



# Freshwater Quality Monitoring in the San Francisco Bay Area Network

## *Biennial Report on Water Years 2015 and 2016*

Natural Resource Report NPS/SFAN/NRR—2017/1471



**ON THE COVER**

Clockwise, from top left: Strentzel Creek in John Muir National Historic Site, Chalone Creek in Pinnacles National Park, Nyhan Creek in Golden Gate National Recreation Area, and John West Fork in Point Reyes National Seashore.

Photos by Katie Wallitner

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# **Freshwater Quality Monitoring in the San Francisco Bay Area Network**

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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), 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 30 SFAN sites monitored during WYs 2015 and 2016 (10/1/2014 – 9/30/2016), including nine sites in PORE, eight in PINN, seven in GOGA, and six in JOMU. During WYs 2015-2016, NPS staff made a total of 593 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 (Coopridier 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 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; 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*.

Monitoring during WYs 2015 and 2016 produced a snapshot of water quality conditions in eight watersheds (in four NPS units). Due to the two-year rotating basin design of the SFAN Freshwater Quality Monitoring Protocol, this specific set of 30 sites will not be monitored again until WYs 2019-2020 (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 2017-2018, this freshwater quality monitoring program will continue at 25 sites within PORE, MUWO, and GOGA.

## Acknowledgments

This monitoring would not be possible without assistance from the Water Resources Division of the National Park Service, and support from individual SFAN parks and network staff. Thank you to Dean Tucker and Paula Galloway, who provided assistance with database management and data storage and handling, and Marie Denn and Daniel George, who provided program oversight and support.

## 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                                 |
| 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 12 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*) [FE<sup>1</sup>], coho salmon (*Oncorhynchus kisutch*) [FE<sup>1</sup>/SE<sup>2</sup>], steelhead (*Oncorhynchus mykiss*) [FT<sup>3</sup>], and California red-legged frog (*Rana draytonii*) [FT<sup>3</sup>]. 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).

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<sup>1</sup> FE – federally endangered

<sup>2</sup> SE – state endangered

<sup>3</sup> FT – federally threatened

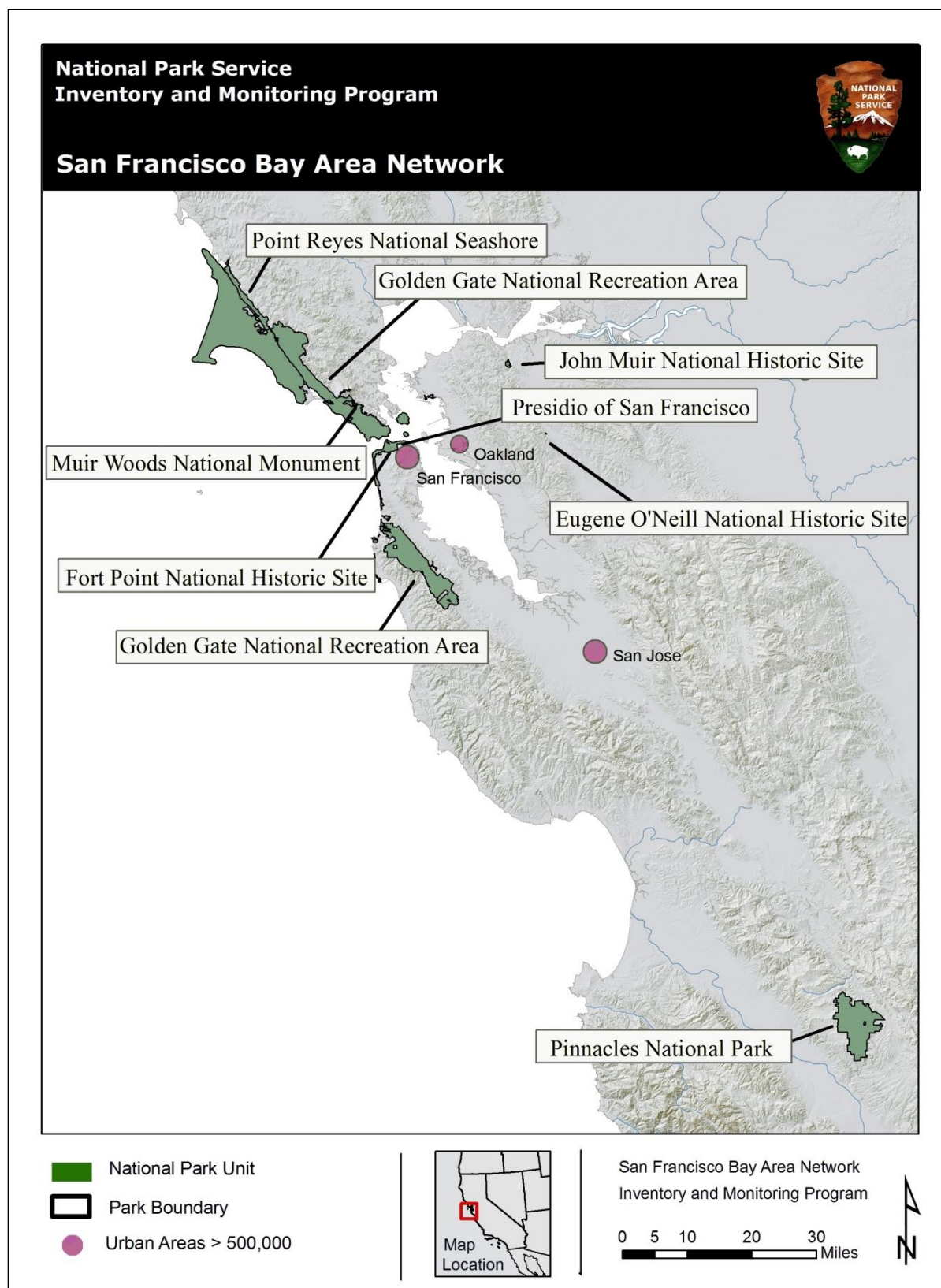


**Figure 1.** Map of the San Francisco Bay Area Inventory and Monitoring Network.

## **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, and 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 2015-2016 (October 1, 2014 – September 30, 2016). 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 2016 marked the tenth year of protocol implementation; however, due to the rotating basin design, ten years of monitoring results in just six years of data for the first rotation, and four years for the second. SFAN staff conducted a preliminary trends analysis, but determined that there are not yet enough data to detect trends for most SFAN sites/parameters.

## **Overview of Aquatic Resources**

Land uses in and around SFAN park units 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. 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. Rangeland water quality best management practices are being implemented throughout PORE. 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 2015-2016 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 (Coopridner and Carson 2006). There are two types of SFAN water quality sites; primary and secondary sites are monitored at the same frequency, but involve slightly different parameters (see Methods section for more information).

### Point Reyes National Seashore (PORE)

The 88 square-mile Lagunitas Creek watershed is the largest within the SFAN. The mainstem flows north from Mount Tamalpais through a series of lakes and dams, eventually flowing through PORE and GOGA before reaching the head of Tomales Bay near the town of Point Reyes Station. Stream discharge records range from 22,100 cubic feet per second (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 (Coopridner 2004). This 14.5 square-mile watershed flows north through the Olema Valley (the landward expression of the San Andreas Fault Zone). Its confluence with Lagunitas Creek lies at the head of Tomales Bay. Approximately 35-40% of the Olema Creek watershed is managed for cattle grazing. Two horse concession operations, Stewart Horse Camp and Five Brooks Stable, are located in the central portion of the watershed. Lagunitas Creek and Olema Creek support viable populations of coho, steelhead, and California red-legged frogs. Because these two creeks provide significant habitat for threatened and endangered species, and also because they are sources of pollutant loading to Tomales Bay, they are the subject of extensive monitoring through this water quality program as well as through 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 began hydrologic monitoring of Olema Creek in 1997 with the installation of a stream gaging station at the Bear Valley Road Bridge. The NPS has conducted water quality monitoring within the Olema Creek watershed since 1999, and fisheries monitoring (focused on coho and steelhead) since 1994. Water quality monitoring under the SFAN Freshwater Quality Monitoring Protocol began in the fall of 2006.

The Pine Gulch watershed extends over approximately 7.5 square miles, situated at the southern end of the Olema Valley. Pine Gulch flows parallel to Olema Creek, although in the opposite direction

(south toward Bolinas Lagoon) because they are separated by the San Andreas Fault. Much of the downstream portion of the watershed is situated on private lands. Pine Gulch supports a viable population of steelhead and an intermittent population of coho, both monitored by the SFAN Coho and Steelhead Monitoring Program.

Three Pine Gulch sites and six Olema Creek watershed sites were included in the SFAN Freshwater Quality Monitoring sampling regime during WYs 2015-2016 (Table 1 and Figure 2).

**Table 1.** Freshwater quality monitoring sites within Point Reyes National Seashore.

| Site   | Site Type | Flow Regime  | Site Description                                                                                  |
|--------|-----------|--------------|---------------------------------------------------------------------------------------------------|
| OLM18  | Primary   | Intermittent | Olema Creek: upstream of Randall Gulch (near Hwy 1 milepost 21.06)                                |
| OLM1   | Primary   | Intermittent | John West Fork: upstream of Highway 1 culvert (near milepost 22.67)                               |
| OLM14  | Primary   | Perennial    | Olema Creek: just downstream of the northernmost Five Brooks bridge                               |
| OLM6A  | Primary   | Perennial    | Davis Boucher Creek: approximately 50 m upstream of footbridge, above confluence with Olema Creek |
| OLM11  | Primary   | Perennial    | Olema Creek: at Bear Valley Road bridge                                                           |
| OLM10B | Primary   | Perennial    | Olema Creek: adjacent to Olema Marsh, below residence #530                                        |
| PNG3   | Primary   | Perennial    | Pine Gulch Creek: near Teixeira Ranch, just upstream of the Olema Valley Trail creek crossing     |
| PNG4   | Primary   | Perennial    | Pine Gulch Creek: just upstream of confluence with Copper Mine Gulch tributary.                   |
| PNG2   | Primary   | Perennial    | Pine Gulch Creek: downstream/south of site PNG4                                                   |
| PNG1   | Primary   | Perennial    | Pine Gulch Creek: downstream of Olema-Bolinas Road bridge, at Gospel Flats Farm footbridge        |

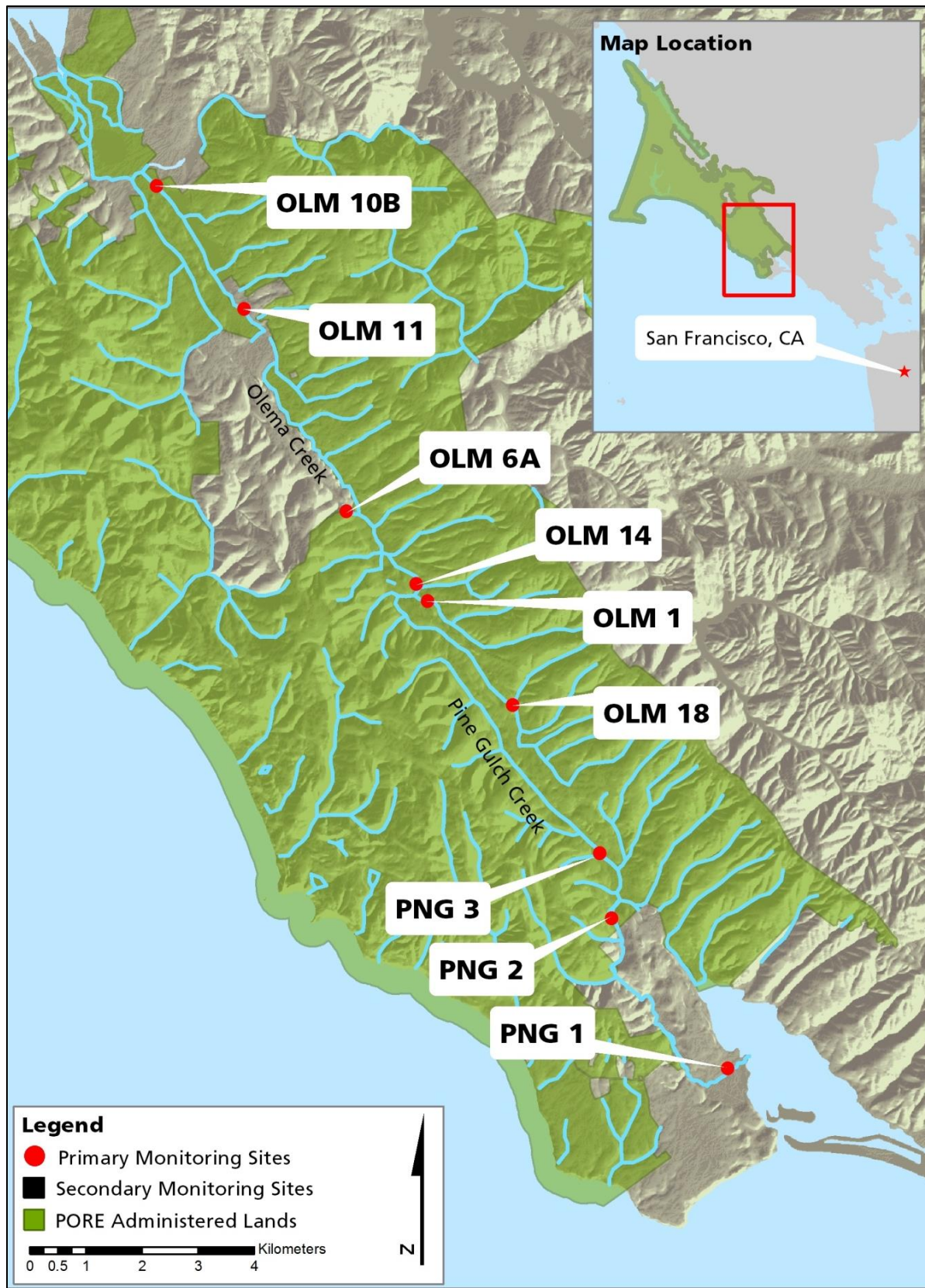


Figure 2. Freshwater quality monitoring sites within Point Reyes National Seashore.

## **Pinnacles National Park (PINN)**

Ninety-five percent of the park is located within the Chalone Creek watershed, which eventually drains into the Salinas River southwest of the park. The Chalone Creek watershed drainage area is approximately 70 square miles; most of its headwaters are located outside the park boundary. The majority of Chalone Creek within the park is intermittent, commonly exhibiting dry conditions for five to six months per year, although some short reaches have water present year-round.

During WY 2011, park staff constructed nine miles of new pig exclusion fencing in the northeastern portion of the park. Park staff plan to eradicate pigs from within the newly-enclosed area in order to reduce erosion and trampling and improve riparian plant cover. During WY 2012, park staff implemented watershed improvements on the West Fork of Chalone Creek, including removal of multiple structures the floodplain, vegetation restoration, and the relocation of new West Side Visitor Contact Station facilities outside of the floodplain. SFAN I&M staff monitored water quality on the mainstem of Chalone Creek during WYs 2015-2016, along with the Bear Gulch, McCabe Canyon, and Sandy Creek tributaries (Table 2 and Figure 3).

