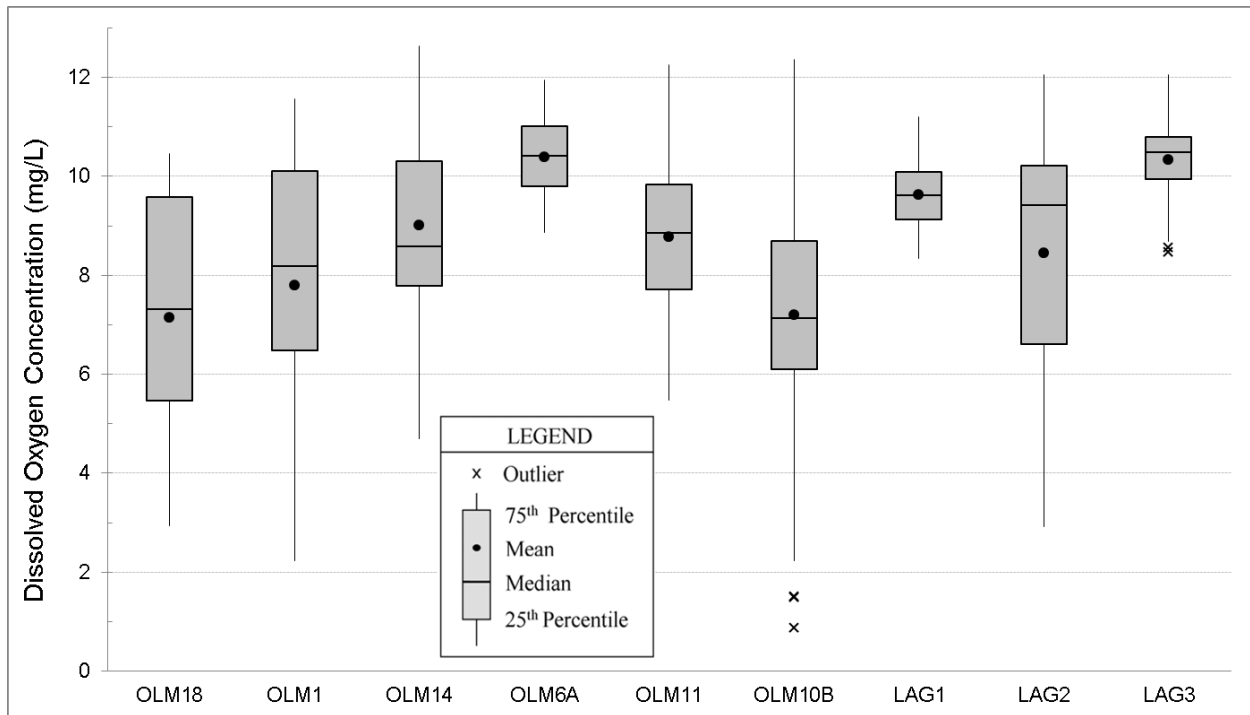


Figure 10. Dissolved oxygen results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

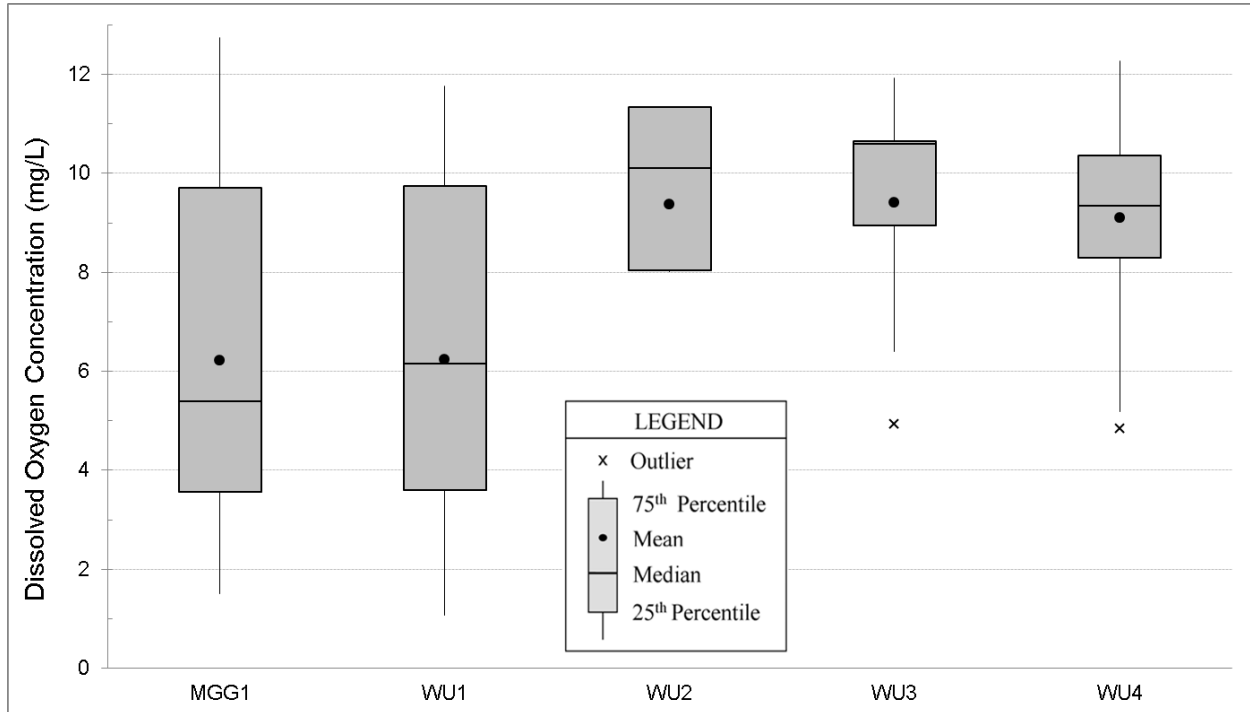


Figure 11. Dissolved oxygen results from the San Francisquito Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

pH

The pH water quality objective for surface waters is an optimal range of 6.5 to 8.5 pH units, based on the conditions necessary to support aquatic life (CA RWQCB 2010). During WYs 2013-2014, 98% of all SFAN pH results fell within their objective range: no results were above 8.5 pH units, and only 10 results (of 550) fell below 6.5 units.

Only two results (of 194) from the Redwood Creek watershed failed to meet the pH objective range. Both of these results were recorded during the winter at the farthest upstream site on Bootjack Creek (BJC1). While these two results were just under 6.5 pH units (6.37 and 6.48), this station also produced some of the watershed's highest results, eleven of which were over 8 pH units (Figure 12). The Lagunitas Creek watershed exhibited the widest range of results in the program. The 10 highest individual results were from site LAG3 in Devil's Gulch (a tributary to Lagunitas Creek) and the two lowest results in the program were from site OLM18 (Figure 13). Similar to the Redwood Creek watershed, the farthest upstream site in the San Francisquito Creek watershed (WU4) produced some of the highest pH results. The 11 highest results in this watershed were all found at site WU4, while the farthest downstream site on West Union Creek produced the three lowest individual values, one of which fell below the pH objective (Figure 14).

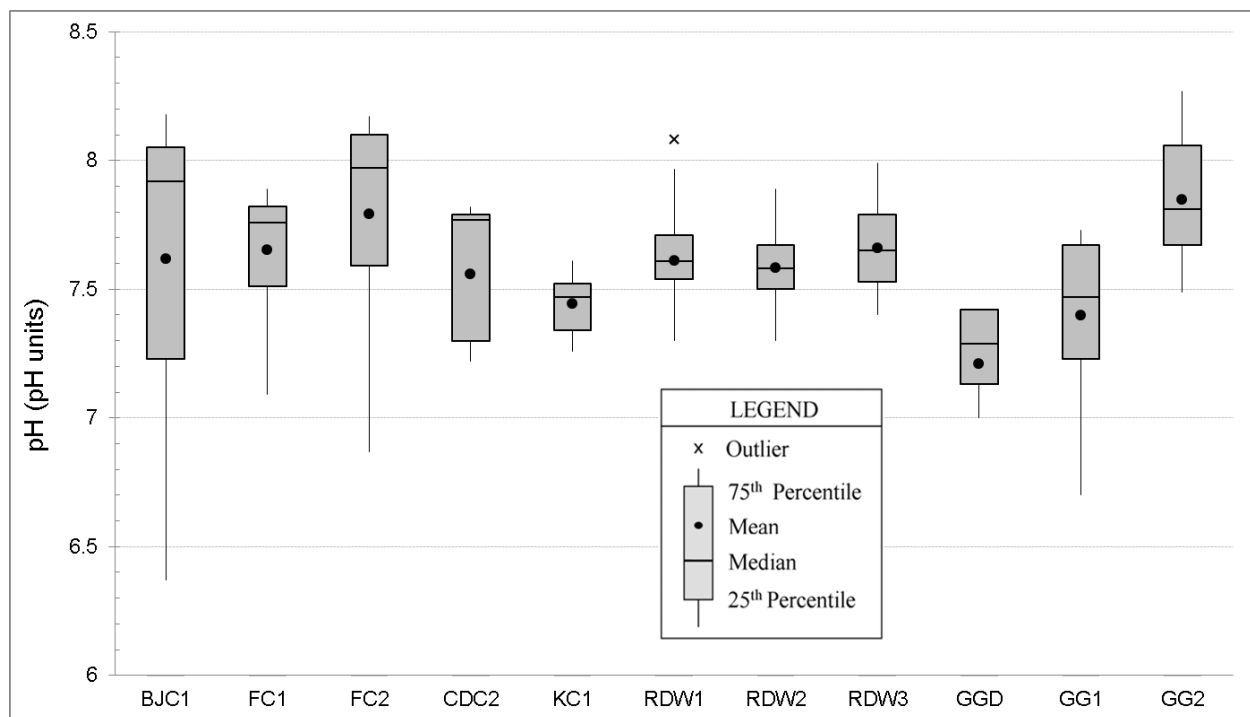


Figure 12. pH results from the Redwood Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