**Table 2.** Freshwater quality monitoring sites within Pinnacles National Park.

| <b>Site</b> | <b>Site Type</b> | <b>Flow Regime</b> | <b>Site Description</b>                                                                     |
|-------------|------------------|--------------------|---------------------------------------------------------------------------------------------|
| BG2         | Primary          | Perennial          | Bear Gulch: directly upstream of footbridge, below Resource Management Office Building      |
| CHA3        | Secondary        | Intermittent       | North Fork Chalone Creek: upstream of North Wilderness Trail & Old Pinnacles Trail junction |
| CHA2        | Primary          | Perennial          | Chalone Creek: upstream of Hwy146 Road bridge                                               |
| CHA1        | Primary          | Perennial          | Chalone Creek: off of the South Wilderness Trail                                            |
| MC1         | Primary          | Perennial          | McCabe Canyon: upstream of Hwy 146, across from the Pinnacles Campground                    |
| SC3         | Secondary        | Perennial          | Sandy Creek: in Pinnacles Campground, downhill from campsite #1, in left bank channel       |
| SC2         | Secondary        | Intermittent       | Sandy Creek: in Pinnacles Campground, downstream of restrooms, across from campsite #68     |
| SC1         | Primary          | Intermittent       | Sandy Creek: opposite of the weather station pull-out on Hwy 146                            |

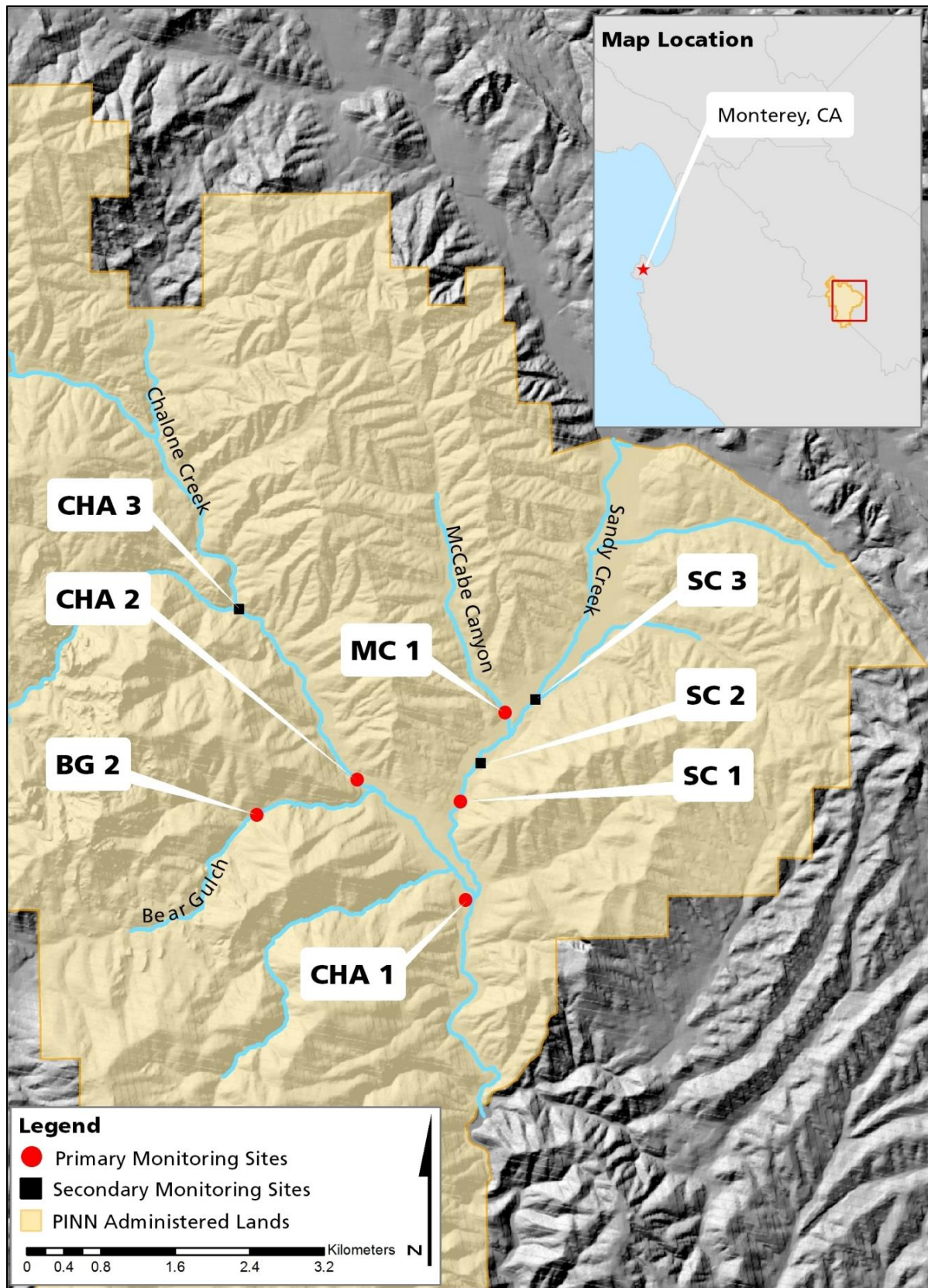


**Figure 3.** Freshwater quality monitoring sites within Pinnacles National Park.

### Golden Gate National Recreation Area (GOGA)

During WYs 2015-2016, staff monitored seven GOGA sites as part of the SFAN Freshwater Quality sampling regime; these included two sites in the Rodeo Creek watershed, three in Tennessee Valley Creek, and one each in Oakwood and Nyhan Creeks (Table 3 and Figure 4).

The Rodeo Creek watershed is approximately 4.4 square miles in size and empties into Rodeo Lagoon at Rodeo Beach in Fort Cronkhite (the southernmost portion of the Marin Headlands). The lagoon is infrequently connected to the ocean and therefore is not commonly affected by tidal influence. The Rodeo Creek headwaters are located almost entirely within GOGA lands in the Marin Headlands. Rodeo Creek is perennial, and is fed by Gerbode Creek and several small, unnamed tributaries. There are 20<sup>th</sup> century military buildings, park housing units, and a commercial horse stable, all located near the monitoring sites. The Tennessee Valley Creek watershed is approximately 2.4 square miles in size, and is situated north of the Rodeo Valley and south of the Redwood Creek watershed. Its headwaters are located entirely within GOGA lands. Tennessee Valley Creek flows northeast to southwest, and empties into the Pacific Ocean at Tennessee Cove. Developments in the watershed include a day-use parking lot and a commercial horse stable at the creek's headwaters. Adjacent to Tennessee Valley is the Oakwood Valley Creek watershed, which flows northwest along the eastern boundary of GOGA property until it joins Nyhan Creek (an approximately 2 square-mile watershed), just outside the park boundary. Nyhan Creek then flows east into Coyote Creek, and eventually to Richardson Bay and the San Francisco Bay.

**Table 3.** Freshwater quality monitoring sites within Golden Gate National Recreation Area.

| Site  | Site Type | Flow Regime  | Site Description                                                                                            |
|-------|-----------|--------------|-------------------------------------------------------------------------------------------------------------|
| RC1   | Primary   | Perennial    | Rodeo Creek: across from Presidio Stables, 420 meters upstream of confluence with Gerbode Creek             |
| GERB1 | Primary   | Perennial    | Gerbode Creek: upstream of Bobcat Trail culvert, near Miwok Trail junction                                  |
| OAK1  | Secondary | Perennial    | Oakwood Valley Creek: upstream end of culvert on east side of Tennessee Valley Road                         |
| NYH1  | Secondary | Perennial    | Nyhan Creek: below footbridge on west side of Tennessee Valley Road                                         |
| TV1   | Secondary | Intermittent | Tennessee Valley Creek: in Miwok Stables area, above farthest upstream building (red house)                 |
| TV2   | Primary   | Intermittent | Tennessee Valley Creek: off of Tennessee Valley Trail, 330 meters upstream of Haypress tributary confluence |
| TV3   | Primary   | Intermittent | Tennessee Valley Creek: off of Tennessee Valley Trail, two meters downstream of Backdoor tributary          |

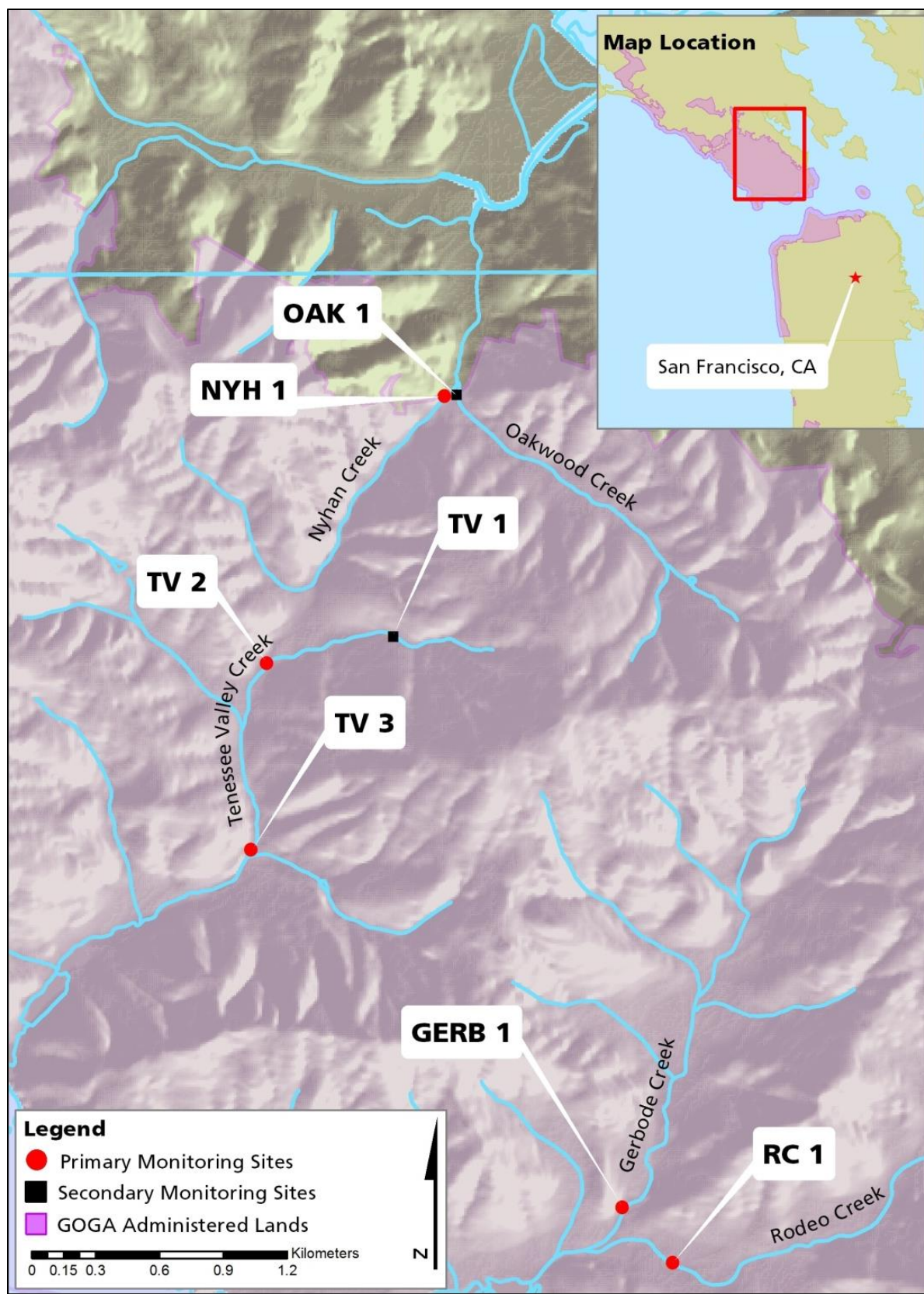


Figure 4. Freshwater quality monitoring sites within Golden Gate National Recreation Area.

### John Muir National Historic Site (JOMU)

The Franklin Creek watershed is three square miles in extent and supports an intermittent stream that flows northward through the monument west of the John Muir house. Downstream of the park boundary, Franklin Creek joins Alhambra Creek (also known as Arroyo del Hambre). Only 500 feet of Franklin Creek is on NPS property, so only one water quality monitoring site is located here. No water quality monitoring had been conducted at this site prior to the 2004 pilot sampling which helped to develop the SFAN Freshwater Quality Monitoring Protocol (Coopridge and Carson 2006). Steelhead have been observed in Franklin Creek, although the reach of creek in JOMU provides limited habitat for salmonids. On the opposite side of Highway 4 the Strentzel Creek watershed drains the southwest side of Mount Wanda; approximately half of this watershed is on monument property. The Strentzel Creek watershed has significant erosion and sedimentation issues; these are a management priority for monument staff (Moore 2006). SFAN staff visit five secondary monitoring sites in this watershed during storm events (Table 4 and Figure 5). During WYs 2015-2016, SFAN staff conducted two storm sampling events in the Strentzel Creek watershed.

**Table 4.** Freshwater quality monitoring sites within John Muir National Historic Site.

| Site | Site Type | Flow Regime  | Site Description                                                                                                  |
|------|-----------|--------------|-------------------------------------------------------------------------------------------------------------------|
| FRA1 | Primary   | Intermittent | Franklin Creek: downstream of footbridge, just upstream of gate & concrete ledge at northern end of park boundary |
| STR1 | Secondary | Ephemeral    | Strentzel Creek: above Strain Ranch, upstream of confluence with fourth north tributary (from east to west)       |
| STR2 | Secondary | Ephemeral    | Fourth north tributary of Strentzel Creek                                                                         |
| STR3 | Secondary | Ephemeral    | Third south tributary of Strentzel Creek                                                                          |
| STR4 | Secondary | Ephemeral    | Strentzel Creek: mainstem Strentzel at first fire road crossing upstream of Strain Ranch                          |
| STR5 | Secondary | Ephemeral    | Strentzel Creek: mainstem Strentzel at Alhambra Ave. culvert                                                      |

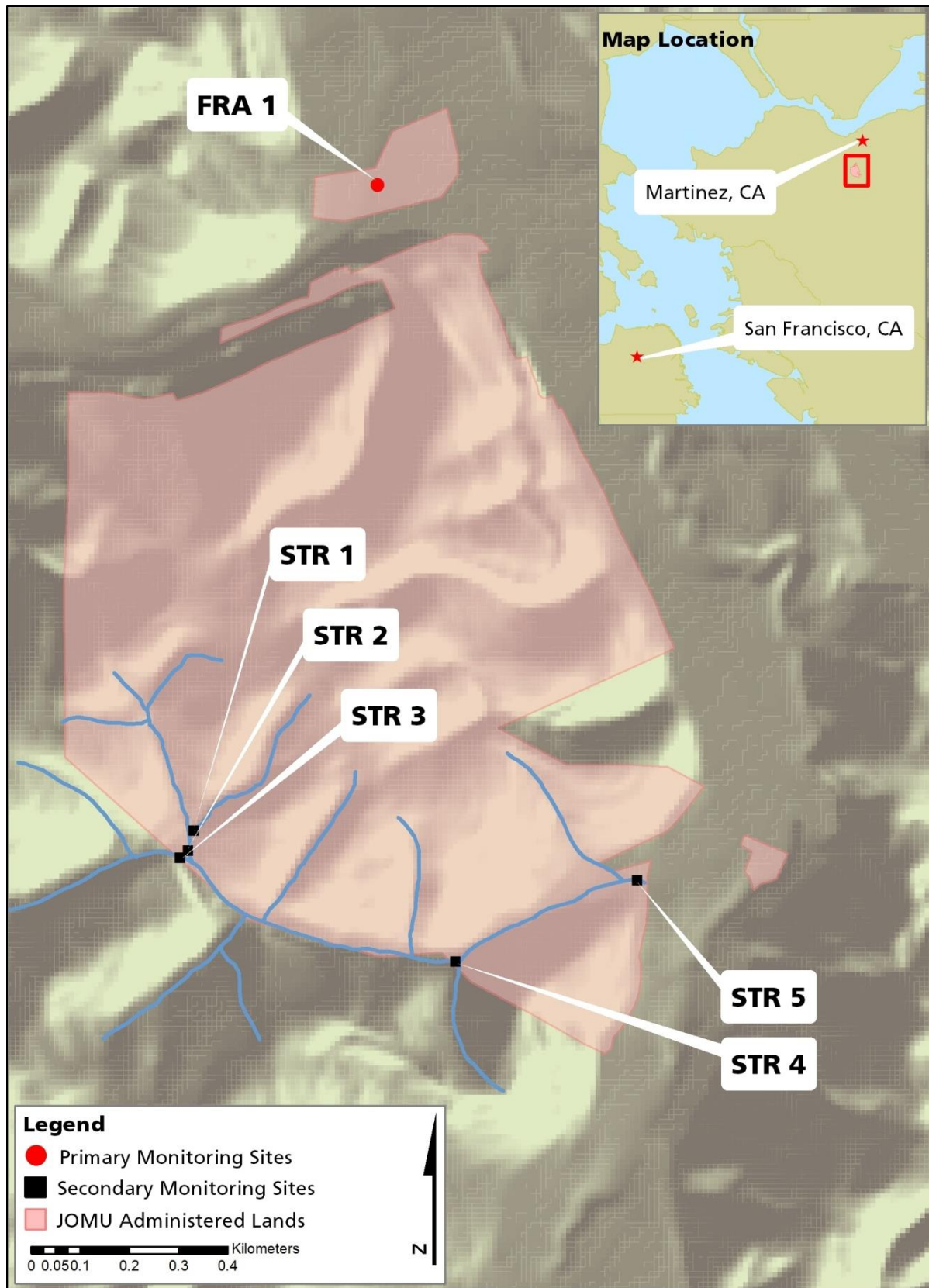


Figure 5. Freshwater quality monitoring sites within John Muir National Historic Site.

## Methods

### Water Quality Objectives

In California, the RWQCBs established Basin Plans, which set “numerical and narrative objectives for surface waters” (Tables 5, 6, and 7). The numerical objectives for bacteria are based on the national criteria established by the United States Environmental Protection Agency (EPA) (EPA 1986). 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, including 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 5.** Numerical objectives for surface waters in PORE, GOGA, and JOMU - from the San Francisco Bay Regional Water Quality Control Board’s Basin Plan (CA RWQCB 2010).

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

**Table 6.** Numerical objectives for surface waters in PINN - from the Central Coast Region Basin Plan (CA RWQCB 2011).

| Parameter        | Water Quality Objective            |
|------------------|------------------------------------|
| Dissolved Oxygen | 5.0 mg/L minimum                   |
| pH               | Less than 8.5 and greater than 7.0 |

**Table 7.** 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 (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 8). Previous monitoring in the SFAN has shown nitrite values to be insignificant, thus the SFAN only samples nitrate (Coopridge 2004).

**Table 8.** Ecoregion III reference values for nutrients (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 Total Maximum Daily Loads, or 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 (Coopridner 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 (Coopridner and Carson 2006).

### Sampling Regime

The SFAN Freshwater Quality Monitoring Program has a rotating basin design in which each watershed is monitored monthly for a two-year period (Table 9). This 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. 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 design is the Olema Creek watershed, which is monitored continuously (every water year) because these sites are included in the Tomales Bay TMDL project. SFAN I&M staff generally visit each site at approximately the same time of day, once per month (except for Strentzel Creek), and attempt to capture at least one storm event per year.

**Table 9.** SFAN water quality monitoring schedule. (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        | Park(s)   | Number of Sites |    | Water Year |           |           |           |           |           |
|------------------|-----------|-----------------|----|------------|-----------|-----------|-----------|-----------|-----------|
|                  |           | 1°              | 2° | 2007-2008  | 2009-2010 | 2011-2012 | 2013-2014 | 2015-2016 | 2017-2018 |
| Olema Creek      | PORE      | 6               | –  | M/S/W      | M/S/W     | M/S/W     | M/S/W     | M/S/W     | M/S/W     |
| Pine Gulch       | PORE      | 3               | –  | M          | –         | M         | –         | M         | –         |
| Franklin Creek   | JOMU      | 1               | –  | M          | –         | M         | –         | M         | –         |
| Strentzel Creek  | JOMU      | –               | 5  | S          | –         | S         | –         | S         | –         |
| Chalone Creek    | PINN      | 5               | 3  | M/S        | M/S       | M/S       | M/S       | M/S       | –         |
| Rodeo Creek      | GOGA      | 2               | –  | M/S        | M/S       | M/S       | M/S       | M/S       | –         |
| Tennessee Creek  | GOGA      | 2               | 1  | M/S        | M/S       | M/S       | M/S       | M/S       | –         |
| Nyhan Creek      | GOGA      | –               | 1  | M/S        | M/S       | M/S       | M/S       | M/S       | –         |
| Oakwood Creek    | GOGA      | –               | 1  | M/S        | M/S       | M/S       | M/S       | M/S       | –         |
| West Union Creek | GOGA      | 3               | 2  | –          | M         | –         | M         | –         | M         |
| Lagunitas Creek  | PORE/GOGA | 3               | –  | –          | M/S       | –         | M/S       | –         | M/S       |
| Redwood Creek    | PORE/GOGA | 10              | 1  | –          | M/S       | –         | M/S       | –         | M/S       |

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 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 calls 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 10). 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*). Staff collected samples during all site conditions, with the exception of fecal coliform (which was skipped if streamflow was disconnected/pooled). Fecal coliform analysis was added to the six Olema Creek watershed sites (only), due to their inclusion in the Tomales Bay Pathogen TMDL Project. Staff All water quality sampling followed the methods described in the SFAN Freshwater Quality Monitoring Protocol (Coopridge and Carson 2006) and manufacturer's equipment manuals.

**Table 10.** 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 11 lists the processing methods used for all parameters. NPS staff collected core parameter data in-situ, using a YSI ProPlus (Professional Series) multiparameter instrument. For fecal coliform sample processing (at Olema Creek watershed sites only), the RWQCB contracted with CEL Analytical Laboratory in San Francisco. 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 11.** 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          | Enzyme substrate coliform test: standard method 9223B using IDEXX Quanti-Tray 2000 with colilert reagent |
| <i>Escherichia coli</i> | Enzyme substrate coliform test: standard method 9223B using IDEXX Quanti-Tray 2000 with colilert reagent |
| Fecal coliform          | Fecal coliform by multiple tube fermentation: standard method 9221B                                      |
| Nitrate (as N)          | EPA method 300 [detection limit: 0.15 mg/L]                                                              |
| Total Kjeldahl Nitrogen | Standard method 4500-Norg C [detection limit: 0.25 mg/L]                                                 |
| Turbidity               | Hach 2100P turbidimeter                                                                                  |

## 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); 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. To accommodate censored data in the SFAN WQ dataset, NPS staff used the Kaplan-Meier statistical method (through the NPSTORET database) to create summary statistics and figures for 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 ( $\pm 0.2$  pH units,  $\pm 5\%$  for dissolved oxygen saturation, and  $\pm 5\%$  for specific conductance). If any parameter failed a post-field drift check, staff flagged all corresponding results from that entire field day as rejected.

In order to assess precision, field staff collected approximately 10% of all samples in duplicate. Additionally, staff created trip blanks (of distilled water) for turbidity and bacteria samples in order to detect any incidences of contamination. Bacteria sample trip blanks were processed at the full concentration (instead of the 10x dilution) in order to more accurately capture/measure potential contamination. Trip blanks were not collected for nutrient samples, but the contracted laboratories processed lab blanks in-house. Field blanks were not collected because no sampling equipment (e.g., splitters, churns, bag samplers, etc.) was utilized in the field; all samples were collected with the grab/hand-dip method. The contracted laboratories performed a variety of internal quality control (QC) practices (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 2015-2016, 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  $\pm 30\%$  (RPD), while the MQO for total coliform and fecal coliform is  $\pm 60\%$  (RPD). The 2006 protocol did not establish an MQO for *E. coli*; however SFAN staff subsequently set it to 60%.

SFAN staff collected a total of 264 duplicate QC samples during WYs 2015-2016, and 19% of these (49 of 264) included at least one censored result which prevented calculation of RPD/precision. Because of this limitation, Table 12 contains the mean RPD values for each parameter calculated only from those QC tests that had quantifiable RPD (i.e., those that 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 nitrate duplicate QC tests was only 3.01%. The TKN results also produced a low mean RPD (15.91%) - well below the precision MQO of 30%. The mean RPD values for the total coliform and *E. coli* QC tests were much higher (24.39% and 37.65%, respectively), but were still well below their MQO of  $\pm 60\%$ . The fecal coliform QC tests (all run by a contracted laboratory) produced the highest mean RPD (59.71%), although this mean was still below the acceptable threshold of 60%.

**Table 12.** Precision of SFAN nutrient and bacteria samples during water years 2015-2016. (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                       | 49                         | 49                             | 68                         | 68                                  | 30                         |
| Number of QC Dups with Measurable RPD <sup>a</sup>  | 25                         | 38                             | 63                         | 59                                  | 30                         |
| Number that Failed to Meet MQO for RPD <sup>a</sup> | 0                          | 5                              | 4                          | 14                                  | 16                         |
| Mean RPD <sup>a</sup> (Precision)                   | 3.01%                      | 15.91%                         | 24.39%                     | 37.65%                              | 59.71%                     |
| SFAN MQO for RPD (Precision)                        | +/- 30%                    | +/- 30%                        | +/- 60%                    | +/- 60%                             | +/- 60%                    |

<sup>a</sup> Nineteen percent of duplicate QC measurements (49 of 264) did not have measurable RPD because of a censored result; therefore, the mean RPD values and number of failures are not calculated from all duplicate QC measurements collected during WYs 2015-2016.

## Results

This report includes results collected from October 1, 2014 through September 30, 2016 (WYs 2015-2016), the ninth and tenth years of protocol implementation. Due to the two-year rotating basin design of this protocol, the WY 2015 and 2016 data represent the fifth and sixth years of monitoring this specific set of sites (nine sites in PORE, eight in PINN, seven in GOGA, and six in JOMU). 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 monitoring events at approximately the same time of day during each monthly visit, and collected at least one round of storm samples from each site in PORE, GOGA, and JOMU during each water year. Due to the scarcity of significant storms and constraints in scheduling official travel, field staff did not conduct storm sampling at the PINN sites. All storm sampling data is included in the results below (with the exception of Strentzel Creek data). Staff conducted storm sampling at the five sites in the Strentzel Creek watershed (JOMU) once during each water year (instead of monthly monitoring). These data are displayed in the summary tables, but are excluded from the figures. Some sites exhibited intermittent seasonal flow patterns and staff characterized these as “dry” or “no flow” on routine monthly visits during WYs 2015-2016. Five sites in PINN (CHA1, CHA3, MC1, SC1, and SC2), three sites in GOGA (TV1, TV2, and OAK1), and the only monthly site in JOMU (FRA1) were too low for sampling at least once during the dry seasons, so their summary statistics are computed from smaller datasets. Field staff may relocate one site in PINN, SC1, farther upstream during the next monitoring period because it was dry on all 24 monthly visits; it is yet to be determined if this was due to weather patterns or a change in hydrologic dynamics. 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 2015-2016, 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.

### 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. Field staff measure these parameters in-situ during every site visit, alongside each sample collection.

Tables 13, 14, 15, and 16 display summary statistics of all core parameter results from WYs 2015-2016, while box and whiskers plots of these data are displayed separately (sorted by parameter) for simplified viewing. The means and standard deviations presented in these tables are rounded to one more decimal place than the least precise value (fewest decimal places) of each corresponding dataset (Sullivan 2011). 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 13.** Core parameter results from Point Reyes National Seashore, water years 2015-2016. (Std. dev. = standard deviation. N of obs. = number of observations.) 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.

| Parameter               | Statistic | OLM18 | OLM1  | OLM14 | OLM6A  | OLM11 | OLM10B | PNG3  | PNG4   | PNG2  | PNG1  |
|-------------------------|-----------|-------|-------|-------|--------|-------|--------|-------|--------|-------|-------|
| Water temperature (°C)  | Minimum   | 4.1   | 6.3   | 5.6   | 5.8    | 5.7   | 5.4    | 9.8   | 10.1   | 10.4  | 10.1  |
|                         | Maximum   | 15.1  | 16.7  | 16.9  | 15.2   | 17.0  | 17.4   | 16.0  | 15.1   | 16.5  | 18.0  |
|                         | Mean      | 11.52 | 12.47 | 12.43 | 12.24  | 12.99 | 13.03  | 12.76 | 12.76  | 13.48 | 13.92 |
|                         | Median    | 11.6  | 12.3  | 12.2  | 12.2   | 12.7  | 13.2   | 13.0  | 13.3   | 13.2  | 13.8  |
|                         | Std. dev. | 2.26  | 2.35  | 2.68  | 1.96   | 2.72  | 2.96   | 1.77  | 1.60   | 2.12  | 2.28  |
|                         | N of obs. | 39    | 39    | 39    | 38     | 39    | 39     | 25    | 11     | 13    | 25    |
| Dissolved oxygen (mg/L) | Minimum   | 0.58  | 0.66  | 4.05  | 9.46   | 5.89  | 0.11   | 8.61  | 9.14   | 8.20  | 7.79  |
|                         | Maximum   | 10.13 | 10.54 | 11.08 | 12.58  | 11.00 | 10.97  | 10.86 | 10.82  | 10.20 | 11.62 |
|                         | Mean      | 7.061 | 7.484 | 9.158 | 10.410 | 8.789 | 7.241  | 9.790 | 10.030 | 9.163 | 9.236 |
|                         | Median    | 8.24  | 8.50  | 9.91  | 10.34  | 9.31  | 8.15   | 9.94  | 10.09  | 8.92  | 9.34  |
|                         | Std. dev. | 2.761 | 3.015 | 1.765 | 0.739  | 1.457 | 2.927  | 0.657 | 0.488  | 0.765 | 1.031 |
|                         | N of obs. | 34    | 34    | 34    | 33     | 34    | 34     | 21    | 11     | 9     | 20    |
| pH (pH units)           | Minimum   | 5.66  | 6.04  | 6.44  | 6.85   | 7.09  | 6.90   | 6.68  | 7.18   | 7.08  | 7.31  |
|                         | Maximum   | 7.57  | 7.47  | 7.82  | 8.30   | 7.82  | 7.78   | 7.93  | 7.87   | 7.84  | 7.84  |
|                         | Mean      | 6.571 | 6.728 | 7.103 | 7.603  | 7.477 | 7.409  | 7.615 | 7.556  | 7.669 | 7.594 |
|                         | Median    | 6.50  | 6.73  | 6.97  | 7.62   | 7.52  | 7.48   | 7.76  | 7.55   | 7.73  | 7.59  |
|                         | Std. dev. | 0.378 | 0.317 | 0.419 | 0.443  | 0.190 | 0.209  | 0.334 | 0.194  | 0.212 | 0.164 |
|                         | N of obs. | 39    | 39    | 39    | 38     | 39    | 39     | 25    | 11     | 13    | 25    |

**Table 13 (continued).** Core parameter results from Point Reyes National Seashore, water years 2015-2016. (Std. dev. = standard deviation. N of obs. = number of observations.) 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.

| Parameter                                        | Statistic | OLM18  | OLM1   | OLM14  | OLM6A  | OLM11  | OLM10B | PNG3   | PNG4   | PNG2   | PNG1   |
|--------------------------------------------------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Specific conductance ( $\mu\text{S}/\text{cm}$ ) | Minimum   | 74.4   | 70.7   | 77.7   | 217.6  | 76.1   | 84.5   | 134.1  | 141.3  | 182.7  | 118.6  |
|                                                  | Maximum   | 312.6  | 268.9  | 370.7  | 350.3  | 364.0  | 371.2  | 294.4  | 291.5  | 292.2  | 307.4  |
|                                                  | Mean      | 148.60 | 185.20 | 250.50 | 289.00 | 264.90 | 264.50 | 227.70 | 208.70 | 248.40 | 249.00 |
|                                                  | Median    | 132.0  | 166.1  | 272.7  | 294.4  | 295.7  | 294.6  | 235.0  | 215.9  | 253.4  | 259.8  |
|                                                  | Std. dev. | 49.09  | 57.57  | 84.41  | 37.62  | 75.97  | 70.41  | 38.33  | 46.36  | 32.95  | 48.00  |
|                                                  | N of obs. | 39     | 39     | 39     | 38     | 39     | 39     | 25     | 11     | 13     | 25     |
| Turbidity <sup>a</sup> (NTU)                     | Minimum   | 0.92   | 0.28   | 0.37   | 0.64   | 1.16   | 0.85   | 0.50   | 0.64   | 0.47   | 0.78   |
|                                                  | Maximum   | 87.8   | 263    | 446    | 23.1   | 602    | 293    | 585    | 113    | 3.81   | 806    |
|                                                  | Mean      | 9.30   | 11.6   | 22.7   | 3.64   | 30.1   | 18.7   | 30.3   | 15.3   | 1.324  | 42.5   |
|                                                  | Median    | 3.95   | 1.04   | 1.11   | 1.79   | 2.09   | 2.95   | 1.01   | 1.17   | 0.97   | 1.70   |
|                                                  | Std. dev. | 16.29  | 44.3   | 80.4   | 5.05   | 108.2  | 56.0   | 117.4  | 34.5   | 0.980  | 167.5  |
|                                                  | N of obs. | 39     | 39     | 39     | 38     | 39     | 39     | 25     | 11     | 13     | 23     |

<sup>a</sup> Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

**Table 14.** Core parameter results from Pinnacles National Park, water years 2015-2016. (Std. dev. = standard deviation. N of obs. = number of observations.) 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.