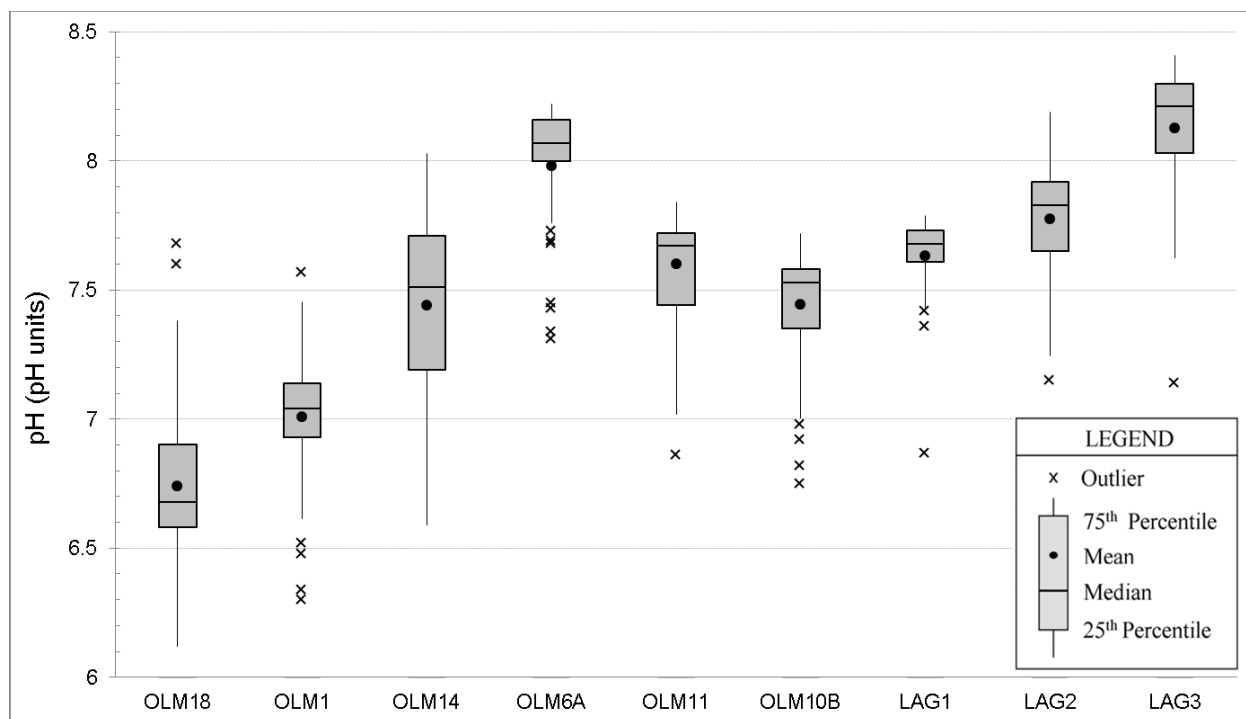


Figure 13. pH results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

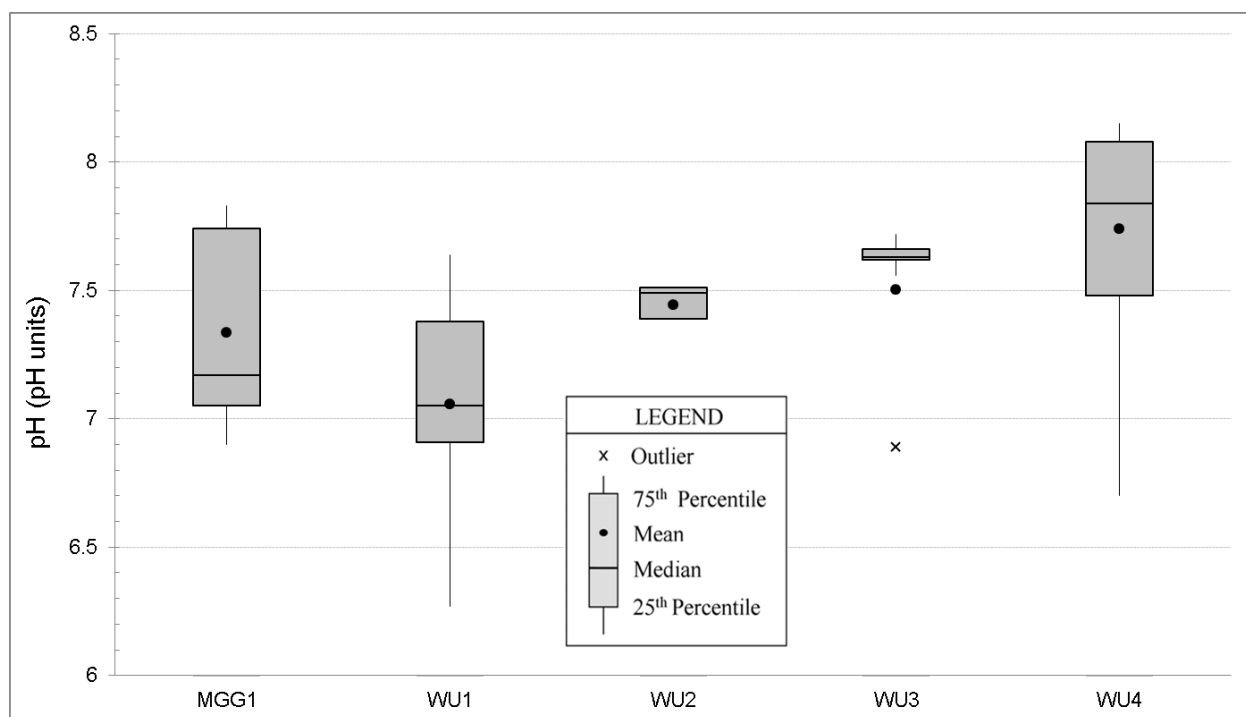


Figure 14. pH results from the San Francisquito Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

Specific Conductance

Conductivity (the ability of a solution to conduct an electrical current) is an indicator of the presence of dissolved solids, and is influenced by local geology as well as urban runoff and other anthropogenic inputs. Since conductivity fluctuates with temperature, a value of *specific conductance* is calculated in-situ using the simultaneously-measured water temperature value in order to yield a value that is corrected to 25°C. The RWQCB Basin Plans do not provide established water quality objectives for specific conductance. Ideally, freshwater streams should have specific conductance levels below 500 $\mu\text{S}/\text{cm}$ in order to support diverse aquatic life; we use this threshold as an ecological objective in this report, in order to give context to the results (Behar 1997).

During WYs 2013-2014 94% of all SFAN specific conductance results (517:550) met (fell below) the ecological objective maximum of 500 $\mu\text{S}/\text{cm}$. Of those that exceeded the objective, 85% were results from the San Francisquito Creek watershed, and the remainder (only five results) were from Redwood watershed sites. We didn't observe any exceedances in the Lagunitas watershed. Of the five Redwood results that exceeded the objective, one was excluded from Figure 15. This was a result of 1,607 $\mu\text{S}/\text{cm}$ that may have been tidally influenced; this was the highest result program-wide. Site GG1 in Green Gulch produced the highest mean value in the watershed and the fifth highest mean in the program (397.6 $\mu\text{S}/\text{cm}$), while the two Fern Creek sites produced two of the lowest mean values program-wide (Figure 15). The lowest mean of all was calculated from site OLM18, the farthest upstream site in the Lagunitas Creek watershed; the mean values in this watershed generally increased with movement downstream (Figure 16). The San Francisquito Creek watershed produced four of the five highest means in the program (all over 400 $\mu\text{S}/\text{cm}$), and nearly half of the individual results (28:57) were above the ecological objective maximum of 500 $\mu\text{S}/\text{cm}$ (Figure 17).

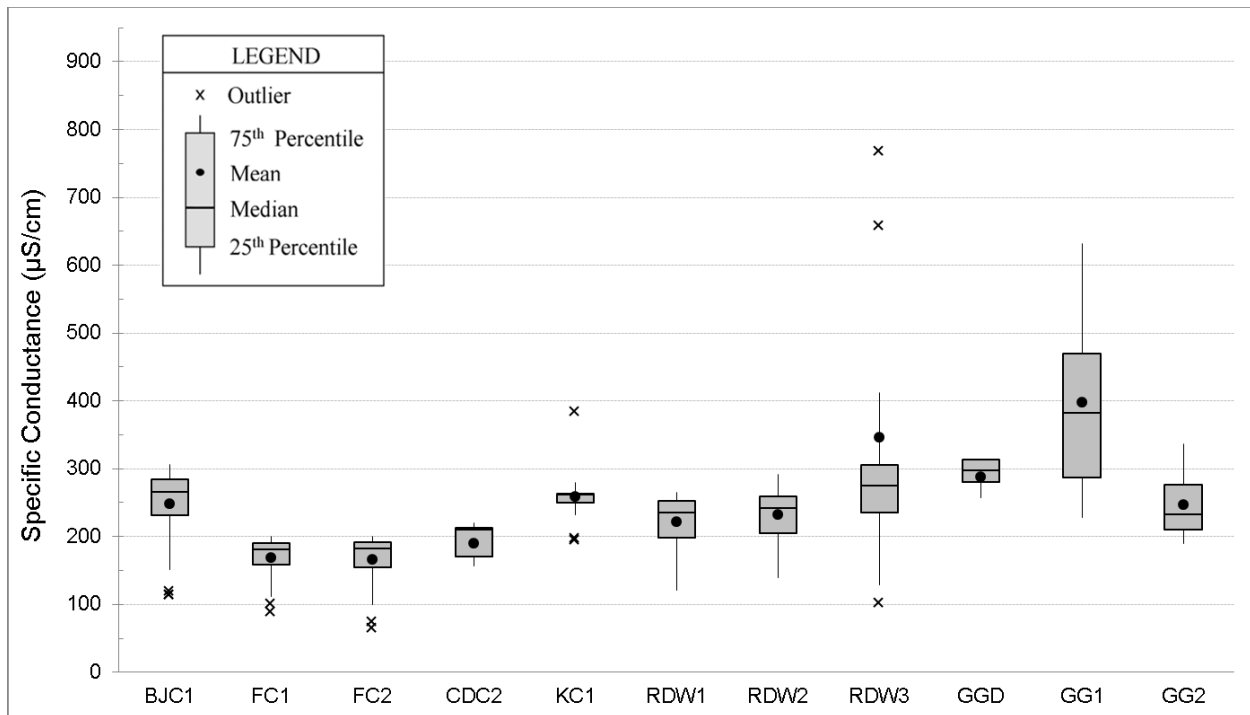


Figure 15. Specific conductance results from the Redwood Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

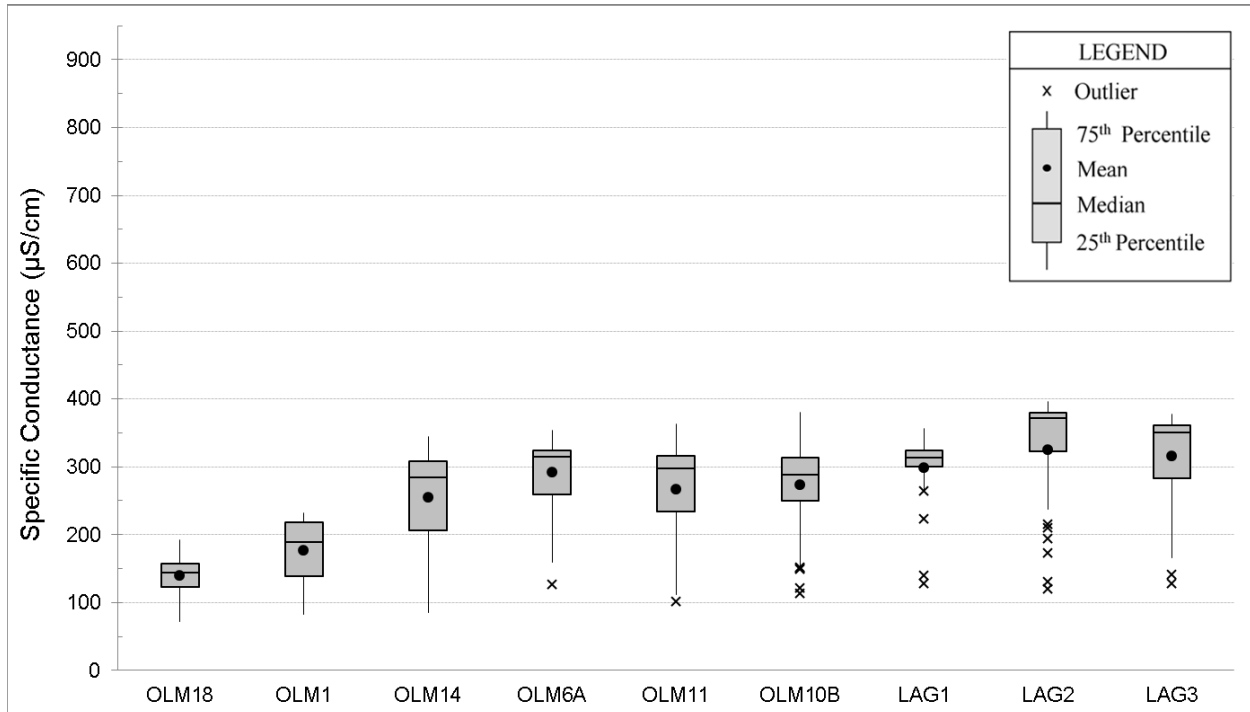


Figure 16. Specific conductance results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