| Parameter                    | Statistic | BG2    | CHA3   | CHA2   | CHA1   | MC1    | SC3     | SC2     |
|------------------------------|-----------|--------|--------|--------|--------|--------|---------|---------|
| Water temperature (°C)       | Minimum   | 7.0    | 7.4    | 4.0    | 11.0   | 6.9    | 5.2     | 4.7     |
|                              | Maximum   | 17.4   | 13.9   | 16.1   | 17.4   | 18.1   | 17.9    | 15.0    |
|                              | Mean      | 12.87  | 10.77  | 12.40  | 14.81  | 14.08  | 12.73   | 10.38   |
|                              | Median    | 13.0   | 10.8   | 12.8   | 14.9   | 14.1   | 13.1    | 10.8    |
|                              | Std. dev. | 2.59   | 2.23   | 2.69   | 1.73   | 2.99   | 3.26    | 3.20    |
|                              | N of obs. | 23     | 10     | 22     | 17     | 14     | 23      | 14      |
| Dissolved oxygen (mg/L)      | Minimum   | 2.44   | 2.35   | 3.43   | 1.80   | 6.81   | 6.68    | 0.86    |
|                              | Maximum   | 9.24   | 11.04  | 10.04  | 10.01  | 11.01  | 10.57   | 3.63    |
|                              | Mean      | 5.797  | 7.184  | 7.059  | 4.326  | 8.371  | 8.460   | 2.227   |
|                              | Median    | 6.21   | 6.92   | 7.29   | 3.38   | 8.32   | 8.36    | 2.54    |
|                              | Std. dev. | 1.969  | 2.811  | 1.501  | 2.466  | 1.003  | 0.887   | 0.853   |
|                              | N of obs. | 21     | 8      | 20     | 15     | 14     | 21      | 12      |
| pH (pH units)                | Minimum   | 5.82   | 6.18   | 6.31   | 6.60   | 6.78   | 6.78    | 6.61    |
|                              | Maximum   | 7.35   | 7.38   | 7.38   | 7.20   | 7.99   | 7.98    | 7.32    |
|                              | Mean      | 6.634  | 6.708  | 6.968  | 6.866  | 7.551  | 7.368   | 6.851   |
|                              | Median    | 6.60   | 6.68   | 7.02   | 6.87   | 7.62   | 7.33    | 6.91    |
|                              | Std. dev. | 0.504  | 0.375  | 0.322  | 0.151  | 0.381  | 0.324   | 0.184   |
|                              | N of obs. | 23     | 10     | 22     | 17     | 14     | 23      | 14      |
| Specific conductance (µS/cm) | Minimum   | 123.8  | 391.9  | 283.9  | 261.6  | 203.2  | 668.0   | 1398.0  |
|                              | Maximum   | 486.3  | 451.9  | 481.0  | 592.8  | 650.0  | 1884.0  | 1808.0  |
|                              | Mean      | 294.20 | 420.90 | 404.00 | 405.30 | 388.60 | 1079.00 | 1567.00 |
|                              | Median    | 330.9  | 424.8  | 393.4  | 412.1  | 327.3  | 1047.0  | 1518.0  |
|                              | Std. dev. | 98.77  | 21.67  | 55.61  | 80.48  | 141.30 | 365.50  | 135.40  |
|                              | N of obs. | 23     | 10     | 22     | 17     | 14     | 23      | 14      |
| Turbidity <sup>a</sup> (NTU) | Minimum   | 0.64   | 0.61   | 0.31   | 0.73   | 22.9   | 1.29    | 1.11    |
|                              | Maximum   | 6.35   | 3.74   | 6.69   | 31.2   | 95.5   | 19.4    | 53.4    |
|                              | Mean      | 1.990  | 1.673  | 1.688  | 3.58   | 52.09  | 5.41    | 7.82    |

<sup>a</sup> Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

**Table 14 (continued).** Core parameter results from Pinnacles National Park, water years 2015-2016. (Std. dev. = standard deviation. N of obs. = number of observations.) 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.

| Parameter                                      | Statistic | BG2   | CHA3  | CHA2  | CHA1 | MC1   | SC3  | SC2   |
|------------------------------------------------|-----------|-------|-------|-------|------|-------|------|-------|
| Turbidity <sup>a</sup><br>(NTU)<br>(continued) | Median    | 1.37  | 1.23  | 1.31  | 1.32 | 47.6  | 2.64 | 2.35  |
|                                                | Std. dev. | 1.552 | 1.124 | 1.467 | 7.21 | 26.74 | 5.22 | 14.78 |
|                                                | N of obs. | 22    | 10    | 22    | 17   | 14    | 23   | 14    |

<sup>a</sup> Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

**Table 15.** Core parameter results from Golden Gate National Recreation Area, water years 2015-2016. (Std. dev. = standard deviation. N of obs. = number of observations.) 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.

| Parameter                  | Statistic | RC1   | GERB1 | OAK1  | NYH1  | TV1   | TV2   | TV3   |
|----------------------------|-----------|-------|-------|-------|-------|-------|-------|-------|
| Water temperature<br>(°C)  | Minimum   | 9.5   | 8.8   | 8.4   | 7.8   | 9.2   | 9.2   | 9.0   |
|                            | Maximum   | 15.2  | 15.3  | 24.2  | 17.9  | 13.0  | 15.1  | 15.9  |
|                            | Mean      | 11.94 | 12.03 | 13.44 | 13.47 | 11.66 | 12.62 | 12.85 |
|                            | Median    | 12.3  | 12.3  | 12.5  | 13.3  | 12.1  | 12.8  | 13.3  |
|                            | Std. dev. | 1.69  | 1.79  | 3.94  | 2.74  | 1.22  | 1.63  | 1.64  |
|                            | N of obs. | 25    | 25    | 17    | 25    | 9     | 14    | 25    |
| Dissolved oxygen<br>(mg/L) | Minimum   | 5.40  | 6.35  | 5.01  | 4.49  | 9.16  | 0.60  | 3.62  |
|                            | Maximum   | 12.03 | 10.34 | 10.46 | 10.69 | 10.32 | 9.50  | 10.27 |
|                            | Mean      | 8.434 | 8.804 | 8.742 | 7.764 | 9.901 | 5.961 | 7.682 |
|                            | Median    | 8.55  | 8.97  | 8.92  | 7.44  | 10.04 | 7.07  | 8.52  |
|                            | Std. dev. | 1.719 | 1.243 | 1.492 | 2.050 | 0.360 | 2.961 | 2.198 |
|                            | N of obs. | 25    | 25    | 17    | 25    | 9     | 14    | 25    |
| pH<br>(pH units)           | Minimum   | 6.39  | 6.50  | 6.89  | 6.60  | 7.12  | 6.64  | 6.57  |
|                            | Maximum   | 8.65  | 8.45  | 7.77  | 7.71  | 7.98  | 7.96  | 8.19  |
|                            | Mean      | 7.474 | 7.508 | 7.387 | 7.264 | 7.596 | 7.350 | 7.381 |
|                            | Median    | 7.38  | 7.43  | 7.47  | 7.38  | 7.70  | 7.50  | 7.15  |
|                            | Std. dev. | 0.738 | 0.574 | 0.280 | 0.301 | 0.311 | 0.406 | 0.493 |
|                            | N of obs. | 25    | 25    | 17    | 25    | 9     | 14    | 25    |

<sup>a</sup> Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

**Table 15 (continued).** Core parameter results from Golden Gate National Recreation Area, water years 2015-2016. (Std. dev. = standard deviation. N of obs. = number of observations.) 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.

| Parameter                    | Statistic | RC1    | GERB1  | OAK1   | NYH1   | TV1    | TV2    | TV3    |
|------------------------------|-----------|--------|--------|--------|--------|--------|--------|--------|
| Specific conductance (µS/cm) | Minimum   | 169.8  | 139.8  | 170.1  | 198.7  | 113.3  | 130.1  | 130.9  |
|                              | Maximum   | 295.9  | 228.4  | 545.0  | 561.6  | 131.1  | 560.1  | 373.6  |
|                              | Mean      | 228.90 | 175.50 | 288.70 | 415.00 | 121.10 | 216.40 | 220.50 |
|                              | Median    | 229.8  | 170.6  | 280.2  | 467.9  | 119.3  | 163.9  | 200.2  |
|                              | Std. dev. | 34.56  | 24.00  | 106.30 | 115.00 | 5.85   | 121.90 | 56.54  |
|                              | N of obs. | 25     | 25     | 17     | 25     | 9      | 14     | 25     |
| Turbidity <sup>1</sup> (NTU) | Minimum   | 3.93   | 3.64   | 0.85   | 1.03   | 7.04   | 5.08   | 2.08   |
|                              | Maximum   | 142    | 116    | 148    | 71.6   | 120    | 98.1   | 132    |
|                              | Mean      | 19.6   | 18.4   | 26.1   | 12.13  | 31.2   | 22.66  | 19.3   |
|                              | Median    | 9.20   | 10.1   | 4.37   | 1.98   | 9.25   | 11.1   | 8.65   |
|                              | Std. dev. | 28.9   | 23.9   | 40.1   | 22.00  | 39.9   | 28.21  | 29.7   |
|                              | N of obs. | 25     | 25     | 17     | 25     | 9      | 14     | 25     |

<sup>a</sup> Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

**Table 16.** Core parameter results from John Muir National Historic Site, water years 2015-2016. (Std. dev. = standard deviation. N of obs. = number of observations.) 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.

| Parameter               | Statistic | FRA1   | STR1  | STR2  | STR3  | STR4  | STR5  |
|-------------------------|-----------|--------|-------|-------|-------|-------|-------|
| Water temperature (°C)  | Minimum   | 9.7    | 12.3  | 11.7  | 11.3  | 11.3  | 11.1  |
|                         | Maximum   | 17.1   | 12.9  | 11.9  | 11.5  | 11.5  | 11.1  |
|                         | Mean      | 12.96  | 12.60 | 11.80 | 11.40 | 11.40 | 11.10 |
|                         | Median    | 12.8   | —     | —     | —     | —     | —     |
|                         | Std. dev. | 2.02   | 0.42  | 0.14  | 0.14  | 0.14  | —     |
|                         | N of obs. | 14     | 2     | 2     | 2     | 2     | 1     |
| Dissolved oxygen (mg/L) | Minimum   | 5.17   | 7.98  | 8.34  | 9.30  | 9.02  | 8.74  |
|                         | Maximum   | 13.15  | 8.43  | 8.67  | 9.97  | 9.41  | 8.74  |
|                         | Mean      | 10.070 | 8.205 | 8.505 | 9.635 | 9.215 | 8.740 |
|                         | Median    | 10.27  | —     | —     | —     | —     | —     |

<sup>a</sup> Values under 1.00 NTU are reported with two significant figures, and values of 1.00 and above are reported with three.

**Table 16 (continued).** Core parameter results from John Muir National Historic Site, water years 2015-2016. (Std. dev. = standard deviation. N of obs. = number of observations.) 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.

| Parameter                    | Statistic | FRA1    | STR1   | STR2   | STR3   | STR4   | STR5   |
|------------------------------|-----------|---------|--------|--------|--------|--------|--------|
| Dissolved oxygen (mg/L)      | Std. dev. | 1.769   | 0.318  | 0.233  | 0.474  | 0.276  | –      |
|                              | N of obs. | 14      | 2      | 2      | 2      | 2      | 1      |
| pH (pH units)                | Minimum   | 6.41    | 7.46   | 7.33   | 7.32   | 6.94   | 7.66   |
|                              | Maximum   | 8.16    | 7.80   | 7.89   | 7.95   | 7.75   | 7.66   |
|                              | Mean      | 7.472   | 7.630  | 7.610  | 7.635  | 7.345  | 7.660  |
|                              | Median    | 7.72    | –      | –      | –      | –      | –      |
|                              | Std. dev. | 0.535   | 0.240  | 0.396  | 0.446  | 0.573  | –      |
|                              | N of obs. | 14      | 2      | 2      | 2      | 2      | 1      |
| Specific conductance (µS/cm) | Minimum   | 502.5   | 260.6  | 258.4  | 181.2  | 224.5  | 207.8  |
|                              | Maximum   | 1521.0  | 374.3  | 369.1  | 194.3  | 279.6  | 207.8  |
|                              | Mean      | 1191.00 | 317.50 | 313.80 | 187.80 | 252.00 | 207.80 |
|                              | Median    | 1289.0  | –      | –      | –      | –      | –      |
|                              | Std. dev. | 341.10  | 80.40  | 78.28  | 9.26   | 38.96  | –      |
|                              | N of obs. | 14      | 2      | 2      | 2      | 2      | 1      |
| Turbidity <sup>a</sup> (NTU) | Minimum   | 0.74    | 21.6   | 42.2   | 66.2   | 55.6   | 189    |
|                              | Maximum   | >1000   | 25.5   | 45.7   | 673    | 200    | 189    |
|                              | Mean      | 32.8    | 23.55  | 43.95  | 369.6  | 127.8  | 189.0  |
|                              | Median    | 1.77    | –      | –      | –      | –      | –      |
|                              | Std. dev. | 66.6    | 2.76   | 2.48   | 429.1  | 102.1  | –      |
|                              | N of obs. | 14      | 2      | 2      | 2      | 2      | 0      |

<sup>a</sup> 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 sometimes refer to 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. However, this is not utilized as an ecological objective, since salmonids do not live in all SFAN watersheds. Water temperature results are summarized below, sorted by NPS unit (Figures 6-9).

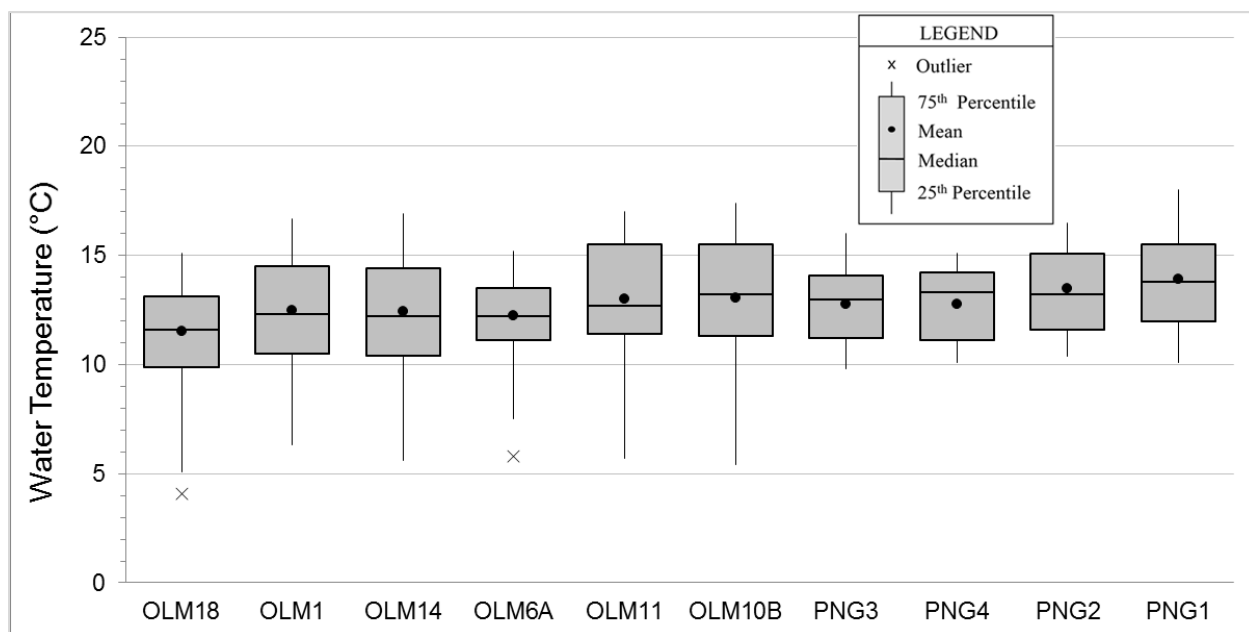


**Figure 6.** Water temperature results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

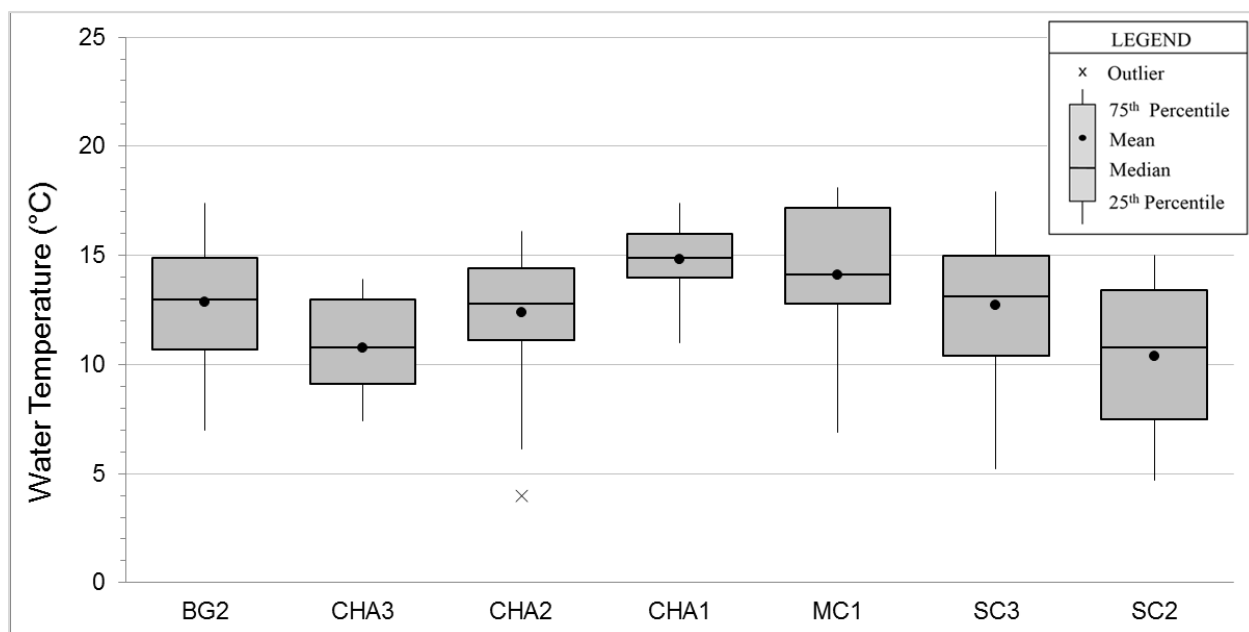


**Figure 7.** Water temperature results from Pinnacles National Park, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

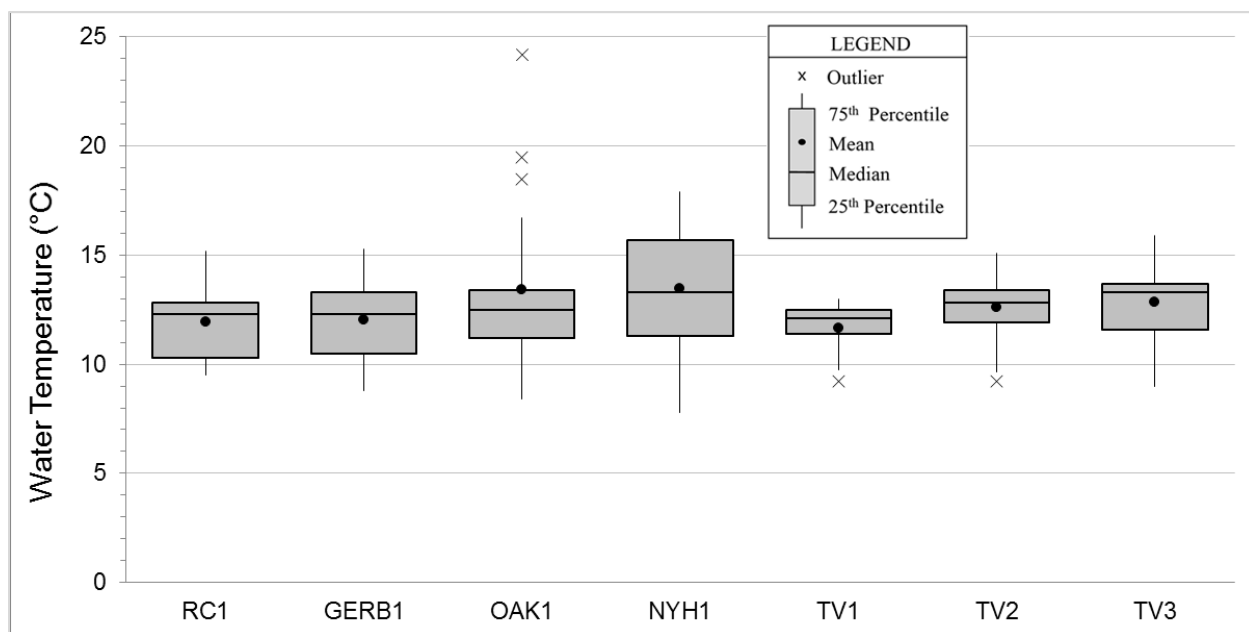


**Figure 8.** Water temperature results from Golden Gate National Recreation Area, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range.

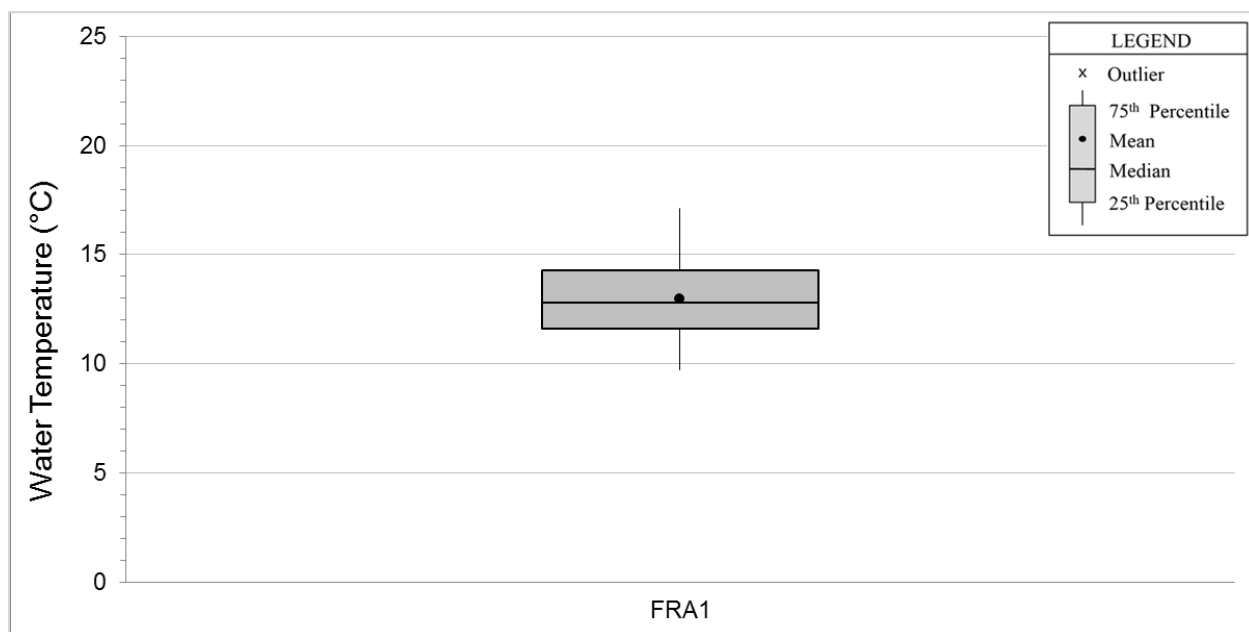


**Figure 9.** Water temperature results from John Muir National Historic Site, water years 2015-2016. This boxplot presents the interquartile range of the dataset, and whiskers are drawn to 1.5 times the interquartile range.

### ***Dissolved Oxygen***

The San Francisco Bay RWQCB established a dissolved oxygen minimum of 7 mg/L, which applies to PORE, GOGA, and JOMU. This threshold is particularly important to the Pine Gulch and Olema

Creek watershed sites in PORE, because they support salmonid populations. A dissolved oxygen minimum of 5 mg/L (established by the Central Coast RWQCB) applies to the eight PINN sites. Dissolved oxygen results are summarized below, sorted by NPS unit (Figures 10-13).

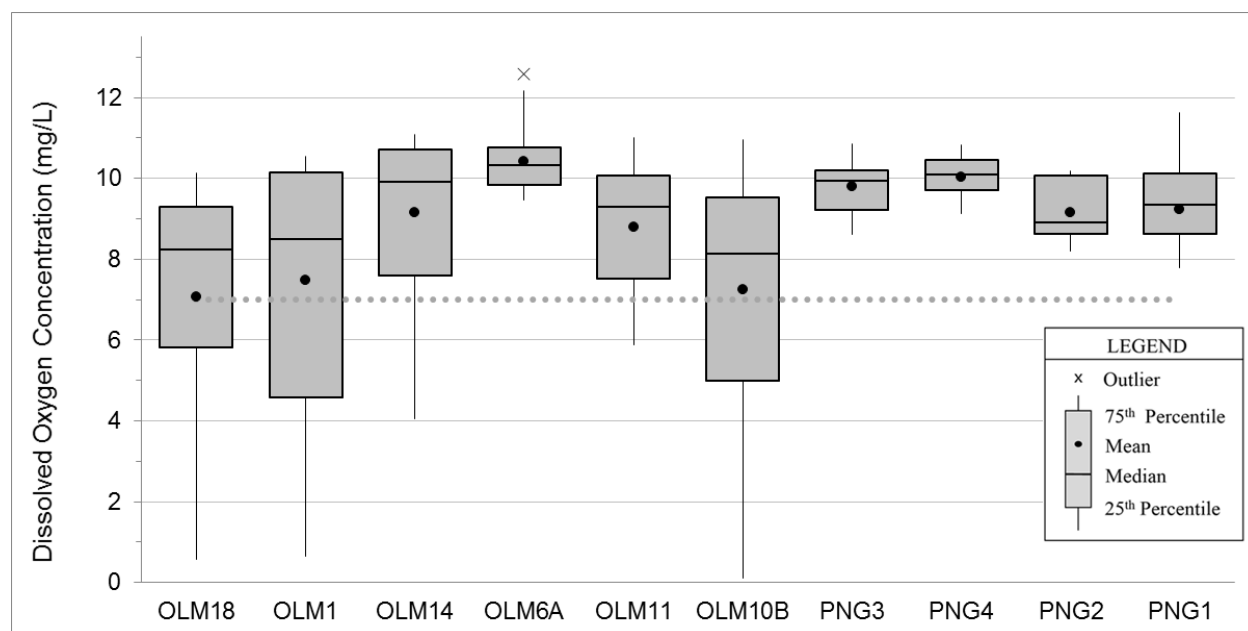


**Figure 10.** Dissolved oxygen results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the minimum objective of 7 mg/L.

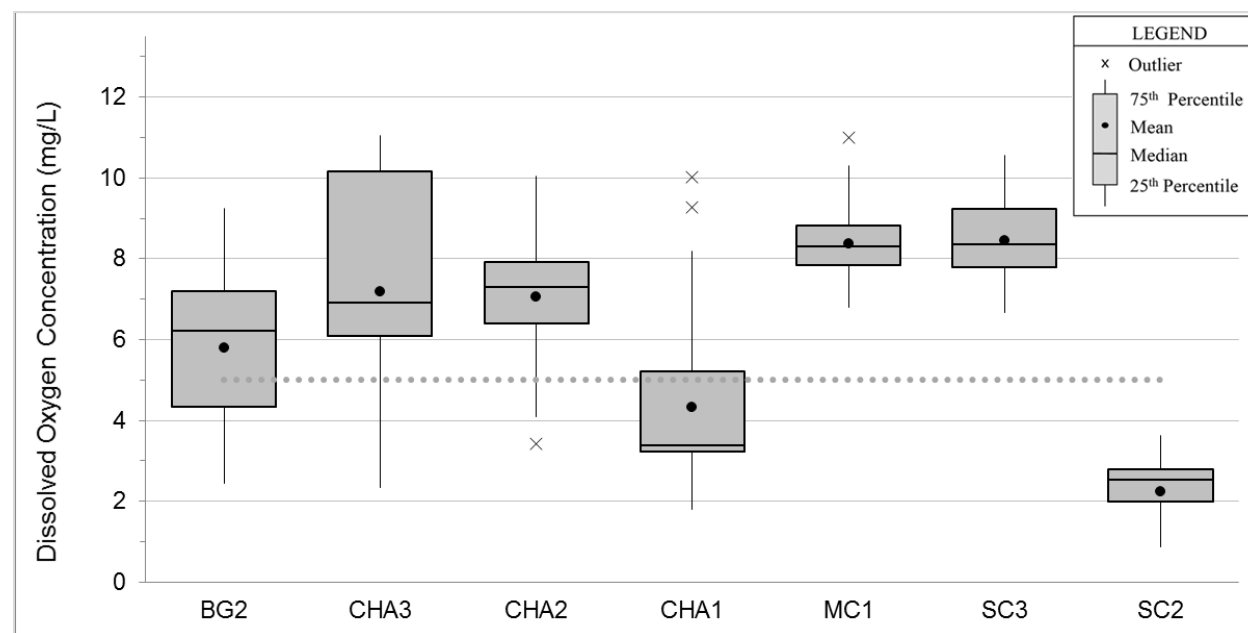


**Figure 11.** Dissolved oxygen results from Pinnacles National Park, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the minimum objective of 5 mg/L.

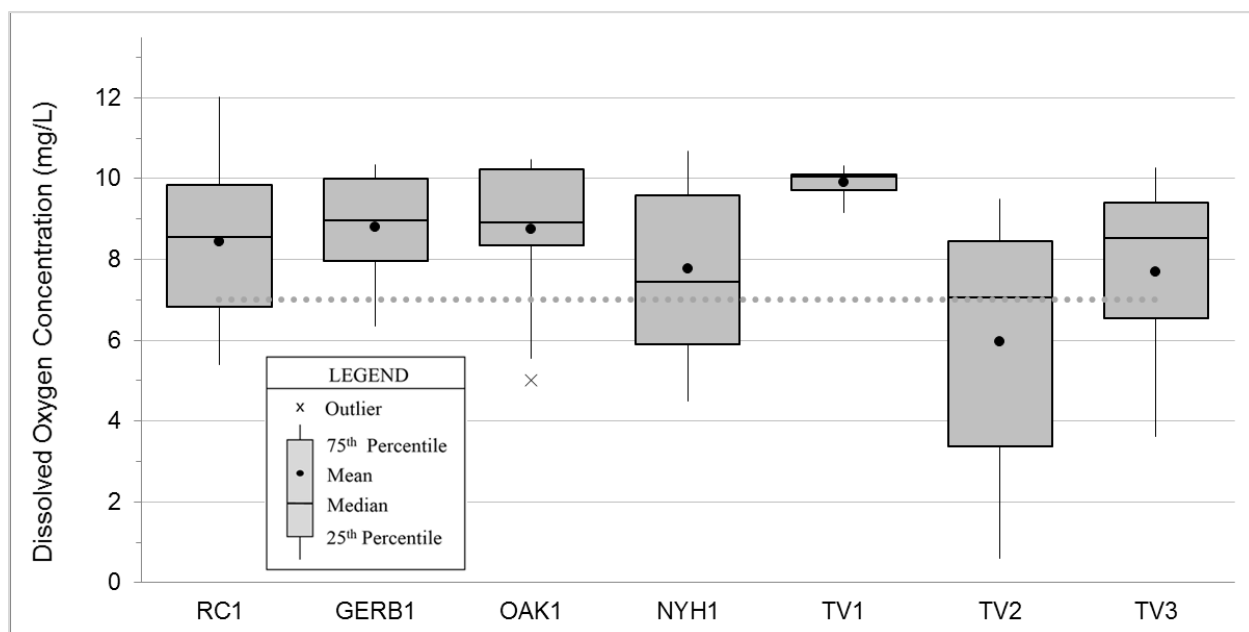


**Figure 12.** Dissolved oxygen results from Golden Gate National Recreation Area, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the minimum objective of 7 mg/L.

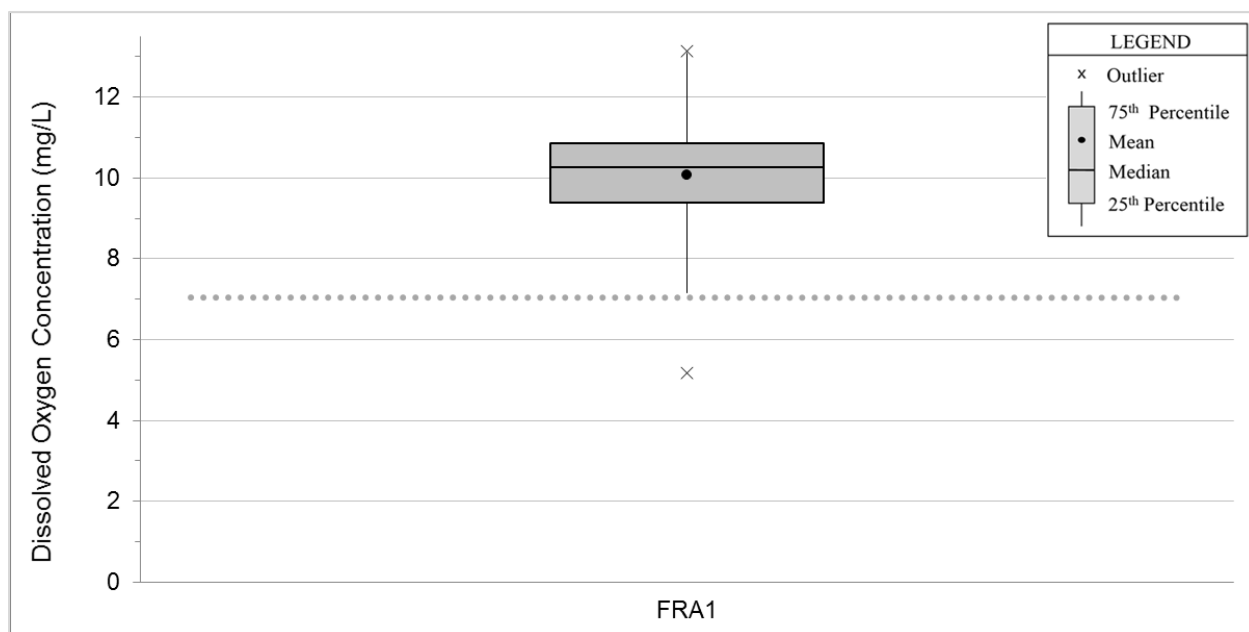


**Figure 13.** Dissolved oxygen results from John Muir National Historic Site, water years 2015-2016. This boxplot presents the interquartile range of the dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the minimum objective of 7 mg/L.