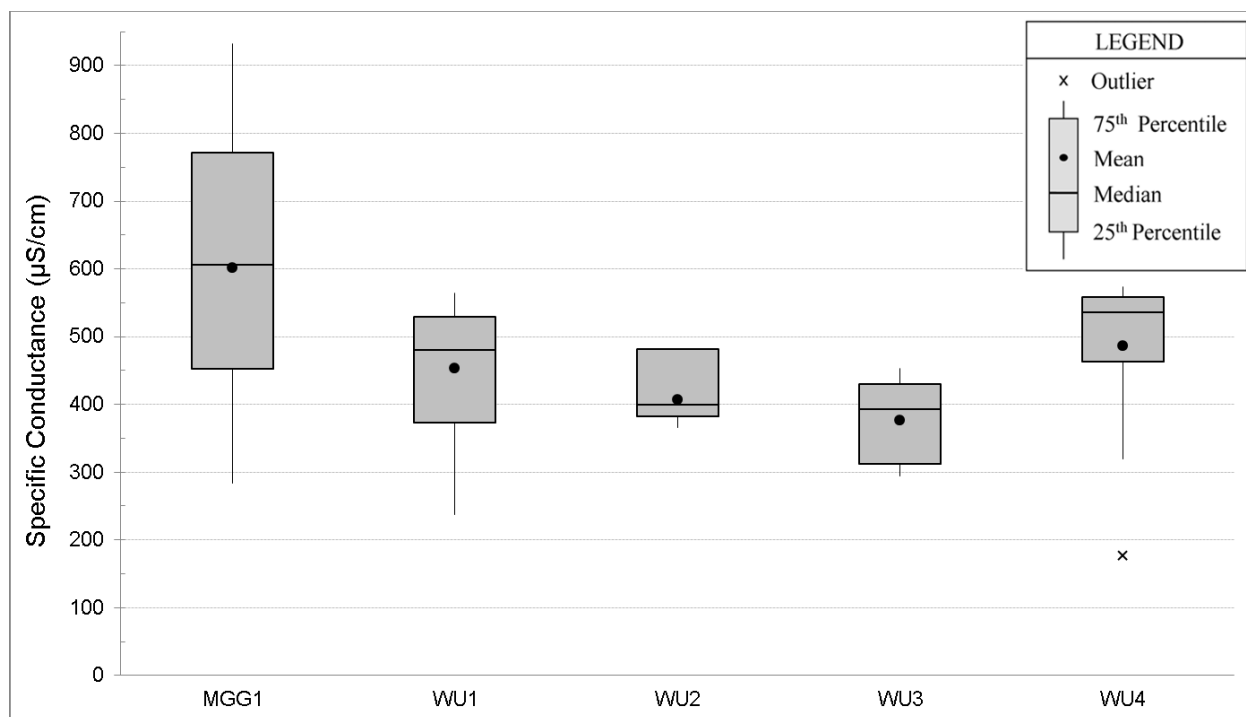


Figure 17. Specific conductance results from the San Francisquito Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

Turbidity

Turbidity is the capacity of suspended sediment (including clay, silt, fine organic and inorganic matter, and microscopic organisms) in water to scatter light (American Public Health Association et al. 1998). Inputs of such solids occur because of erosion from stream banks, runoff from various source areas within a watershed, and re-suspension from the streambed during storm events. While erosion and sedimentation are natural processes, agriculture and land development can accelerate these means of sediment transport and result in an imbalance in the amount of sediment in a stream system (Coopridge and Carson 2006). Turbidity is often measured in nephelometric turbidity units (NTU). A level of turbidity greater than 5 NTU is considered visible turbidity and turbidity levels above 25 NTU have been shown to cause reductions in salmonid growth (Sigler et al. 1984). There is not an established objective for turbidity levels in SFAN streams, but we compared observed data to an ecological objective maximum of 25 NTU. Although these objectives are important to keep in mind, it is often not the peak levels that determine negative ecological consequences, but the persistence of high levels after storm events: longer durations of high turbidity levels are more likely to cause damage to fish and other aquatic organisms (Newcombe and MacDonald 1991). This program captures single turbidity samples during site visits, and does not conduct continuous monitoring or turbidity threshold sampling. Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

During WYs 2013-2014 93% of all SFAN turbidity results (511:549) met (fell below) the ecological objective maximum of 25 NTU. We observed the majority of the exceedances (89%) during the

winter months. Over half of these exceedances (22:38) were from the Lagunitas Creek watershed, while 15 were from Redwood sites. We only recorded one exceedance in the San Francisquito watershed. The Redwood and Lagunitas Creek watersheds had similar exceedance rates (eight and seven percent, respectively). The Redwood Creek watershed produced one of the highest means program-wide (39.8 NTU for site CDC2), as well as one of the lowest means in the program (1.71 NTU for site FC2 in Fern Creek) (Figure 18). The Lagunitas Creek watershed produced four of the five highest mean turbidity values in the program, as well as the only individual result that exceeded the quantifiable range of the equipment: a value over 1,000 NTU collected during the February 2014 storm event (Figure 19). The San Francisquito Creek watershed produced four of the five lowest means program-wide, and only had one result that exceeded the ecological objective (a value of 49.2 NTU at the McGarvey Gulch site) (Figure 20).

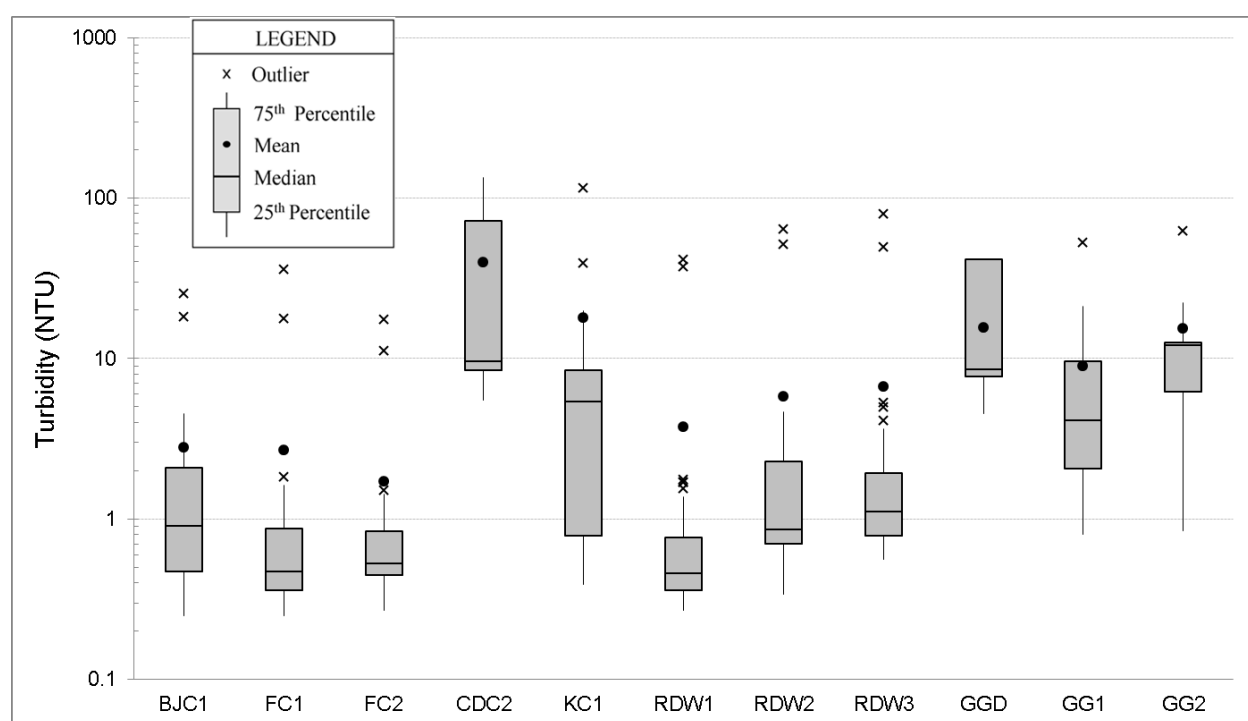


Figure 18. Turbidity results from the Redwood Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

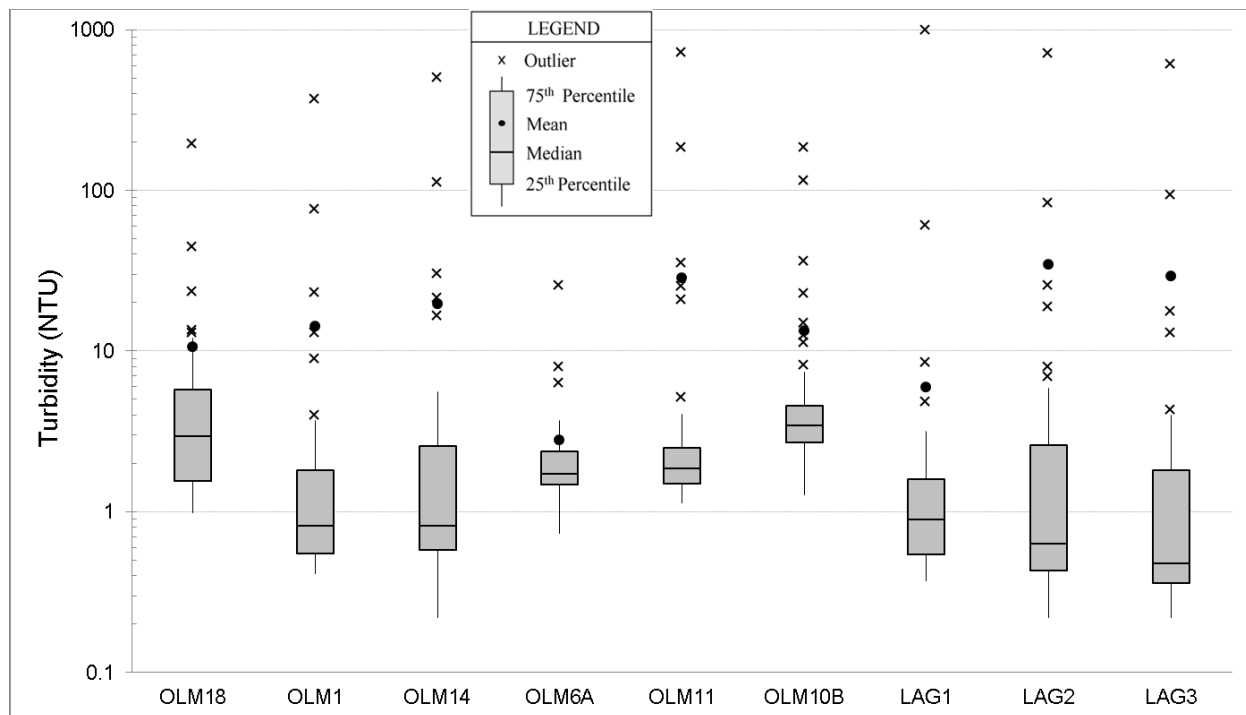


Figure 19. Turbidity results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

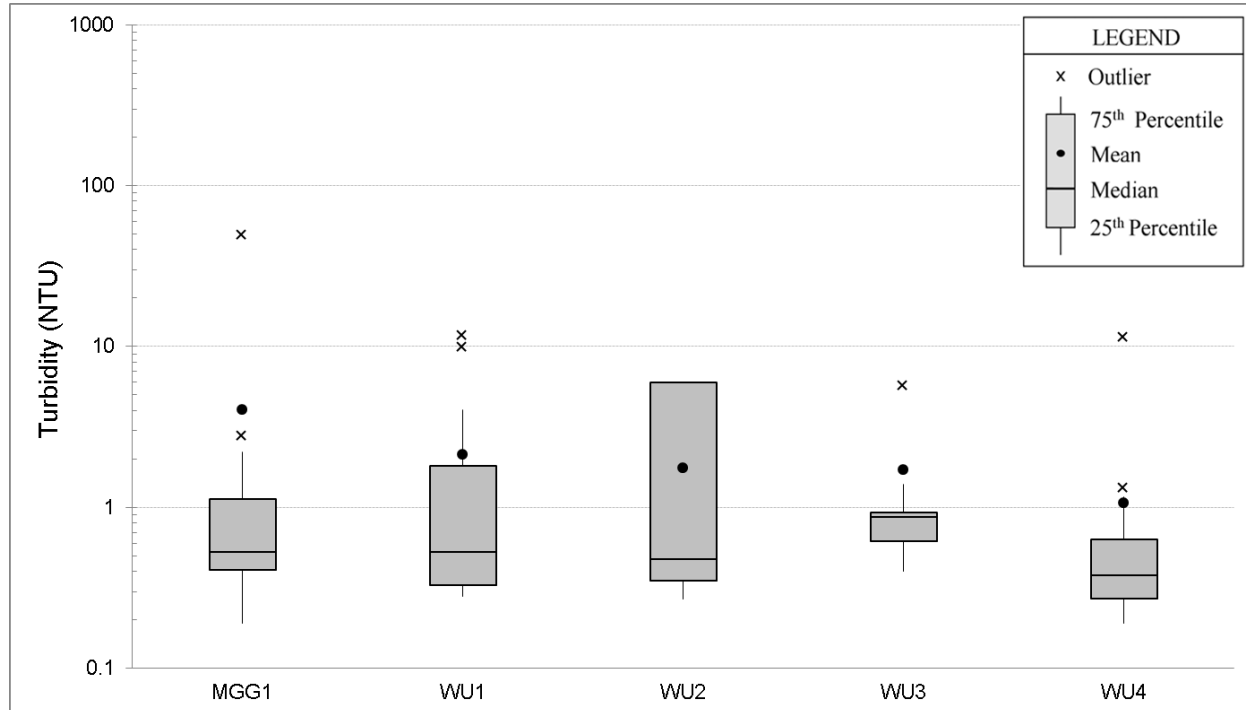


Figure 20. Turbidity results from the San Francisco Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

Nutrient Parameters

Field staff collected all nutrient samples in sterile, laboratory-issued bottles during each site visit and stored them immediately on ice until transfer to the contracted laboratory for processing. During WYs 2013-2014 nitrate (as N) and TKN were sampled on a monthly basis (and during storms) at 21 primary SFAN water quality sites. Out of the 25 SFAN sites monitored during WYs 2013-2014, four are secondary sites. Because they are secondary stations, we did not conduct nutrient sampling at FC2 in the Redwood Creek watershed, or at WU2, WU3, or WU4 in the San Francisquito Creek watershed.