### pH

The pH water quality objective for surface waters is an optimal range of 7 to 8.5 pH units for PINN, and 6.5 to 8.5 pH units for PORE, GOGA, and JOMU; these are based on the conditions necessary to

support aquatic life (CA RWQCB 2010). The SFAN pH results are summarized below, sorted by NPS unit (Figures 14-17). Means are not displayed in these four figures; it is mathematically unacceptable to calculate arithmetic means from pH values because they are on a logarithmic scale.

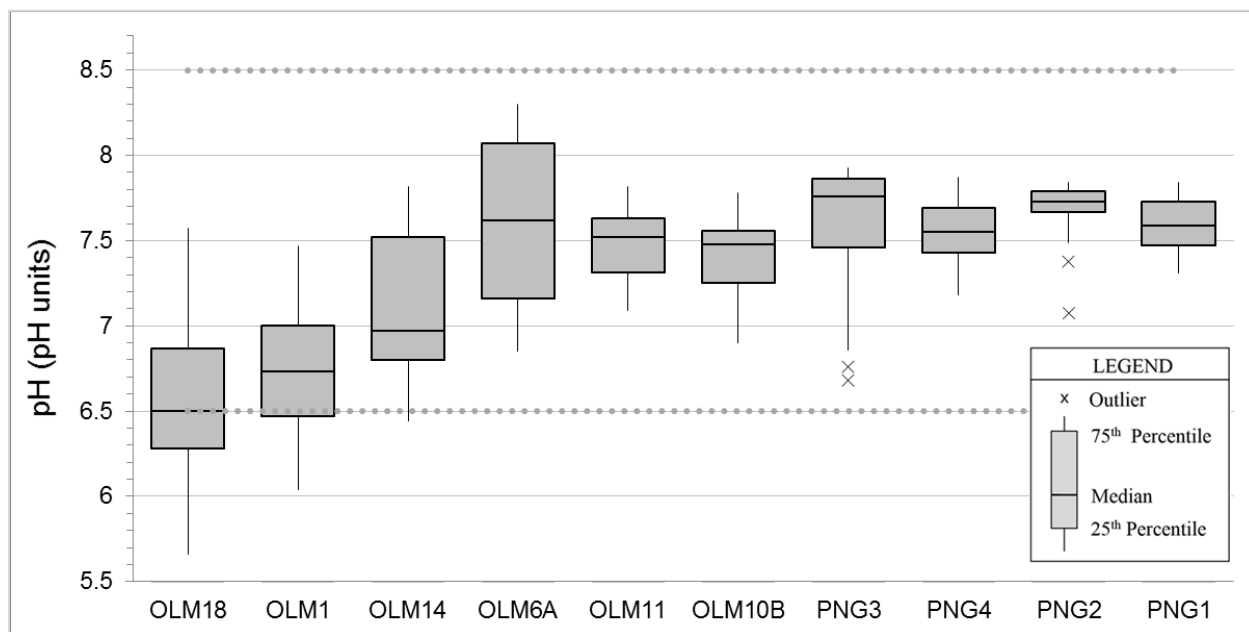


**Figure 14.** pH results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted lines represent the objective range of 6.5 to 8.5 pH units.

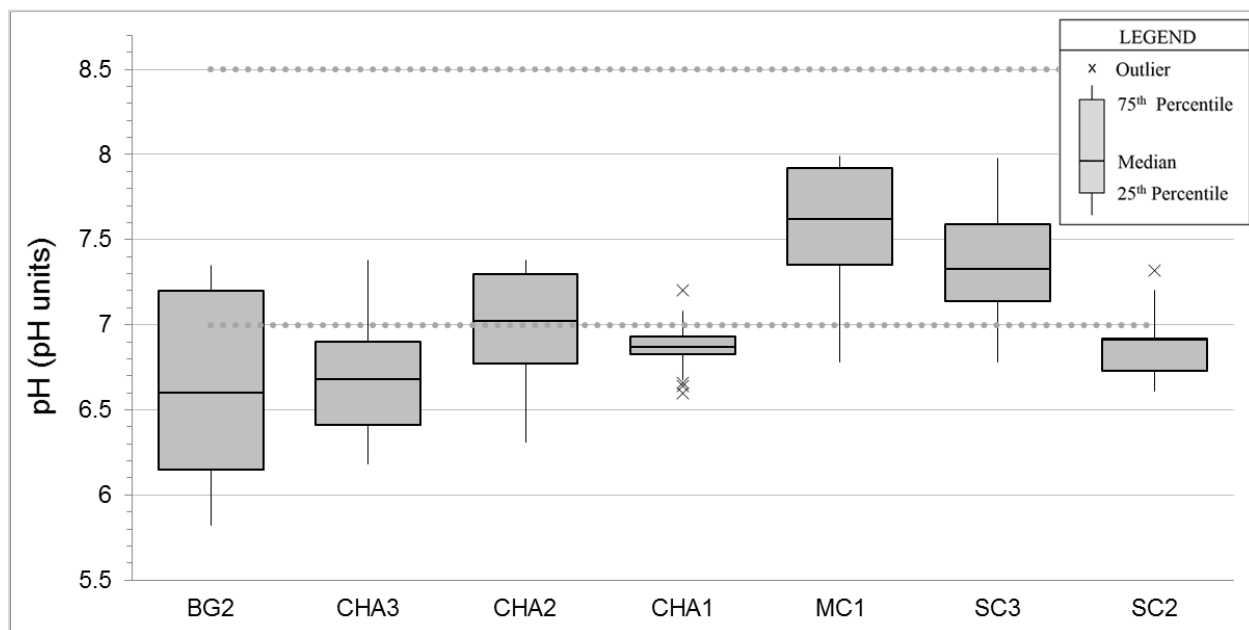


**Figure 15.** pH results from Pinnacles National Park, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted lines represent the objective range of 7 to 8.5 pH units.

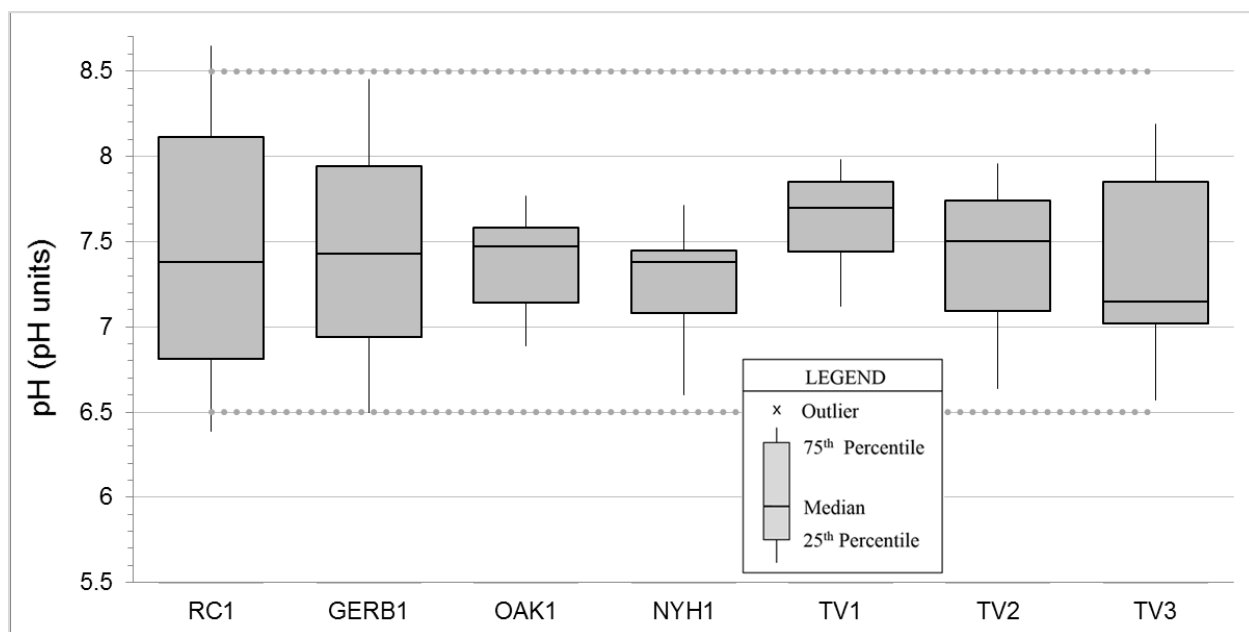


**Figure 16.** pH results from Golden Gate National Recreation Area, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted lines represent the objective range of 6.5 to 8.5 pH units.

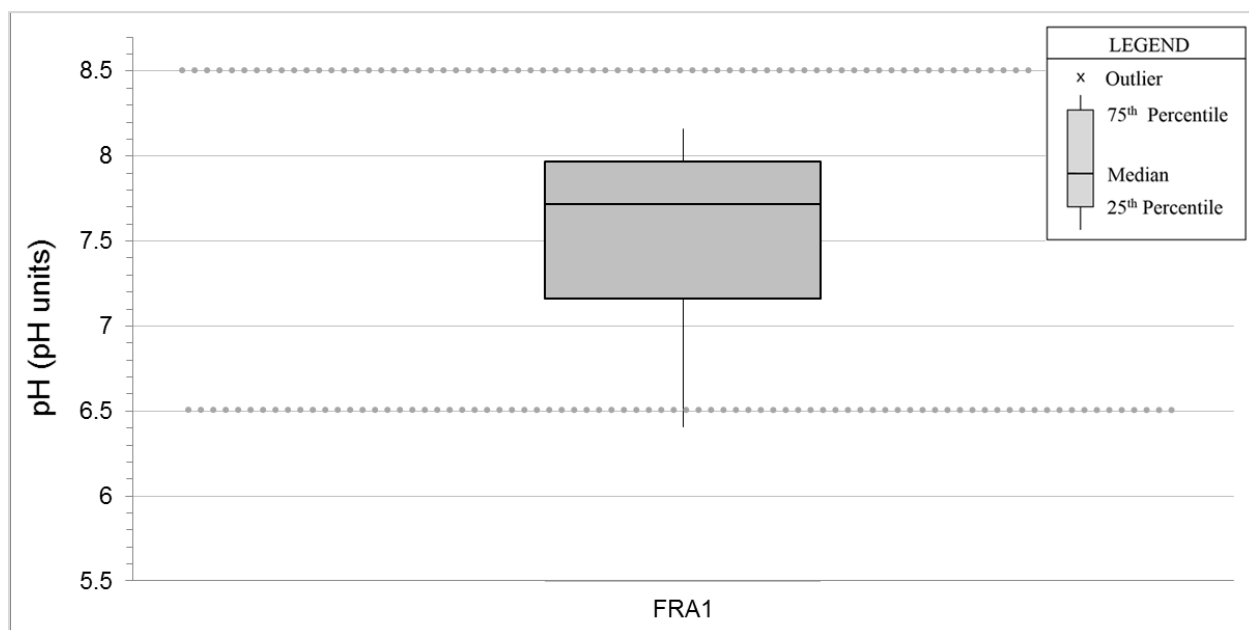


**Figure 17.** pH results from John Muir National Historic Site, water years 2015-2016. This boxplot presents the interquartile range of the dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted lines represent the objective range of 6.5 to 8.5 pH units.

### **Specific Conductance**

Conductivity (the ability of a solution to conduct an electrical current) is an indicator of the presence of dissolved solids. It 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 in the units of microSiemens per centimeter ( $\mu\text{S}/\text{cm}$ ). 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). Specific conductance results are summarized below, sorted by NPS unit (Figures 18-21).

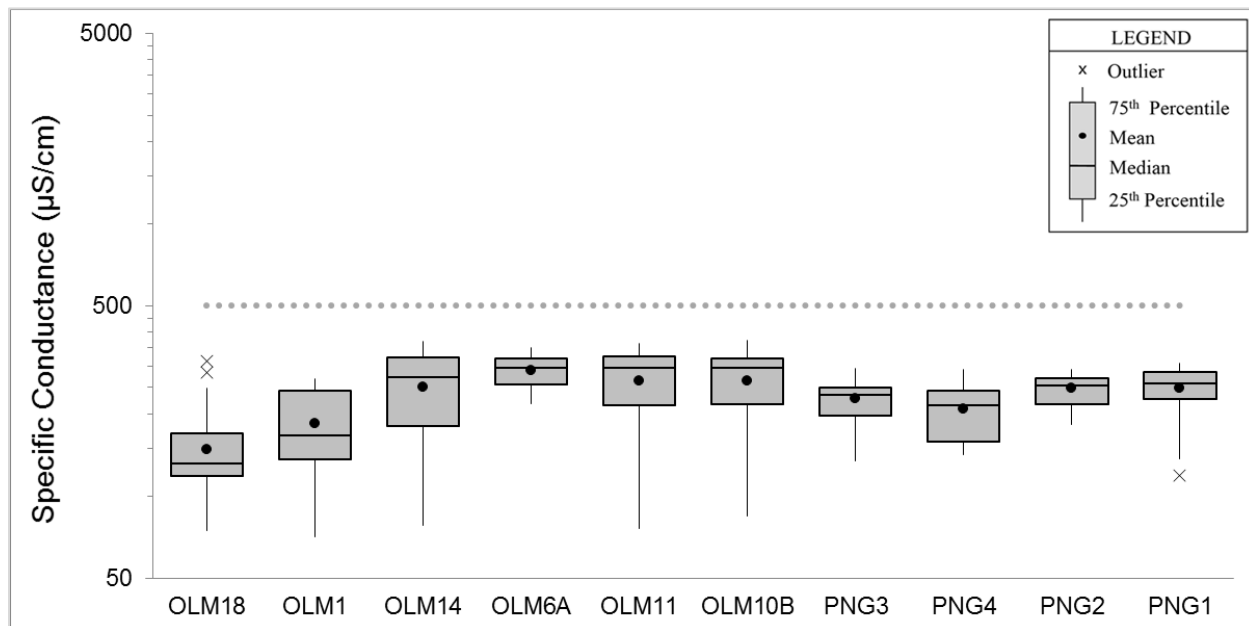


**Figure 18.** Specific conductance results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the ecological objective maximum of 500  $\mu\text{S}/\text{cm}$ .

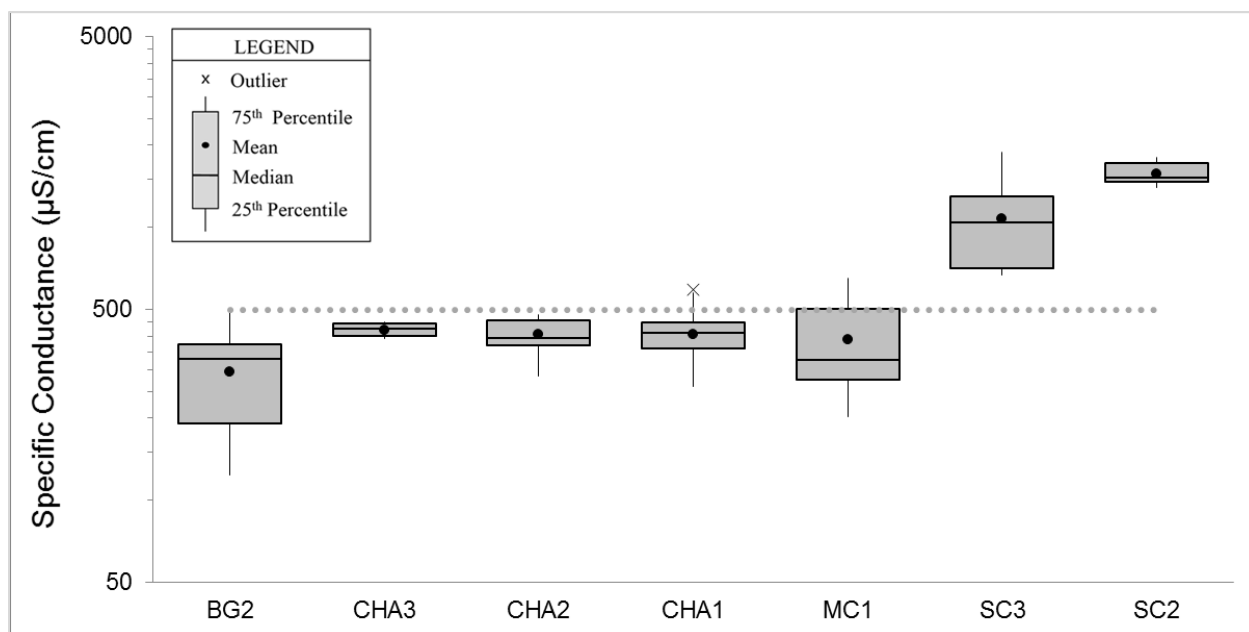


**Figure 19.** Specific conductance results from Pinnacles National Park, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the ecological objective maximum of 500 µS/cm.

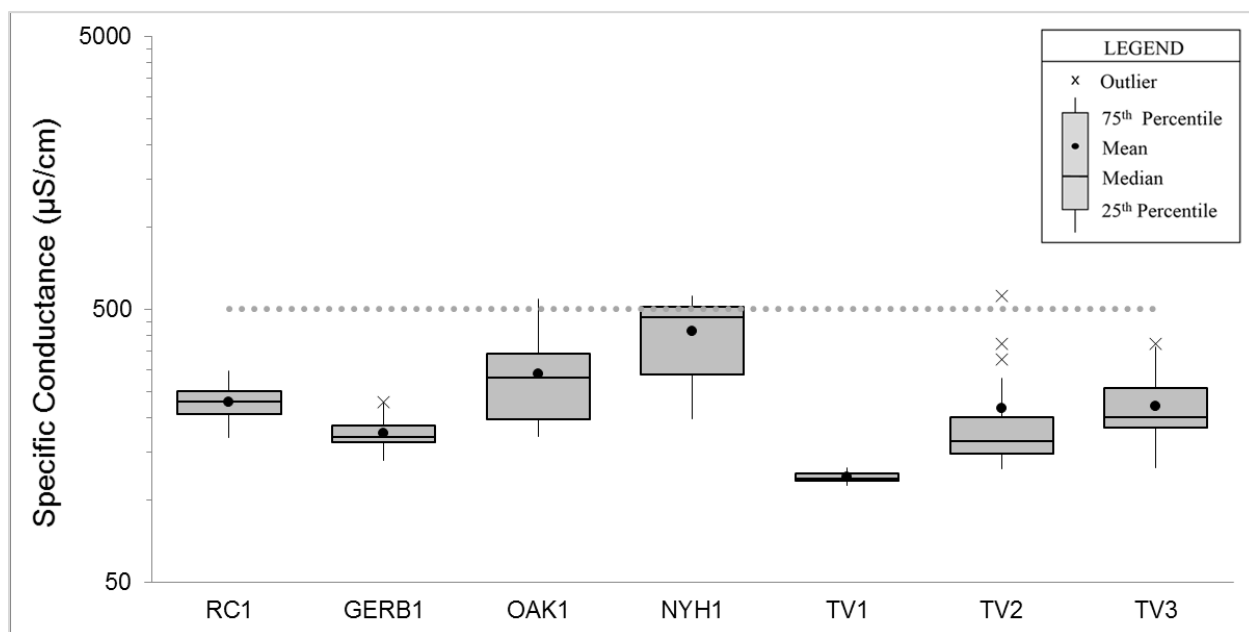


**Figure 20.** Specific conductance results from Golden Gate National Recreation Area, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the ecological objective maximum of 500 µS/cm.

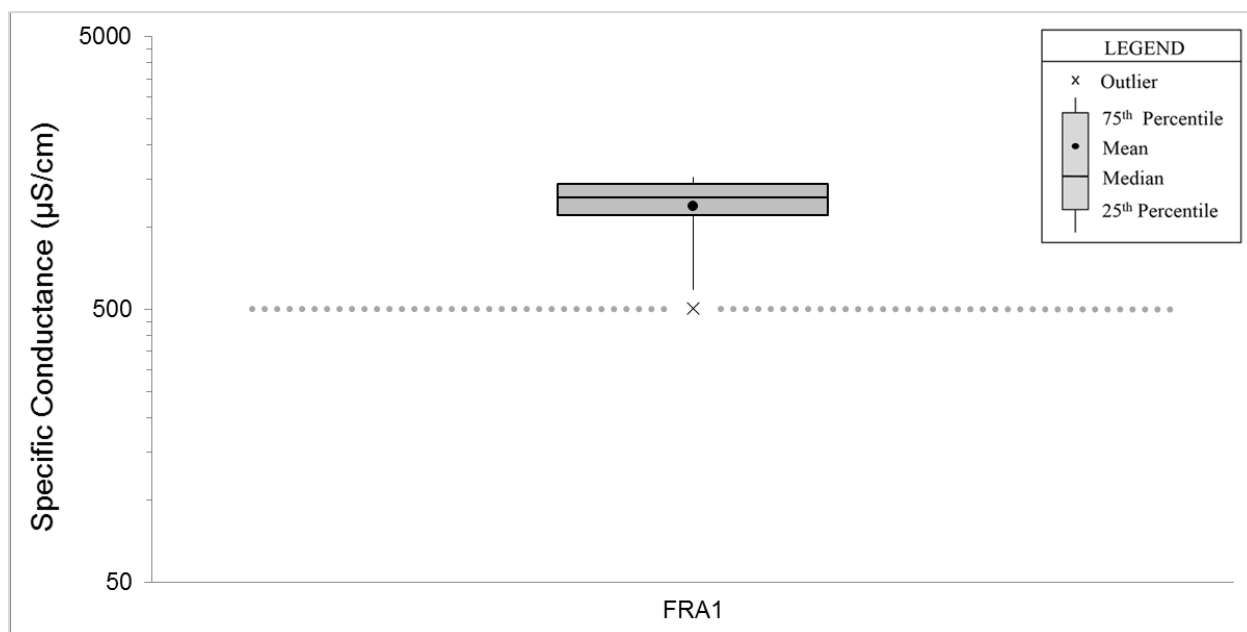


**Figure 21.** Specific conductance results from John Muir National Historic Site, water years 2015-2016. This boxplot presents the interquartile range of the dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the ecological objective maximum of 500 µS/cm.

### ***Turbidity***

Turbidity is the capacity of suspended sediment in water to scatter light (American Public Health Association et al. 1998). Suspended sediment can include clay, silt, fine organic and inorganic matter, and microscopic organisms. 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. It is often not the peak turbidity levels that cause 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. Turbidity results are summarized below, sorted by NPS unit (Figures 22-25).

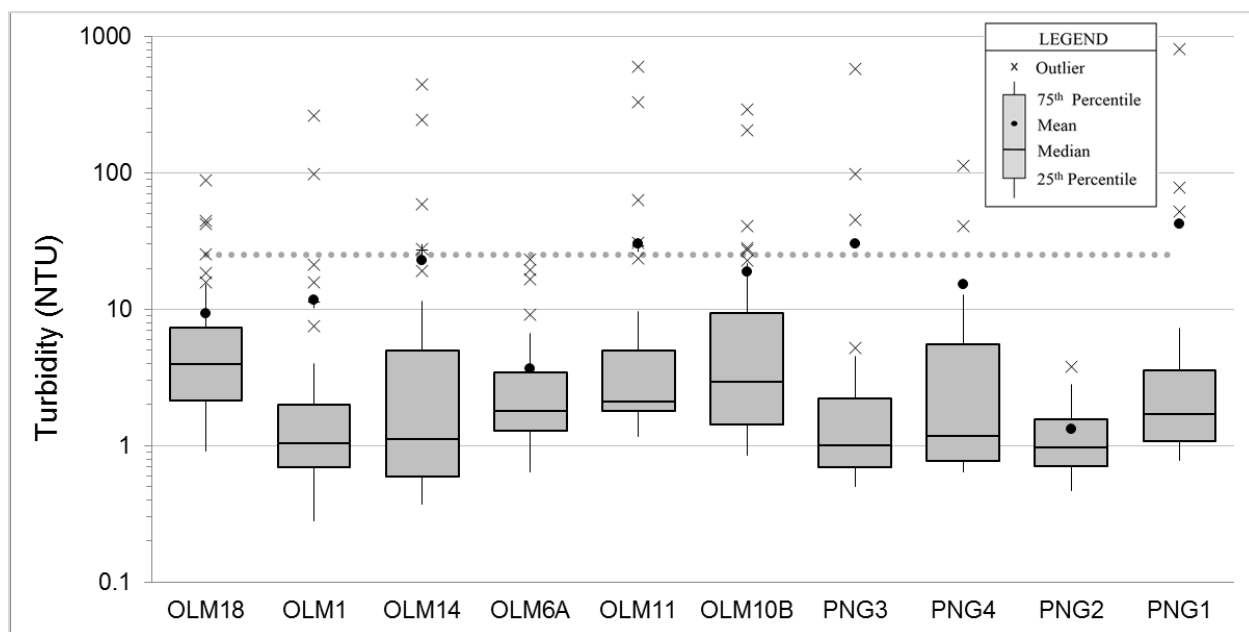


**Figure 22.** Turbidity results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the ecological objective maximum of 25 NTU.

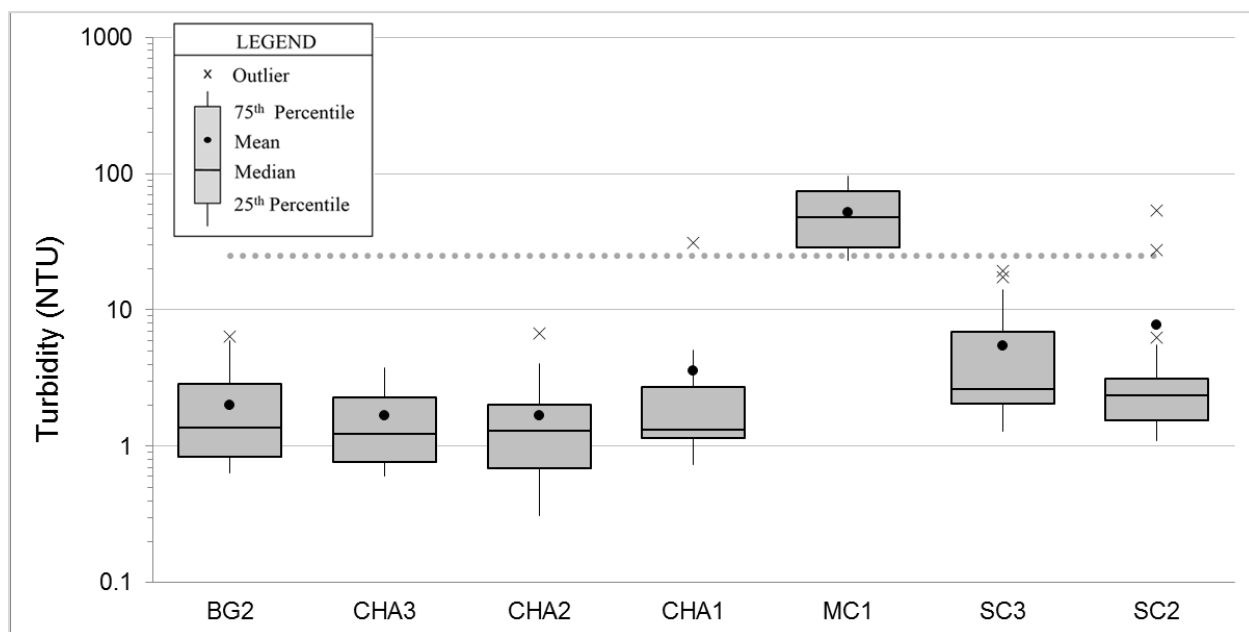


**Figure 23.** Turbidity results from Pinnacles National Park, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the ecological objective maximum of 25 NTU.

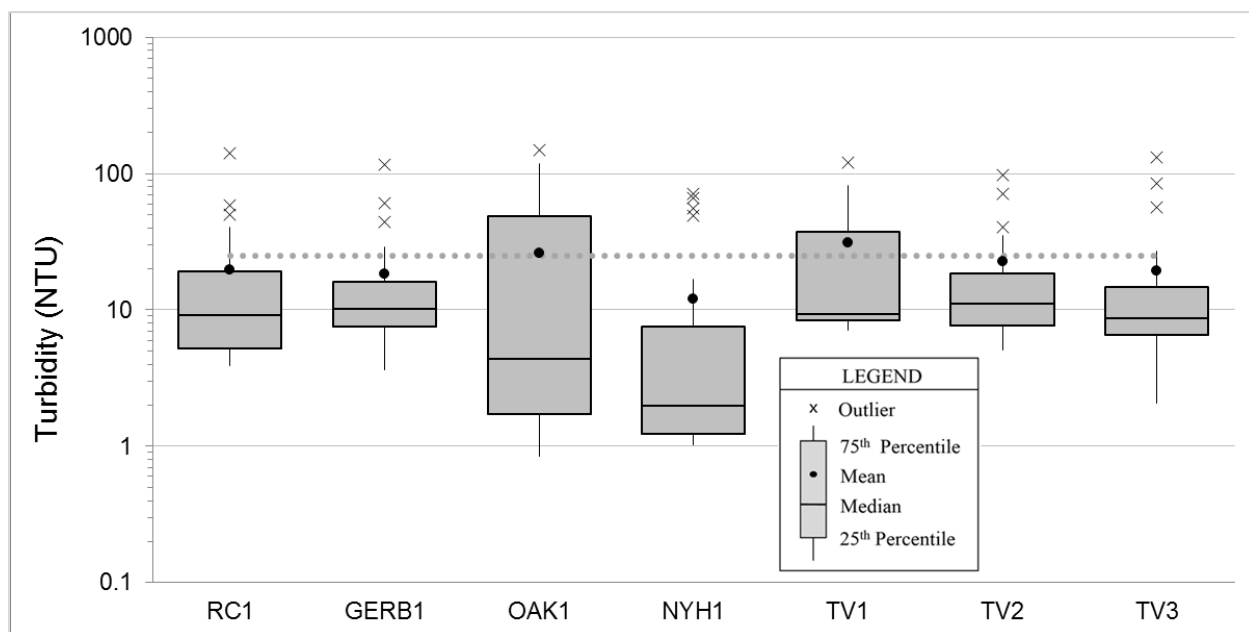


**Figure 24.** Turbidity results from Golden Gate National Recreation Area, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the ecological objective maximum of 25 NTU.

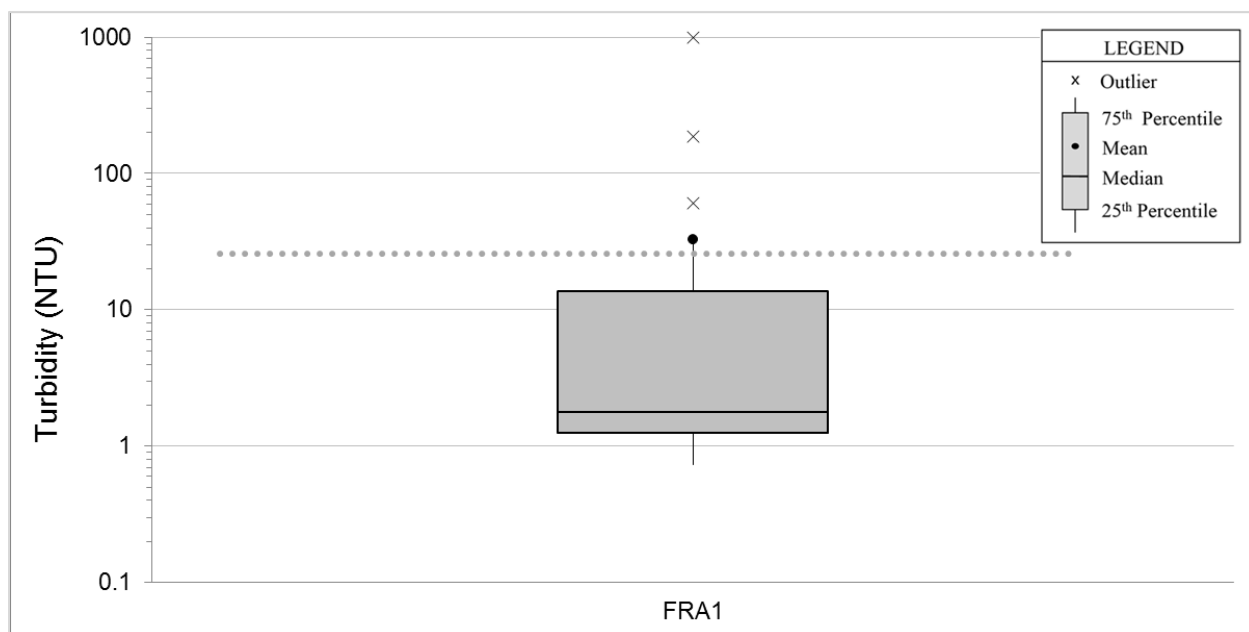


**Figure 25.** Turbidity results from John Muir National Historic Site, water years 2015-2016. This boxplot presents the interquartile range of the dataset, and whiskers are drawn to 1.5 times the interquartile range. The dotted line represents the ecological objective maximum of 25 NTU.