Tables 14, 15, and 16 present summary statistics of all nutrient data collected during WYs 2013-2014, while box and whiskers plots of these data are displayed separately (sorted by parameter) for simplified viewing. Due to relatively low nutrient levels in the SFAN streams, the contracted laboratory reported many results as non-detect, which means that the analyte was not detected at or above the laboratory's reporting detection limit (RDL). For these censored results, NPS staff used the nonparametric Kaplan-Meier method (through the NPSTORET database) for analysis of all SFAN nutrient results (see Data Handling and Analysis in the Methods section for a description). All summary statistics are based on instantaneous measurements routinely collected at approximately the same time of day on each visit; therefore, the data in the tables and figures presented do not reflect the true minimum and maximum values of diel variation.

Table 14. Nutrient results from the Redwood Creek watershed (water years 2013-2014). All raw nutrient results are reported with two significant figures. All means and standard deviations (std. dev.) are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	BJC1	FC1	CDC2	KC1	RDW1	RDW2	RDW3	GGD	GG1	GG2
Nitrate as nitrogen (mg/L)	Minimum	<0.15	<0.15	0.35	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15
	Maximum	0.31	0.19	2.7	0.70	0.22	0.33	0.34	<0.15	0.99	0.29
	Mean	0.204	-	1.09	0.221	-	-	-	-	0.377	-
	Median	0.19	-	0.69	<0.15	-	-	-	-	0.34	-
	Std. dev.	0.056	-	0.90	0.181	-	-	-	-	0.278	-
	# NDs/ # Results ¹	6/21	18/21	0/6	6/9	17/21	17/21	17/21	4/4	6/14	6/8
Total Kjeldahl nitrogen (mg/L)	Minimum	<0.25	<0.25	0.29	0.25	<0.25	<0.25	<0.25	0.45	0.34	0.29
	Maximum	0.68	0.47	1.0	1.0	0.63	0.86	0.89	0.93	1.1	1.0
	Mean	0.387	0.302	0.51	0.52	0.332	0.392	0.406	0.663	0.61	0.53
	Median	0.36	0.28	0.43	0.42	0.29	0.35	0.37	0.71	0.59	0.46
	Std. dev.	0.136	0.068	0.26	0.26	0.114	0.160	0.155	0.208	0.19	0.22
	# NDs/ # Results ¹	6/21	9/21	0/6	0/9	7/21	3/21	1/21	0/4	0/14	0/8

¹ The number of results that were reported as 'ND' (not detected at or above the reporting detection limit) are shown above, as a ratio over the total number of results from that site.

- Dashes represent datasets for which a high percentage of censoring prevented calculation.

Table 15. Nutrient results from the Lagunitas Creek watershed (water years 2013-2014). All raw nutrient results are reported with two significant figures. All means and standard deviations (std. dev.) are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	OLM18	OLM1	OLM14	OLM6A	OLM11	OLM10B	LAG1	LAG2	LAG3
Nitrate as nitrogen (mg/L)	Minimum	<0.15	<0.15	<0.15	0.17	<0.15	<0.15	0.35	<0.15	<0.15
	Maximum	0.88	2.0	1.3	1.2	3.2	3.7	1.2	2.9	1.6
	Mean	-	0.30	0.30	0.33	0.43	0.42	0.63	0.35	0.33
	Median	-	0.15	0.20	0.23	0.17	<0.15	0.62	0.16	0.21
	Std. dev.	-	0.41	0.25	0.25	0.68	0.78	0.22	0.59	0.33
	# NDs/ # Results ¹	19/22	14/22	2/22	0/21	11/22	15/22	0/22	7/22	1/22
Total Kjeldahl nitrogen (mg/L)	Minimum	<0.25	<0.25	<0.25	<0.25	0.26	<0.25	<0.25	<0.25	<0.25
	Maximum	1.9	1.6	3.0	1.2	3.0	1.8	11	3.4	3.4
	Mean	0.53	0.47	0.58	0.43	0.65	0.69	1.0	0.61	0.55
	Median	0.42	0.37	0.44	0.37	0.46	0.62	0.42	0.46	0.36
	Std. dev.	0.35	0.32	0.59	0.22	0.65	0.39	2.3	0.68	0.67
	# NDs/ # Results ¹	1/22	2/22	1/22	2/21	0/22	1/22	2/22	1/22	5/22

¹ The number of results that were reported as 'ND' (not detected at or above the reporting detection limit) are shown above, as a ratio over the total number of results from that site.

- Dashes represent datasets for which a high percentage of censoring prevented calculation.

Table 16. Nutrient results from the San Francisquito Creek watershed (water years 2013-2014). All raw nutrient results are reported with two significant figures. All means and standard deviations (std. dev.) are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	MGG1	WU1
Nitrate as nitrogen (mg/L)	Minimum	<0.15	<0.15
	Maximum	<0.15	0.23
	Mean	-	-
	Median	-	-
	Std. dev.	-	-
	# NDs/ # Results ¹	14/14	13/14
Total Kjeldahl nitrogen (mg/L)	Minimum	<0.25	<0.25
	Maximum	0.55	0.56
	Mean	0.348	0.376
	Median	0.33	0.38
	Std. dev.	0.097	0.101
	# NDs/ # Results ¹	4/14	3/14

¹ The number of results that were reported as 'ND' (not detected at or above the reporting detection limit) are shown above, as a ratio over the total number of results from that site.

- Dashes represent datasets for which a high percentage of censoring prevented calculation.

Nitrate as N (Nitrogen)

Neither the State of California nor the San Francisco Bay RWQCB has quantitative objectives for nitrates. However, the EPA has established a national drinking water objective of 10 mg/L nitrate (as N) and a regional reference value is 0.16 mg/L (U.S. EPA 2000). Additionally, a study by L. M. Roche and colleagues (2013) referenced a threshold of 0.30 mg/L nitrate (as N) for limiting eutrophication of streams (Roche et al. 2013). For this report, we compared our observations to this ecological threshold of 0.30 mg/L nitrate (as N) (Roche et al. 2013). The RDL for all nitrate (as N) samples processed during WYs 2013-2014 was 0.15 mg/L (utilizing EPA Method 300).

NPS field staff collected a total of 373 nitrate (as N) samples from the 21 SFAN primary sites during WYs 2013-2014. Seventy-nine percent of these were below the ecological objective maximum of 0.30 mg/L. Over half of the nitrate samples (195:373) were reported as non-detect, and the majority of these non-detects were from the Redwood Creek watershed. Although the Redwood watershed produced 66% non-detect results and many low nitrate levels, it ended up with the highest mean in the program: a value of 1.09 mg/L at Camino del Canyon (CDC2), a tributary to Redwood Creek (Figure 21). Twelve percent of Redwood watershed results exceeded the ecological objective maximum and most of these were from two sites on tributaries (CDC2 and GG1). The Lagunitas Creek watershed produced the highest percentage of exceedances: 31% of results were above the 0.30 mg/L threshold. The three highest individual nitrate results program-wide were all from this watershed as well (values of 2.9, 3.2, and 3.7 mg/L nitrate-N recorded during the February 2014 storm event). Regardless of spikes, the Lagunitas Creek watershed sites all produced fairly similar

means (Figure 22). Every water quality sample collected from the San Francisquito Creek watershed registered below the ecological objective maximum for nitrate (as N), and nearly all of these had undetectable levels (97 % were reported as non-detect). Because of this high percentage of censored data, we cannot present a figure for this watershed.

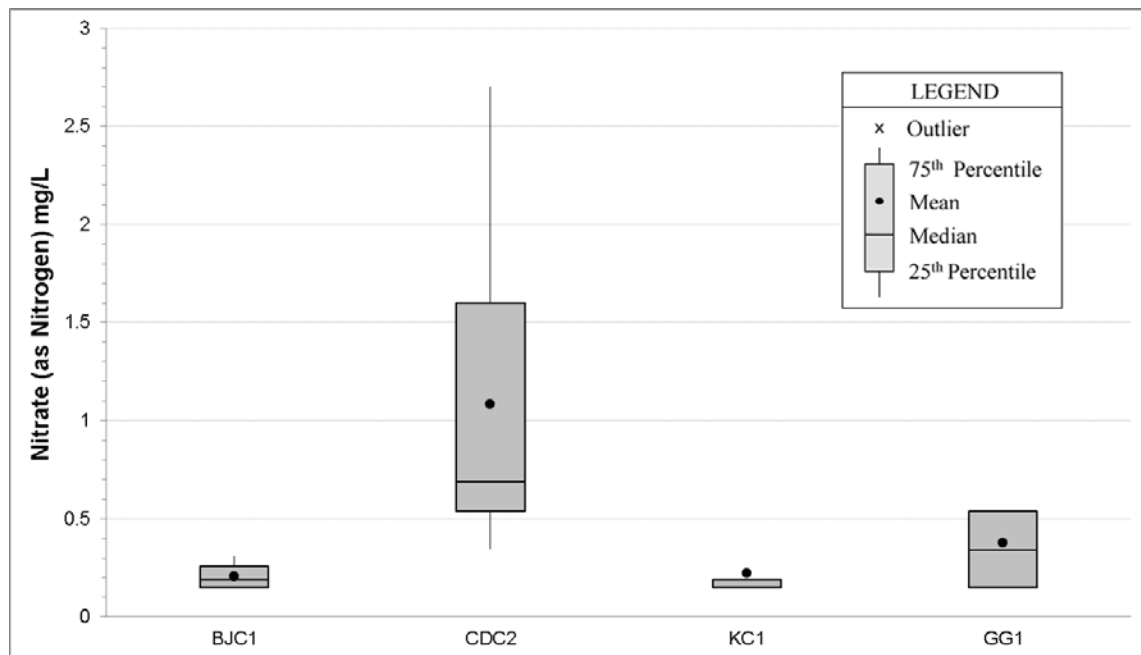


Figure 21. Nitrate (as nitrogen) results from the Redwood Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range, except for sites KC1 and GG1 (high censoring prevented computation). Most sites (FC1, RDW1, RDW2, RDW3, GGD, and GG2) were excluded due to their high percentage of censored data. The laboratory reporting detection limit was 0.15 mg/L.

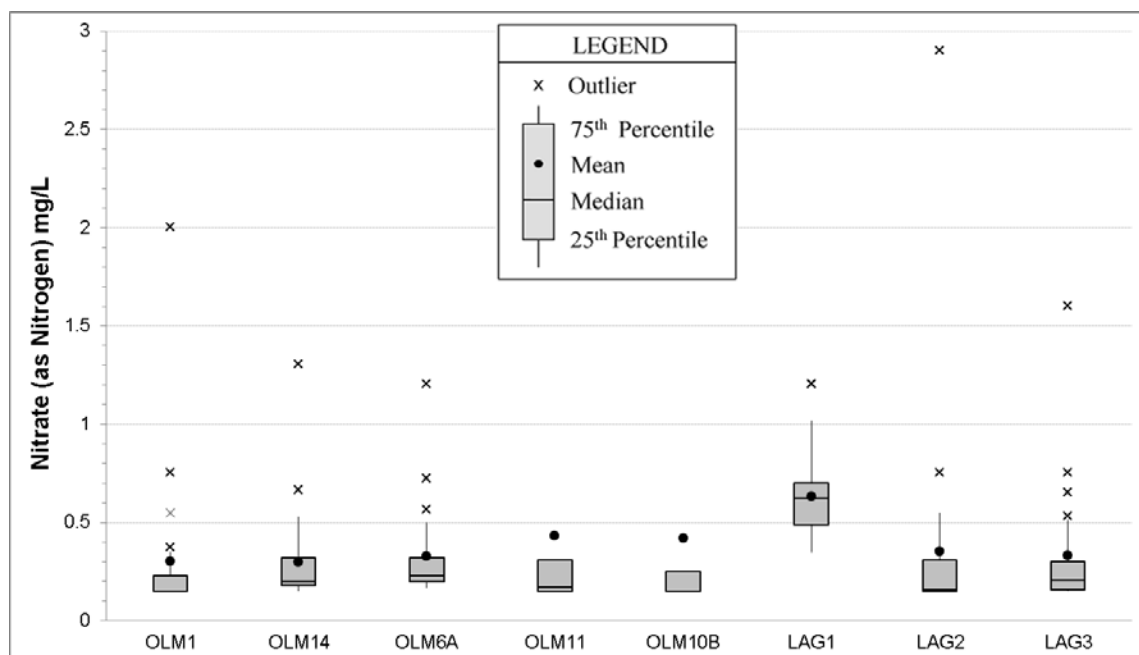


Figure 22. Nitrate (as nitrogen) results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range, except for sites OLM11 and OLM10B (high censoring prevented computation); one outlier from each of these sites is excluded from the figure (3.2 mg/L and 3.7 mg/L, respectively). OLM18 was excluded due to its high percentage of censored data. The laboratory reporting detection limit was 0.15 mg/L.

Total Kjeldahl Nitrogen (TKN)

Combined ammonia-nitrogen and organic nitrogen are referred to as TKN. Different forms of nitrogen can exist in streams as a result of both natural and anthropogenic sources. Monitoring TKN, in addition to nitrate and ammonia, can create a clearer understanding of what forms of nitrogen (organic or inorganic) are available at different times of the year. The San Francisco Bay RWQCB's Basin Plan does not currently have an established criterion for TKN, however, the EPA encouraged the establishment of regulatory objectives for nutrients by conducting a large scale survey to provide states with regional reference values. The regional reference value for SFAN streams is 0.36 mg/L TKN (U.S. EPA 2000).

During WYs 2013-2014, the laboratory's RDL for all TKN tests (Standard Method 4500-Norg C) varied: it was usually 0.25 mg/L, although sometimes it was raised if high concentrations were present (to 0.30 mg/L, or 1.2 mg/L in one case). Fifty-six percent of WY 2013-2014 results exceeded the regional reference value of 0.36 mg/L, and each watershed produced similar percentages of exceedance. The highest ten percent of results were all from samples collected during storm events. The two lowest means in the program were from sites FC1 and RDW1 in the Redwood Creek watershed (Figure 23), while the two highest means in the program were from the Lagunitas Creek watershed (sites OLM10B and LAG1) (Figure 24). The highest individual result was from a storm sampling event at LAG1 in February 2014, when the water was extremely dark brown in color (darker than any other site). This site visit also produced the highest turbidity result program-wide

during WY 2013-2014. Field staff also collected TKN samples from the two primary sites in the San Francisquito Creek watershed (MGG1 and WU1); each of these sites produced a very similar range of results, as well as similar mean and median values (Figure 25).

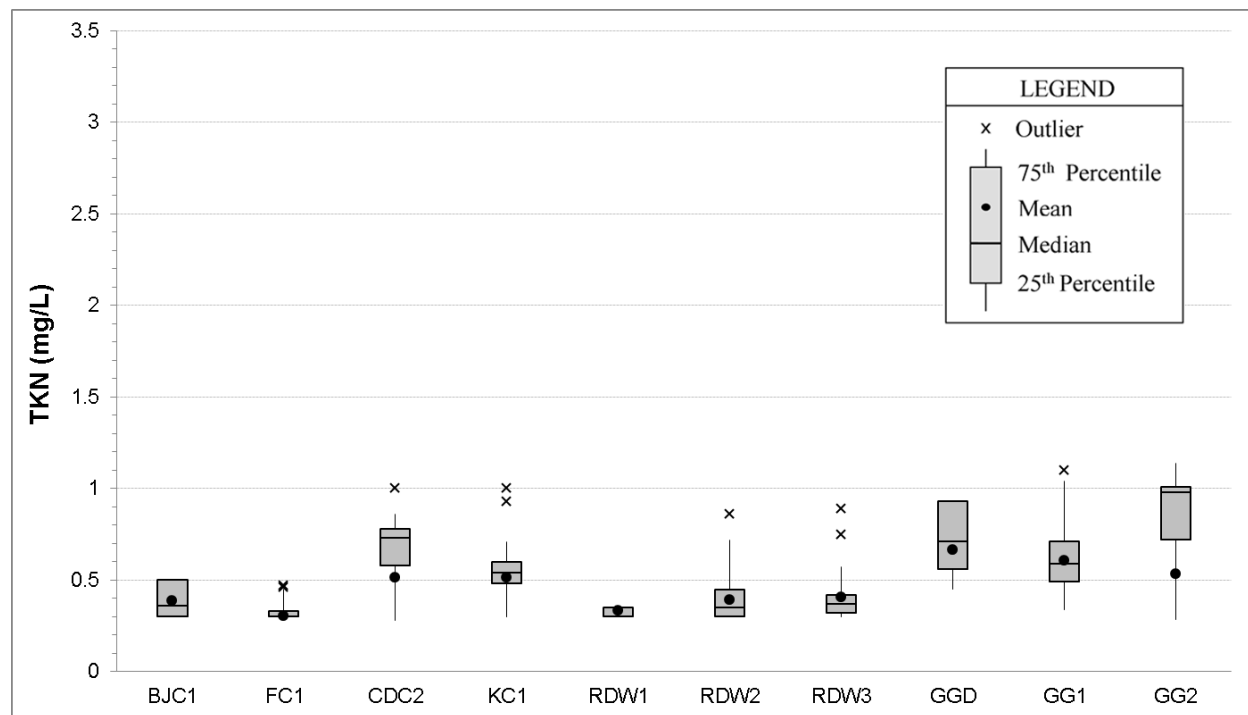


Figure 23. Total Kjeldahl nitrogen (TKN) results from the Redwood Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range (unless high censoring prevented computation).

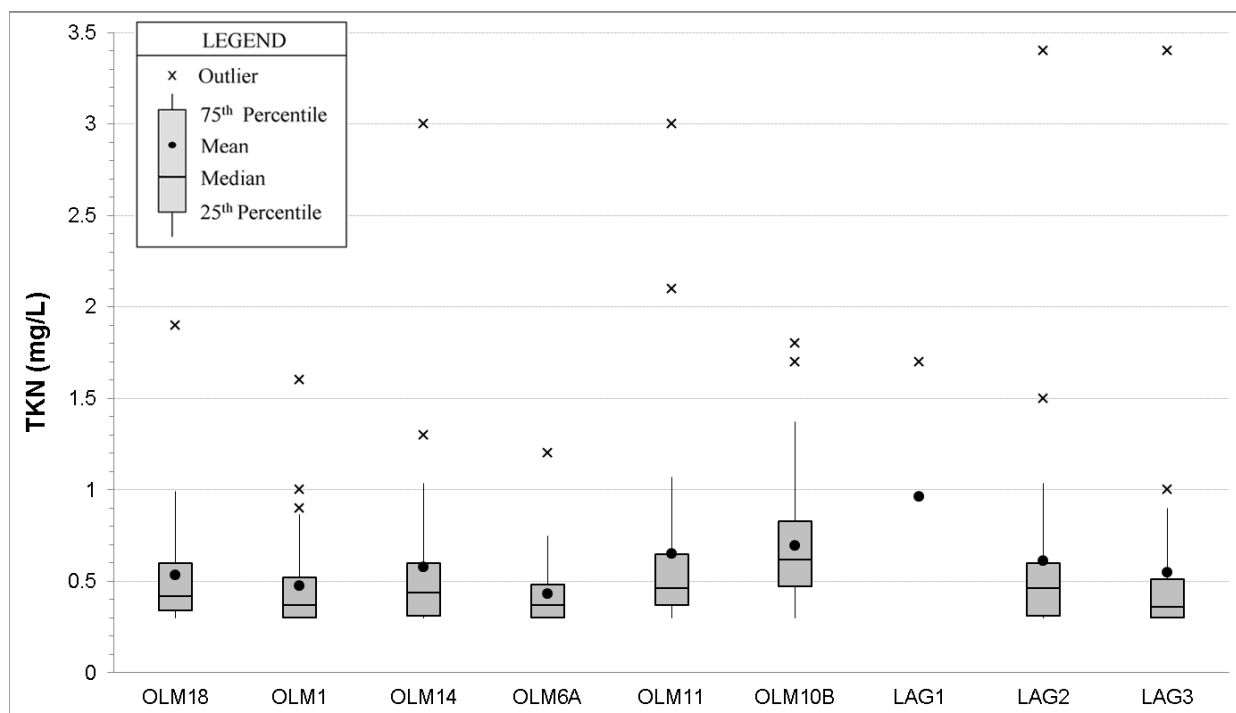


Figure 24. Total Kjeldahl nitrogen (TKN) results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset and whiskers are drawn to 1.5 times the interquartile range (unless high censoring prevented computation). One outlier is excluded from this figure: a value of 11 mg/L at site LAG1.

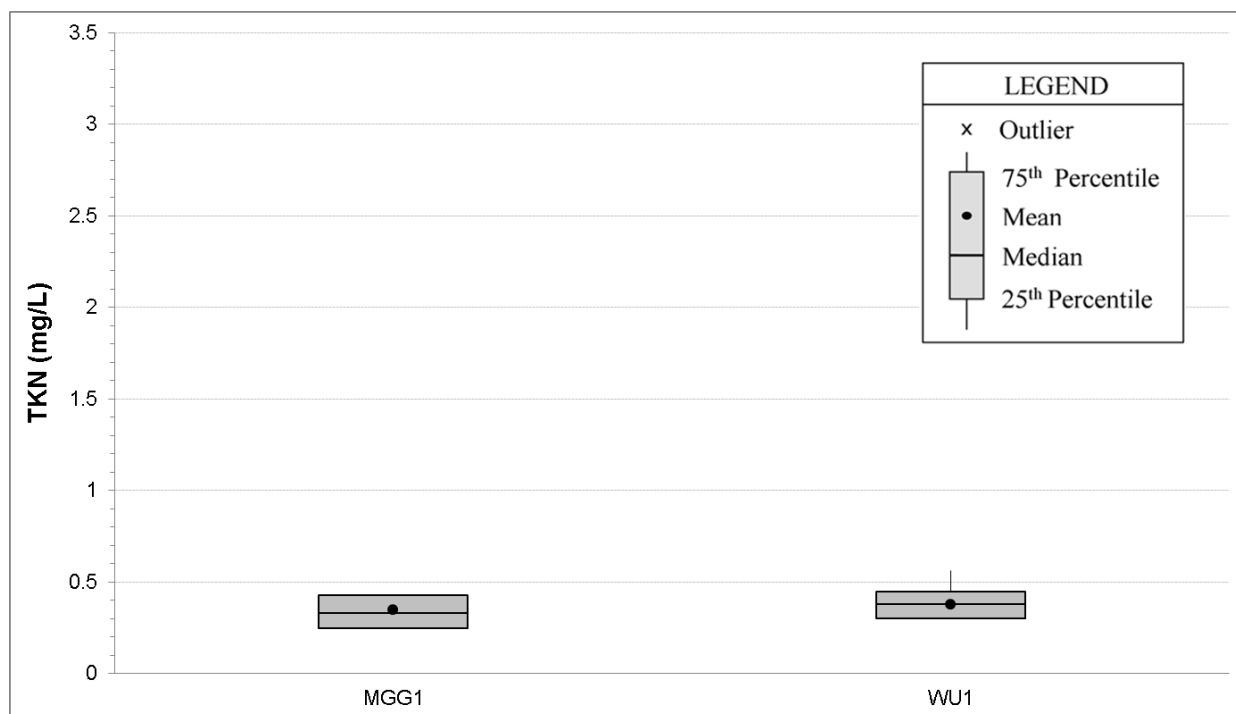


Figure 25. Total Kjeldahl nitrogen (TKN) results from the San Francisco Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range (unless high censoring prevented computation).

Pathogenic Indicator Bacteria

Total coliform, *Escherichia coli* (*E. coli*), and fecal coliform bacteria are indicators of pathogens that can be detrimental to human health. The results from these parameters are reported with the units “MPN/100 mL” which stands for “the most probable number of colony-forming units per 100 mL of sample volume.” These results do not quantify the amount of bacteria in a body of water, but are used to estimate concentrations of bacteria that may indicate the presence of pathogens. The EPA uses *E. coli* as an indicator of risk to human health, and it is the recommended bacteria parameter for fresh water. Total coliform bacteria results are generated along with *E. coli* (from the same test), and although these results may be used to view long-term trends in the future, total coliform is not commonly used as a pathogenic indicator for human health concerns. Since human contact with surface water is uncommon at the SFAN monitoring sites, the established objectives may seem irrelevant. However, the water from these sites may influence a variety of recreational sites downstream, and the numerical objectives also help to provide context when examining the magnitude of recorded exceedances.

During WYs 2013-2014 field staff collected fecal coliform at the six Olema Creek sites in PORE. This sampling is organized by the San Francisco Bay RWQCB and is mandated by the Tomales Bay Pathogen TMDL Program. The program requires that fecal coliform samples are processed by the RWQCB’s contracted laboratory (Excelchem Environmental Labs) to ensure consistency and data comparability between all samples, regardless of the partner organization collecting the samples. Field staff collected all bacteria samples in sterile, factory-sealed bottles and stored immediately on ice. Staff collected total coliform and *E. coli* (TC/EC) samples during every site visit of WYs 2013-2014 (at both primary and secondary sites) and processed the samples at the in-house laboratory at PORE. In this laboratory, TC/EC results are produced together from a single test.

Unlike the nutrient data that are often censored at the lower end (from non-detect results), the TC/EC data can be censored on either end due to the laboratory method used. This makes data analysis more challenging and requires use of the Kaplan-Meier statistical method in order to create summary statistics and figures (see Data Handling and Analysis section under Methods). In addition to the complication of censoring on both ends, the TC/EC data can also have varying lower and upper quantification limits that differ between sites and seasons. Samples processed at the standard 10x dilution factor have a quantification range of 10 to 24,190 MPN/100 mL.

Tables 17, 18, and 19 present summary statistics of all bacteria data collected during WYs 2013-2014, while box and whiskers plots display these data separately (sorted by parameter) for simplified viewing. All summary statistics are based on instantaneous measurements routinely collected at approximately the same time of day on each visit; therefore, the data in the tables and figures presented do not reflect the true minimum and maximum values of diel variation.

Table 17. Pathogenic indicator bacteria results from the Redwood Creek watershed (water years 2013-2014). All means and standard deviations (std. dev.) are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	BJC1	FC1	FC2	CDC2	KC1	RDW1	RDW2	RDW3	GGD	GG1	GG2
Total coliform (MPN/100 mL)	Minimum	250	41	110	1100	140	170	160	400	1100	330	260
	Maximum	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL
	Mean	3068.0	541.5	617.6	2567.0	3956.0	1299.0	2398.0	3720.0	3000.0	5142.0	1907.0
	Median	1800	200	200	2600	560	1000	2200	3300	3300	3300	1700
	Std. dev.	3168.0	970.1	1213.0	983.6	6932.0	941.5	1526.0	2768.0	1367.0	3831.0	1045.0
	# censored/ # results ¹	2/25	1/25	1/25	2/6	1/10	1/25	1/24	3/25	1/4	2/15	2/9
<i>E. coli</i> (MPN/100 mL)	Minimum	<10	<10	<10	52	<10	<10	<10	<10	10	10	<10
	Maximum	310	210	160	860	320	220	320	750	140	1500	270
	Mean	30.8	30.4	39.2	295.5	90.8	49.4	85.0	130.4	50.3	234.1	99.1
	Median	10	10	10	75	52	20	52	63	31	97	41
	Std. dev.	67.4	52.9	42.6	359.0	121.9	58.3	100.2	188.3	60.4	398.0	94.5
	# censored/ # results ²	13/25	14/25	8/25	0/6	2/10	3/25	1/24	1/25	0/4	0/15	1/9

¹ These results are above the upper quantification limit (UQL) of 24,190 and are shown as a ratio over the total number of results.

² These censored results are below the lower quantification limit (LQL) and are shown as a ratio over the total number of results.

Table 18. Pathogenic indicator bacteria results from the Lagunitas Creek watershed (water years 2013-2014). All means and standard deviations (std. dev.) are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	OLM18	OLM1	OLM14	OLM6A	OLM11	OLM10B	LAG1	LAG2	LAG3
Total coliform (MPN/100 mL)	Minimum	390	160	310	260	470	440	660	98	280
	Maximum	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL	>UQL
	Mean	3214.0	4027.0	2093.0	1730.0	12619.0	5207.0	4478.0	2204.0	2501.0
	Median	1700	1900	1300	1200	10000	2500	2300	700	1700
	Std. dev.	4741.0	5426.0	2567.0	1402.0	8974.0	5435.0	4432.0	3347.0	2366.0
	# censored/ # results ¹	1/36	2/36	2/36	1/35	5/36	4/36	1/25	2/25	2/25
<i>E. coli</i> (MPN/100 mL)	Minimum	<10	<10	<10	<10	10	10	41	<10	<10
	Maximum	3100	1600	1900	400	2600	2800	1500	1500	3300
	Mean	172.7	142.6	183.6	51.3	365.2	343.3	189.6	214.9	290.0
	Median	41	31	84	20	180	110	110	63	86
	Std. dev.	547.2	310.8	383.8	74.9	523.1	687.7	301.7	382.4	693.7
	# censored/ # results ²	11/36	9/36	2/36	3/35	0/36	0/36	0/25	3/25	1/25
Fecal coliform (MPN/100 mL)	Minimum	<2	<2	2	<2	30	4			
	Maximum	170	900	500	240	900	>1600			
	Mean	47.5	150.2	105.5	55.6	209.4	99.5			
	Median	23	30	50	30	130	80			
	Std. dev.	52.0	251.3	119.7	62.0	210.9	71.8			
	# censored/ # results ²	1/17	1/17	0/17	1/17	0/17	1/17*			

¹ These results are above the upper quantification limit (UQL) of 24,190 and are shown as a ratio over the total number of results.

² These censored results are below the lower quantification limit (LQL) and are shown as a ratio over the total number of results.

* The OLM10B fecal coliform column is the only exception – this site produced one censored result above the UQL.

Table 19. Pathogenic indicator bacteria results from the San Francisquito Creek watershed (water years 2013-2014). All means and standard deviations (std. dev.) are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	MGG1	WU1	WU2	WU3	WU4
Total coliform (MPN/100 mL)	Minimum	30	41	63	62	63
	Maximum	4400	13000	840	2500	4100
	Mean	754.7	1928.0	309.0	616.4	931.7
	Median	350	630	270	160	600
	Std. dev.	1128.0	3301.0	367.2	1055.0	1155.0
	# censored/ # results	0/15	0/15	0/4	0/5	0/18
<i>E. coli</i> (MPN/100 mL)	Minimum	<10	<10	<10	<10	<10
	Maximum	350	590	190	74	310
	Mean	63.0	88.7	57.5	26.8	-
	Median	10	10	20	20	-
	Std. dev.	100.9	199.7	88.5	26.9	-
	# censored/ # results ¹	6/15	8/15	1/4	1/5	13/18

¹ These censored results are below the lower quantification limit (LQL) and are shown as a ratio over the total number of results.

Total Coliform

The contact recreation maximum for total coliform, established by the San Francisco Bay RWQCB's Basin Plan, is 10,000 MPN/100 mL for a single sample. During WYs 2013-2014 field staff collected 540 total coliform samples from the SFAN water quality sites; 11% of the results (60:540) exceeded the contact recreation maximum, and all but one of the exceedances were from the Redwood and Lagunitas Creek watersheds.

Field staff collected a total of 193 bacteria samples from the Redwood Creek watershed sites during WYs 2013-2014 and 10% of these (19:193) exceeded the objective maximum of 10,000 MPN/100 mL. Each Redwood site had at least one exceedance, and the majority of these (16:19) were from samples collected during storm events. The two Fern Creek tributary sites produced the lowest mean total coliform levels in the Redwood Creek watershed (Figure 26). The Lagunitas Creek watershed produced a slightly higher rate of exceedance (14%) compared to Redwood, yet less than half of these were from storm samples. Most of the highest quantifiable results (not exceeding the quantification limit) program-wide were from the Lagunitas Creek watershed. Site OLM11, at the Bear Valley Road Bridge, produced the five highest quantifiable results as well as the highest mean in the program (Figure 27). Total coliform levels in the San Francisquito Creek watershed were consistently low on almost every visit. Only one individual result exceeded the objective maximum of 10,000 MPN/100 mL (13,000 MPN/100 mL at site WU1 in December 2012) (Figure 28).

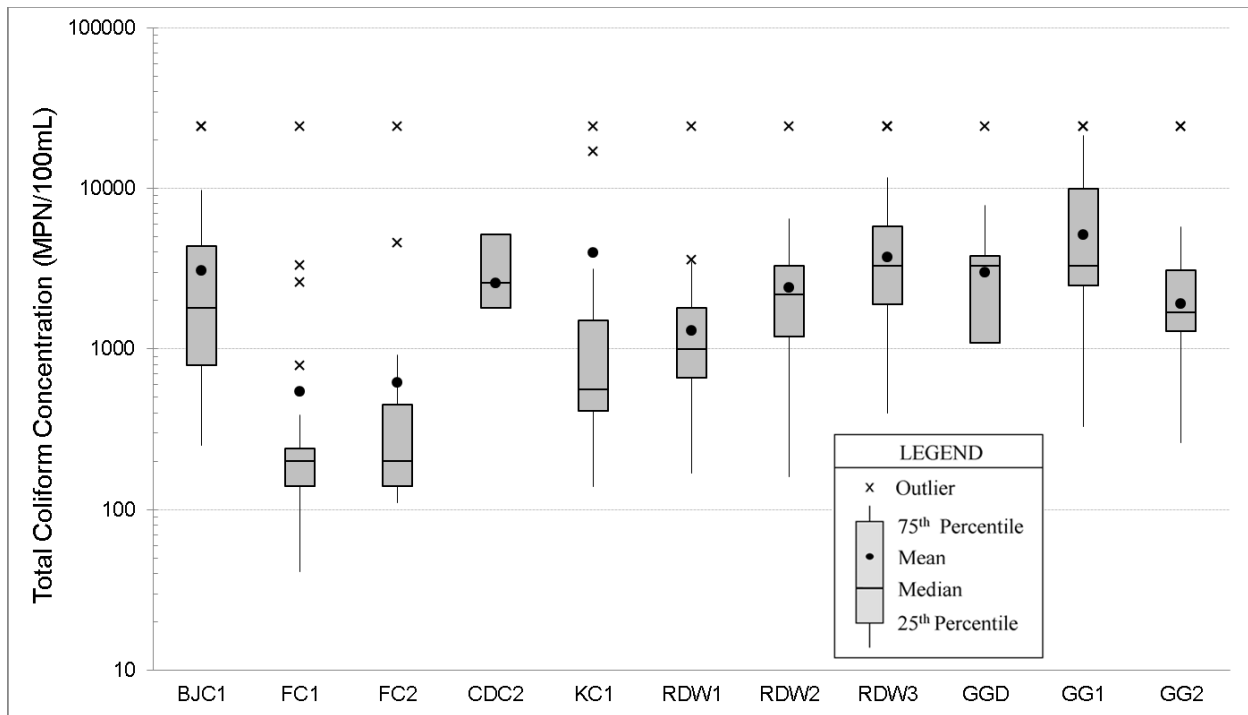


Figure 26. Total coliform results from the Redwood Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset and whiskers are drawn to 1.5 times the interquartile range (unless high censoring prevented computation).

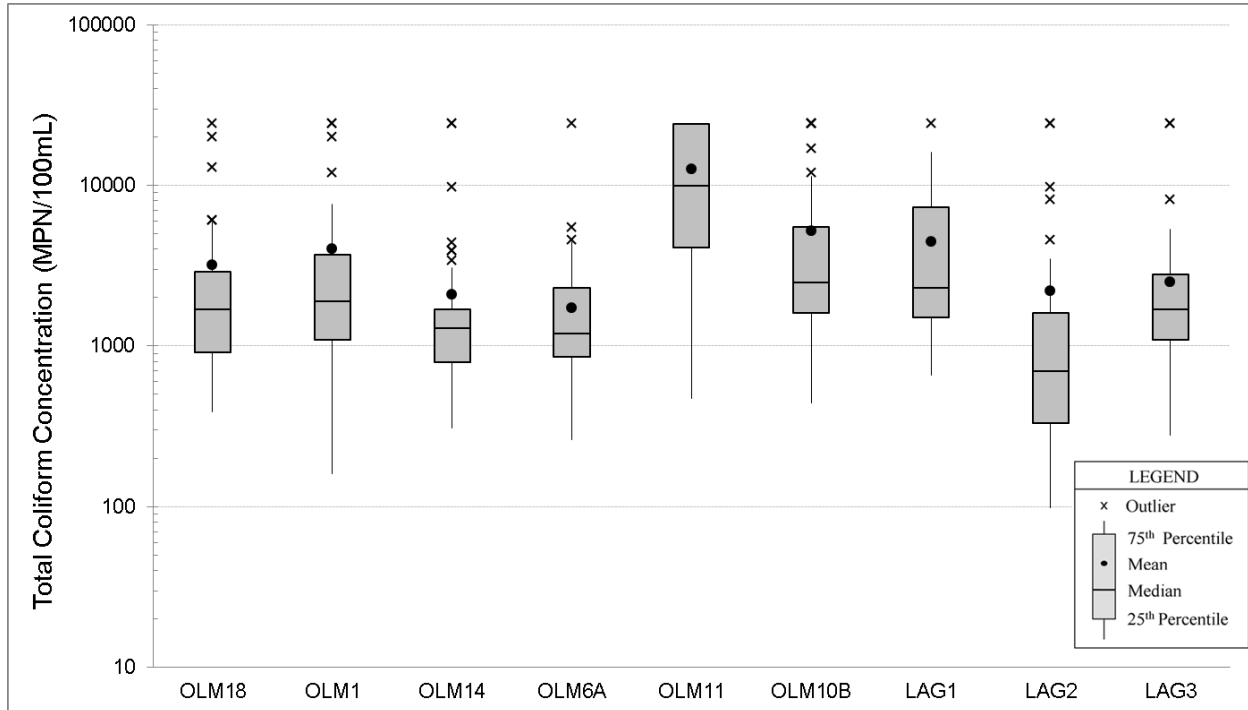


Figure 27. Total coliform results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset and whiskers are drawn to 1.5 times the interquartile range (unless high censoring prevented computation).

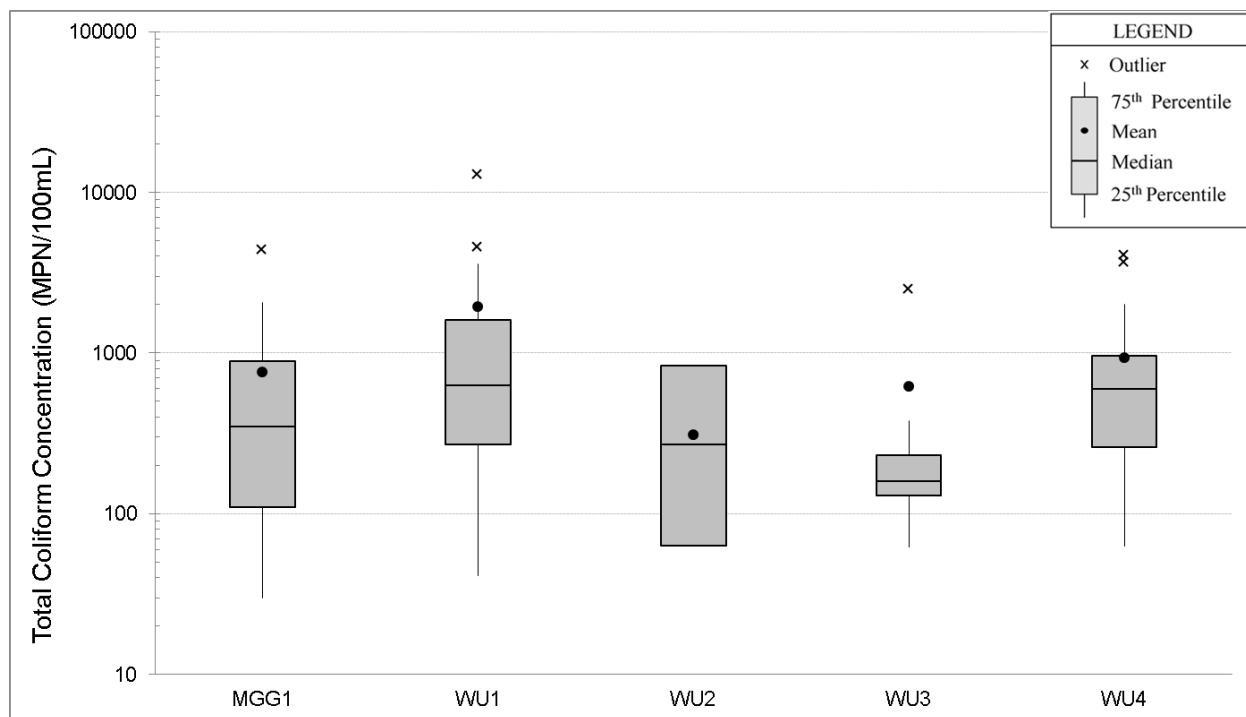


Figure 28. Total coliform results from San Francisquito Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset and whiskers are drawn to 1.5 times the interquartile range (unless high censoring prevented computation).

***Escherichia coli* (*E. coli*)**

The contact recreation maximum for *E. coli*, established by the San Francisco Bay RWQCB's Basin Plan, is 235 MPN/100 mL for a single sample. During WYs 2013-2014 field staff collected a total of 540 *E. coli* samples from the SFAN water quality sites. Thirteen percent of these results (69:540) exceeded the contact recreation maximum, and about $\frac{3}{4}$ of these exceedances (50:69) were from the Lagunitas Creek watershed. Nineteen percent of all samples program-wide (101:540) were reported as non-detect (below the quantification limit of 10 MPN/100mL). Several non-detects were from the Redwood and San Francisquito datasets, while the Lagunitas watershed had a higher percentage of detection (90% of results were above the detection limit).

Field staff collected a total of 193 bacteria samples from the Redwood Creek watershed sites during WYs 2013-2014 and only eight percent of these exceeded the objective maximum of 235 MPN/100 mL (and the majority of these were collected during storm events). The Redwood watershed produced some of the lowest mean *E. coli* values in the program (at the upper watershed sites BJC1, FC1, FC2, and RDW1), as well as the third highest mean in the program (295.5 MPN/100 mL at site CDC2) (Figure 29). The Lagunitas watershed results were also very site dependent; site OLM6A produced one of the lowest means in the program, while sites OLM11 and OLM10B produced two of the highest (Figure 30). Seventeen percent of the Lagunitas watershed results exceeded the objective maximum of 235 MPN/100 mL, while only seven percent of the San Francisquito results were above this threshold. Site WU3 in the San Francisquito Creek watershed produced the lowest mean (26.8 MPN/100 mL) in the entire program (Figure 31). Although there were only five *E. coli* samples

collected from this site during WYs 2013-2014, the data suggests that higher water levels (and higher inputs) during winter and spring (when all five were collected) are not necessarily correlated with higher bacteria levels at this site, as they are at many of the other SFAN sites.

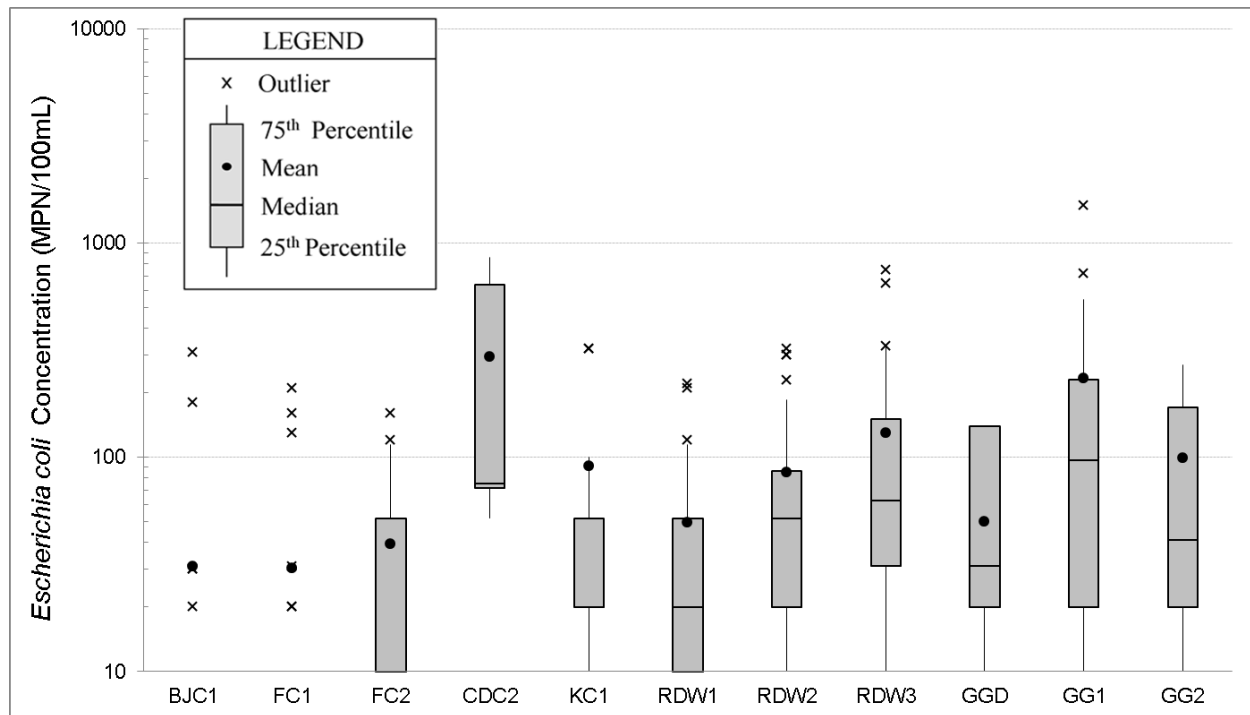


Figure 29. *Escherichia coli* results from the Redwood Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset and whiskers are drawn to 1.5 times the interquartile range (unless high censoring prevented computation).

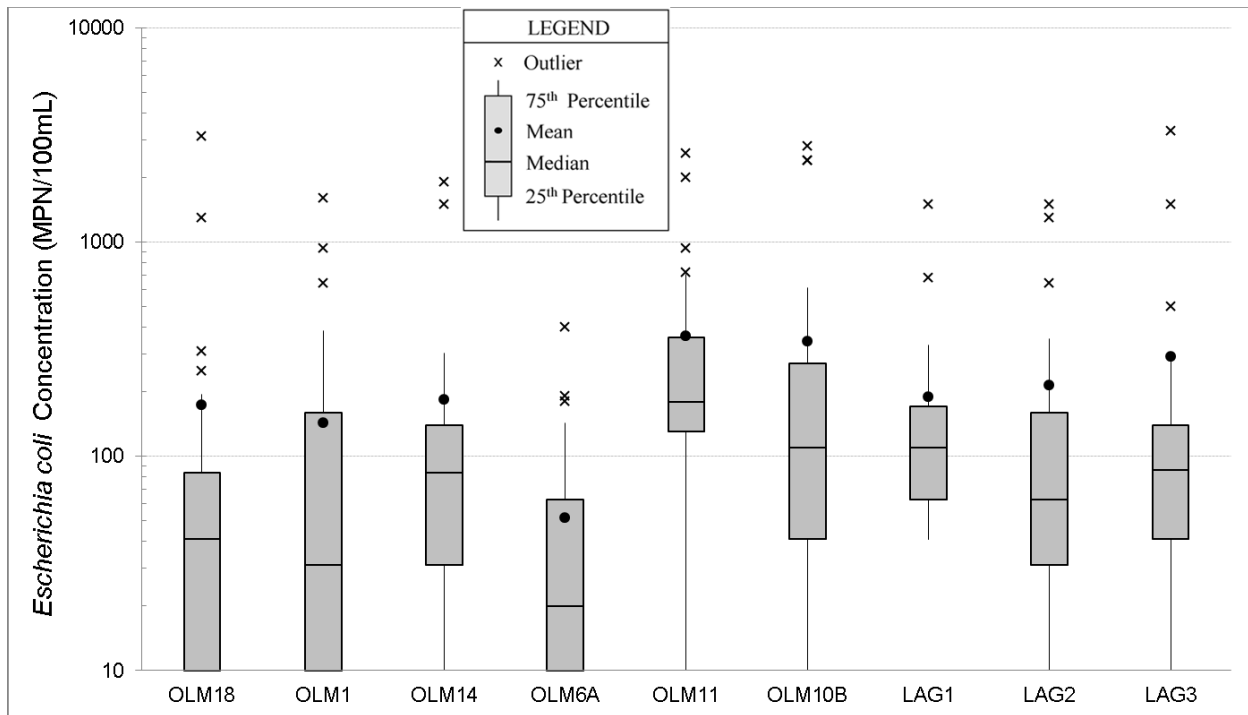


Figure 30. *Escherichia coli* results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset and whiskers are drawn to 1.5 times the interquartile range.

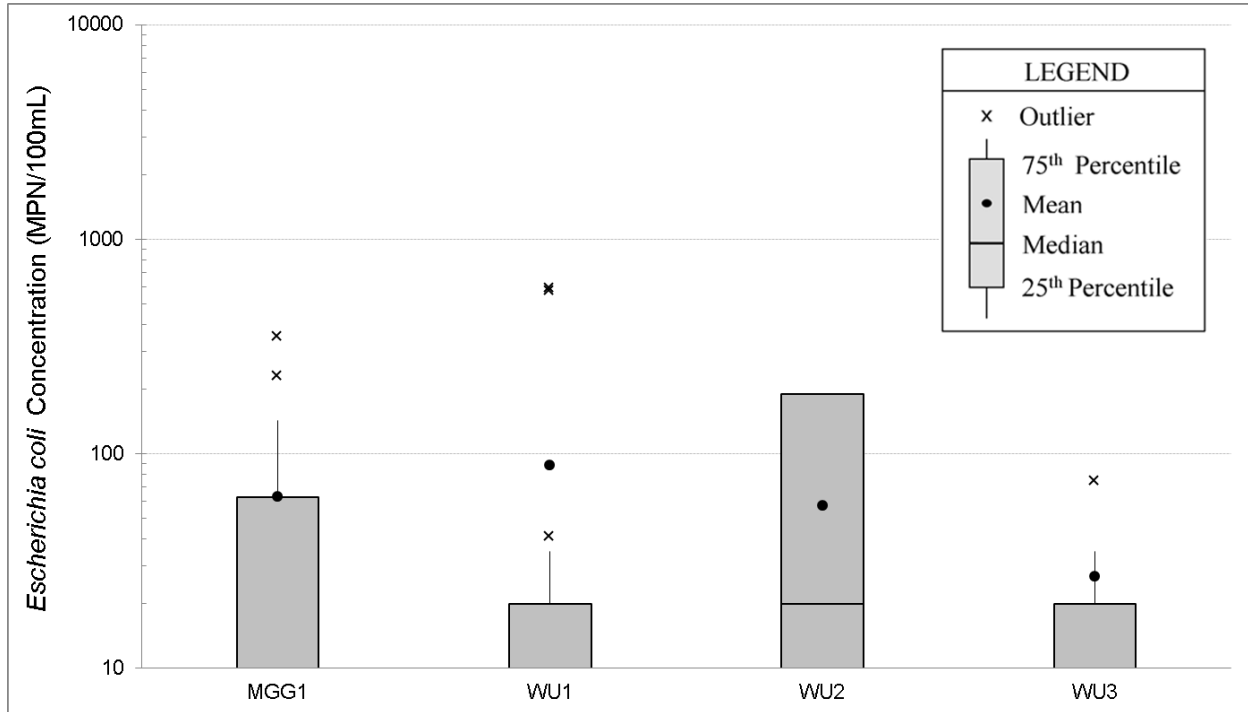


Figure 31. *Escherichia coli* results from the San Francisquito Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset and whiskers are drawn to 1.5 times the interquartile range (unless high censoring prevented computation).

Fecal Coliform

The contact recreation maximum for fecal coliform, established by the San Francisco Bay RWQCB's Basin Plan, is 400 MPN/100 mL for a single sample. Over the last decade, the sampling plan for the Tomales Bay Pathogen TMDL Program has included an intensive fecal coliform sampling period of five consecutive weeks, in the winter and summer, in addition to routine monthly monitoring. However, the program discontinued the routine sampling for most months during this reporting period and a change in the laboratory contracting prevented the five week winter sampling event from taking place during WY 2014. Thus, the sparse sampling schedule was as follows: one monthly sampling event each, in October and December 2012, and only three sets of the five-week sampling events (in February 2013, July 2013, and July 2014). None of the scheduled sampling days overlapped with storm sampling events.

During WYs 2013-2014 field staff collected a total of 102 fecal coliform samples from the six Olema Creek (and tributary) sites in the Lagunitas Creek watershed. Seven percent of these results (7:102) exceeded the contact recreation maximum of 400 MPN/100 mL. We recorded exceedances at every site, except for sites OLM18 and OLM6A, which also produced the two lowest mean fecal coliform values (47.5 and 55.6 MPN/100 mL, respectively). One of the downstream sites on the mainstem, OLM11, produced a mean fecal coliform level of 209.4 MPN/100 mL, which was the highest in the watershed (Figure 32). This site also produced the highest mean *E. coli* level program-wide.

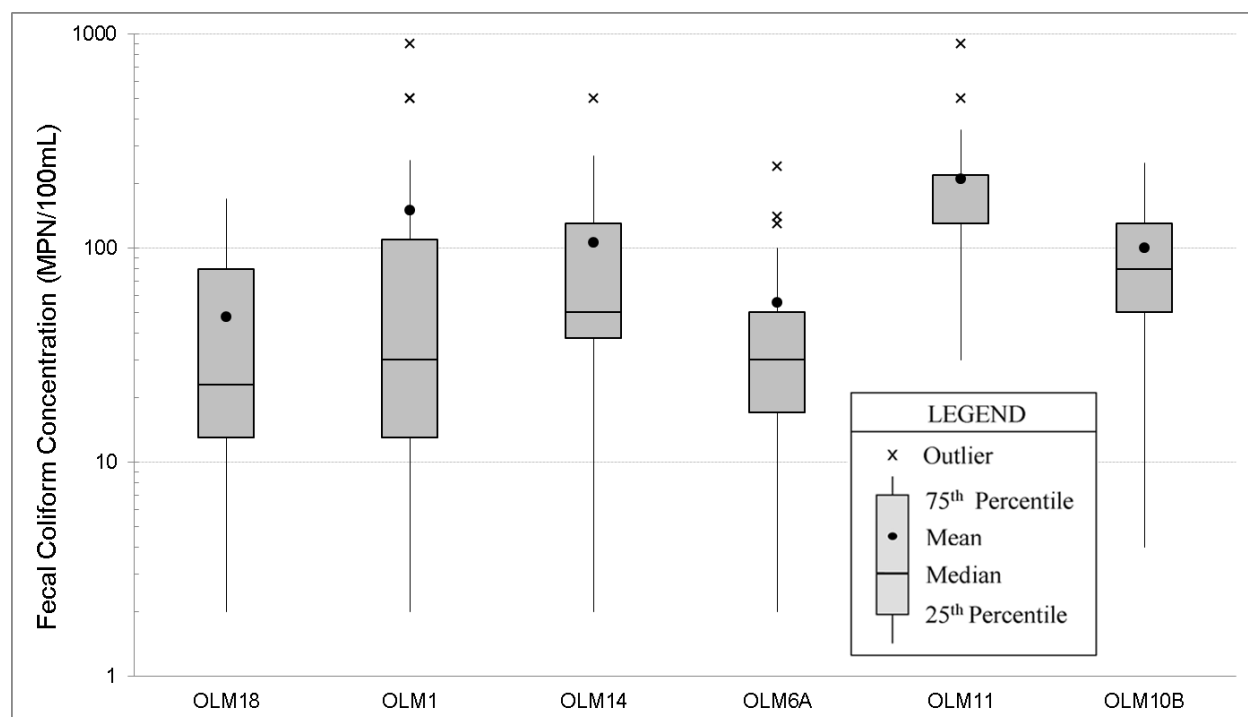


Figure 32. Fecal coliform results from the Lagunitas Creek watershed (water years 2013-2014). Boxplots present the interquartile range of each dataset and whiskers are drawn to 1.5 times the interquartile range.

Conclusions

This biennial report presents the physical, chemical, and biological ranges found at the SFAN water quality sites during WYs 2013-2014 (October 2012 – September 2012). NPS staff monitored twenty-five water quality sites, and the resulting data show that waters commonly met most established water quality objectives. Overall, the Redwood Creek watershed results commonly met their respective objectives, while the Lagunitas and San Francisquito Creek watershed results met the water quality objectives with slightly less frequency. The San Francisquito results exhibited high failure rates for two core parameters, while the Lagunitas results had more issues with pathogenic bacteria and nutrient loading (Table 20).

Table 20. Percentages of results that failed to meet water quality objectives¹, sorted by NPS unit. The parameters of the greatest concern (more than 10% failure rate) are shaded for simplified viewing.

Parameter	Redwood	Lagunitas	San Francisquito
Dissolved oxygen	7%	24%	39%
pH	1%	1%	2%
Specific conductance	3%	0%	49%
Turbidity	8%	7%	2%
Nitrate (as nitrogen)	12%	31%	0%
Total coliform	10%	14%	2%
<i>Escherichia coli</i>	8%	17%	7%
Fecal coliform	n/a	7%	n/a

¹ Water quality objectives and corresponding references: > 7 mg/L dissolved oxygen (CA RWQCB 2010), 6.5 to 8.5 pH units (CA RWQCB 2010), < 500 μ S/cm specific conductance (Behar 1997), < 25 NTU turbidity (Sigler et al. 1984), < 0.30 mg/L nitrate as nitrogen (Roche et al. 2013), < 10,000 MPN/100mL total coliform (CA RWQCB 2010), < 235 MPN/100mL *E. coli* (CA RWQCB 2010), and < 400 MPN/100mL fecal coliform (CA RWQCB 2010).

The watershed with the highest rates of exceedance (for any monitored parameter) was the San Francisquito Creek watershed: 49% of specific conductance results exceeded the ecological objective of 500 μ S/cm, and 39% of dissolved oxygen results were below the objective of 7 mg/L. Although these two parameters had high failure rates, the San Francisquito Creek watershed results commonly met water quality objectives for all other monitored parameters (Table 20).

The Lagunitas watershed harbors many resources of management concern, including a viable population of coho salmon and steelhead. This watershed most commonly failed to meet water quality objectives during WYs 2013-2014: 24% of the dissolved oxygen results failed to meet the established objective of 7 mg/L; 31% of nitrate results exceeded the ecological objective of 0.30 mg/L; 14% of total coliform results exceeded the objective maximum of 10,000 MPN/100 mL; and 17% of *E. coli* results exceeded the contact recreation maximum objective of 235 MPN/100 mL. High levels of pathogenic indicator bacteria in the Lagunitas Creek watershed have been documented for many years, and monitoring of these levels continues through the San Francisco RWQCB's Tomales Bay Pathogen TMDL Program; however, the fecal coliform results exhibited a relatively

low exceedance rate (7%) during WYs 2013-2014. The Lagunitas Creek watershed results exhibited low failure rates for all other monitored parameters (pH, specific conductance, and turbidity).

The other watershed that supports a viable population of coho salmon and steelhead is Redwood. During WYs 2013-2014, the Redwood Creek watershed exhibited a slightly elevated failure rate for nitrate as nitrogen (12%). All other parameters monitored in the Redwood Creek watershed commonly fell within the water quality objectives.

Two monitoring objectives proposed in the SFAN Freshwater Quality Monitoring Protocol are not addressed in this report. Diel variability has not been evaluated because of significant needs for additional funding, staff time, and continuous monitoring equipment. Additionally, loading has never been calculated by the San Francisco Bay RWQCB's Pathogen TMDL Program (nor is it a requirement of their program). This water quality monitoring program satisfies the third objective of the SFAN protocol, by determining the extent that the sites meet established federal and state water quality standards, through routine sampling.

The data presented in this report summarize the seventh and eighth years of monitoring under the SFAN Freshwater Quality Monitoring Protocol (Coopridge and Carson 2006). This two-year rotation (WYs 2013-2014) involved routine monitoring of 25 sites in three major watersheds, and it will be repeated in WYs 2017-2018. WYs 2015-2016 will repeat the sampling routine of the alternate rotation, which includes 30 different sites in four SFAN parks (PINN, JOMU, GOGA, and PORE) (Table 9). After WYs 2013-2014 there will be eight years of protocol implementation, but due to the rotating basin design, this will yield just four years of data for each of these SFAN watersheds. After WY 2014, more extensive data analysis will be considered, but the first protocol objective (long-term trends analysis) may not be possible until there is a more substantial dataset.

During water years 2013 and 2014, this water quality program produced a clear snapshot of watershed health in eight SFAN watersheds. Continuation of this long-term monitoring program is necessary to document seasonal ecological fluctuations, determine trends, inform management decisions, and assist with the evaluation of restoration projects.

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