## 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 2015-2016, field staff sampled nitrate (as N) and TKN on a monthly basis (and during storms) at 18 primary SFAN water quality sites. Out of the 30 SFAN sites monitored during WYs 2015-2016, five are only monitored during storms (sites STR1 through STR5) and seven are secondary sites. Because they are secondary stations, we did not conduct nutrient sampling at CHA3/SC1/SC2/SC3 in PINN or TV1/NYH1/OAK1 in GOGA.

Tables 17 and 18 present summary statistics of all nutrient data collected during WYs 2015-2016, while box and whiskers plots of these data are displayed separately, sorted by parameter, for simplified viewing. The means and standard deviations presented in these tables are rounded to one more decimal place than the least precise value (fewest decimal places) of each corresponding dataset (Sullivan 2011). 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. 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 17.** Nutrient results from Point Reyes National Seashore, water years 2015-2016. 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 | PNG3  | PNG4  | PNG2  | PNG1  |
|--------------------------------|----------------------------------|----------------|-------|-------|-------|-------|--------|-------|-------|-------|-------|
| Nitrate as nitrogen (mg/L)     | Minimum                          | <0.15          | <0.15 | <0.15 | 0.17  | <0.15 | <0.15  | 0.21  | 0.19  | 0.18  | <0.15 |
|                                | Maximum                          | 1.1            | 2.2   | 1.7   | 1.8   | 2.0   | 2.1    | 1.6   | 0.84  | 0.44  | 1.2   |
|                                | Mean                             | — <sup>b</sup> | 0.36  | 0.39  | 0.44  | 0.40  | 0.37   | 0.46  | 0.390 | 0.254 | 0.35  |
|                                | Median                           | — <sup>b</sup> | <0.15 | 0.25  | 0.29  | 0.21  | 0.17   | 0.31  | 0.34  | 0.23  | 0.24  |
|                                | Std. dev.                        | — <sup>b</sup> | 0.53  | 0.43  | 0.43  | 0.47  | 0.53   | 0.34  | 0.198 | 0.082 | 0.28  |
|                                | # NDs/<br># Results <sup>a</sup> | 19/26          | 18/26 | 1/26  | 0/26  | 11/26 | 12/26  | 0/25  | 0/11  | 0/13  | 5/25  |
| Total Kjeldahl nitrogen (mg/L) | Minimum                          | <0.25          | <0.25 | <0.25 | <0.25 | <0.25 | <0.25  | <0.25 | <0.25 | <0.25 | <0.25 |
|                                | Maximum                          | 1.6            | 0.68  | 1.6   | 1.0   | 1.7   | 1.2    | 2.5   | 1.2   | 0.68  | 3.7   |
|                                | Mean                             | 0.54           | 0.334 | 0.48  | 0.36  | 0.47  | 0.46   | 0.49  | 0.39  | 0.379 | 0.52  |
|                                | Median                           | 0.42           | 0.28  | 0.30  | 0.30  | 0.35  | 0.42   | 0.27  | 0.26  | 0.37  | 0.29  |
|                                | Std. dev.                        | 0.34           | 0.120 | 0.40  | 0.19  | 0.34  | 0.21   | 0.52  | 0.29  | 0.136 | 0.70  |
|                                | # NDs/<br># Results <sup>a</sup> | 3/26           | 8/26  | 9/26  | 8/26  | 6/26  | 2/26   | 10/25 | 4/11  | 2/13  | 6/25  |

<sup>a</sup> 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.

<sup>b</sup> Calculation prevented due to a high percentage of censoring.

**Table 18.** Nutrient results from Pinnacles National Park (PINN), Golden Gate National Recreation Area (GOGA), and John Muir National Historic Site (JOMU) during water years 2015-2016. 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                        | PINN           |                |                |       |                | GOGA           |       |                | JOMU  |
|--------------------------------|----------------------------------|----------------|----------------|----------------|-------|----------------|----------------|-------|----------------|-------|
|                                |                                  | BG2            | CHA2           | CHA1           | MC1   | RC1            | GERB1          | TV2   | TV3            | FRA1  |
| Nitrate as nitrogen (mg/L)     | Minimum                          | <0.15          | <0.15          | <0.15          | <0.15 | <0.15          | <0.15          | <0.15 | <0.15          | 0.32  |
|                                | Maximum                          | 1.6            | 1.4            | 0.7            | 0.51  | 0.70           | 0.35           | 0.42  | 0.48           | 2.5   |
|                                | Mean                             | — <sup>b</sup> | — <sup>b</sup> | — <sup>b</sup> | 0.232 | — <sup>b</sup> | — <sup>b</sup> | 0.198 | — <sup>b</sup> | 1.03  |
|                                | Median                           | — <sup>b</sup> | — <sup>b</sup> | — <sup>b</sup> | 0.19  | — <sup>b</sup> | — <sup>b</sup> | <0.15 | — <sup>b</sup> | 0.80  |
|                                | Std. dev.                        | — <sup>b</sup> | — <sup>b</sup> | — <sup>b</sup> | 0.109 | — <sup>b</sup> | — <sup>b</sup> | 0.085 | — <sup>b</sup> | 0.54  |
|                                | # NDs/<br># Results <sup>a</sup> | 18/23          | 16/22          | 15/17          | 5/14  | 18/25          | 19/25          | 9/14  | 21/25          | 0/14  |
| Total Kjeldahl nitrogen (mg/L) | Minimum                          | <0.25          | 0.25           | <0.25          | 0.54  | <0.25          | <0.25          | <0.25 | <0.25          | <0.25 |
|                                | Maximum                          | 1.1            | 0.91           | 0.90           | 3.1   | 1.6            | 1.6            | 1.6   | 1.4            | 4.2   |
|                                | Mean                             | 0.45           | 0.478          | 0.447          | 1.62  | 0.48           | 0.51           | 0.68  | 0.49           | 0.98  |
|                                | Median                           | 0.39           | 0.41           | 0.36           | 1.6   | 0.39           | 0.43           | 0.53  | 0.39           | 0.43  |
|                                | Std. dev.                        | 0.20           | 0.203          | 0.207          | 0.90  | 0.28           | 0.28           | 0.41  | 0.27           | 1.16  |
|                                | # NDs/<br># Results <sup>a</sup> | 1/23           | 0/22           | 1/17           | 0/14  | 2/25           | 1/25           | 1/14  | 2/25           | 1/14  |

<sup>a</sup> 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.

<sup>b</sup> Calculation prevented due to a high percentage of censoring.

### 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 of 0.16 mg/L (EPA 2000). Additionally, Crunkilton (2000) found that a level of 1.1 mg/L nitrate (as N) can be toxic to aquatic life, especially fish and amphibian eggs. For this report, SFAN nitrate results are compared to the ecological threshold of 1.1 mg/L nitrate (as N). The RDL for all nitrate (as N) samples processed during WYs 2015-2016, was 0.15 mg/L (utilizing EPA Method 300). Nitrate results are summarized below, sorted by NPS unit (Figures 26-27).

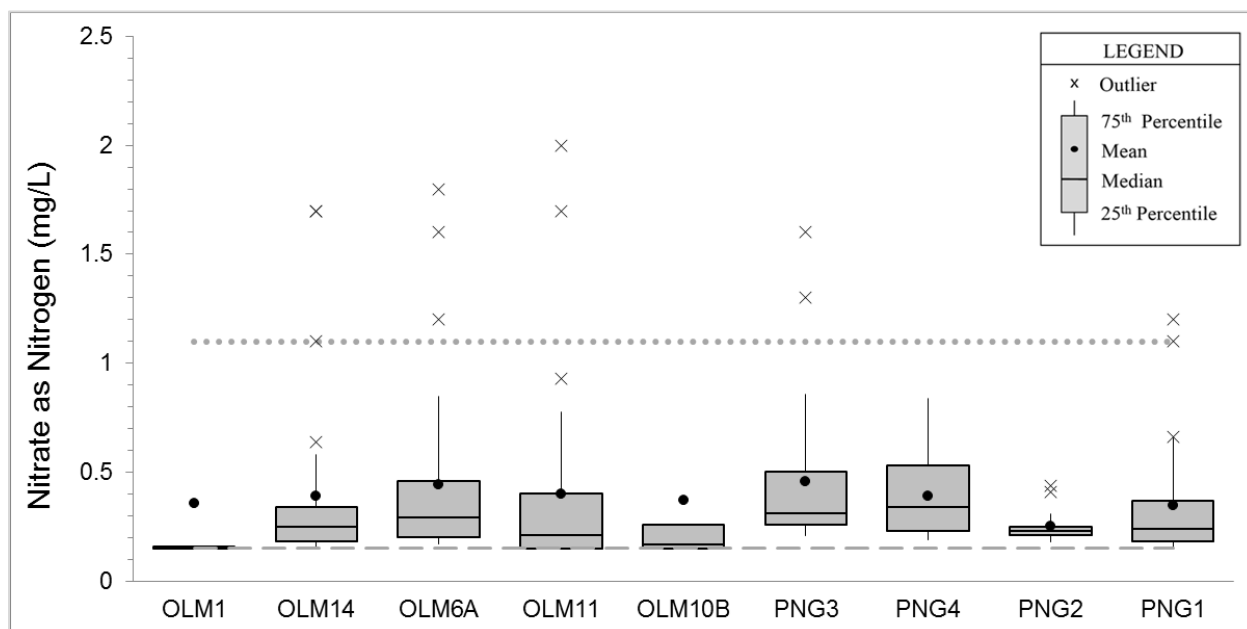


**Figure 26.** Nitrate (as nitrogen) results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range, unless high censoring prevented computation. The dashed line represents the laboratory reporting detection limit of 0.15 mg/L, and the dotted line represents the ecological objective maximum of 1.1 mg/L. Site OLM18 was excluded due to a high percentage of censored data.

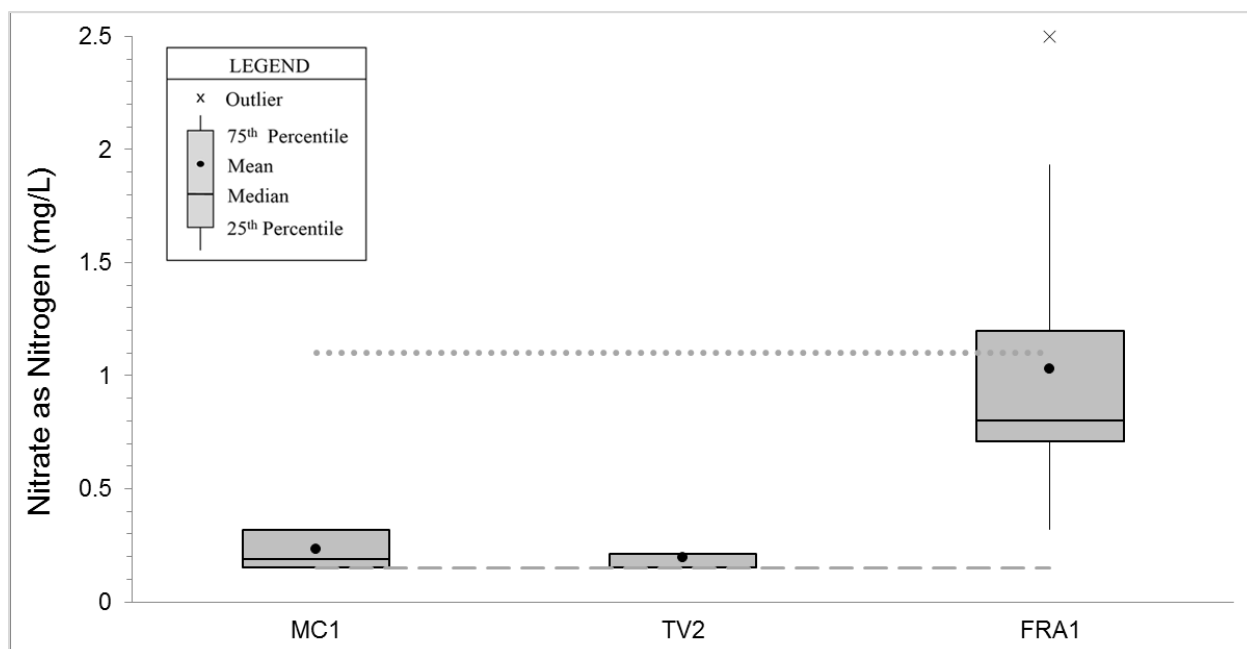


**Figure 27.** Nitrate (as nitrogen) results from Pinnacles National Park (site MC1), Golden Gate National Recreation Area (site TV2), and John Muir National Historic Site (site FRA1) during water years 2015-2016. All other sites from these NPS units were excluded due to a high percentage of censored data. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range, unless high censoring prevented computation. The dashed line represents the laboratory reporting detection limit of 0.15 mg/L, and the dotted line represents the ecological objective maximum of 1.1 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, 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 (EPA 2000). During WYs 2015-2016, the laboratory's RDL for all TKN tests (Standard Method 4500-Norg C) was 0.25 mg/L. TKN results are summarized below, sorted by NPS unit (Figures 28-31).

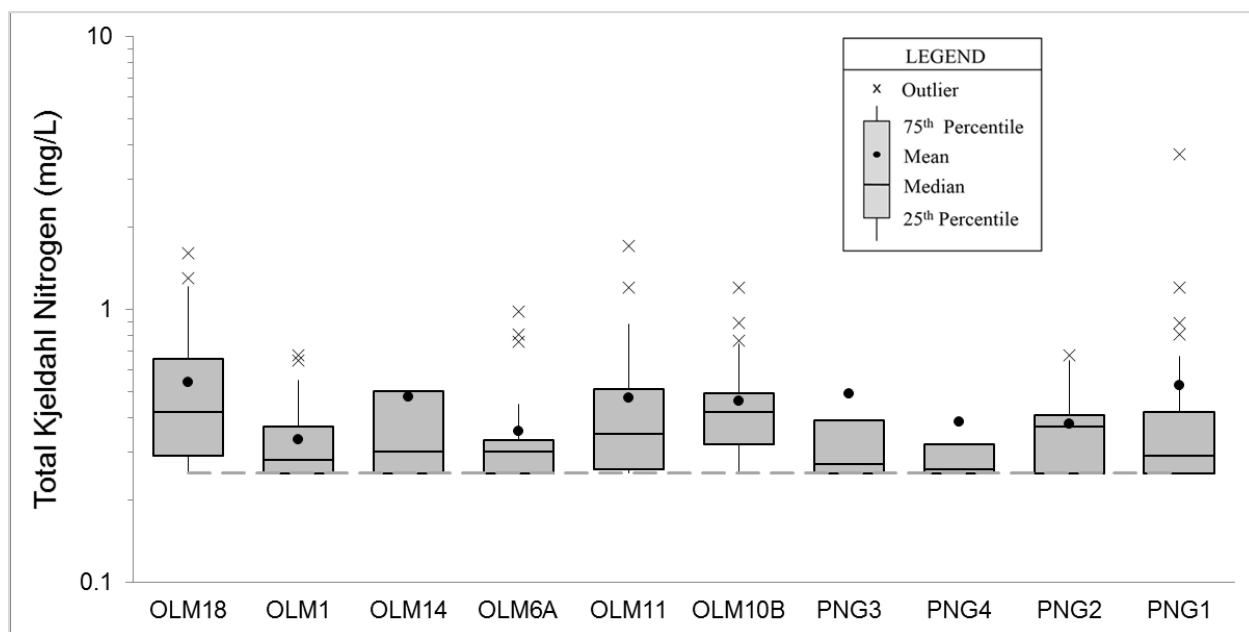


**Figure 28.** Total Kjeldahl nitrogen (TKN) results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range, unless high censoring prevented computation. The dashed line represents the laboratory reporting detection limit of 0.25 mg/L.

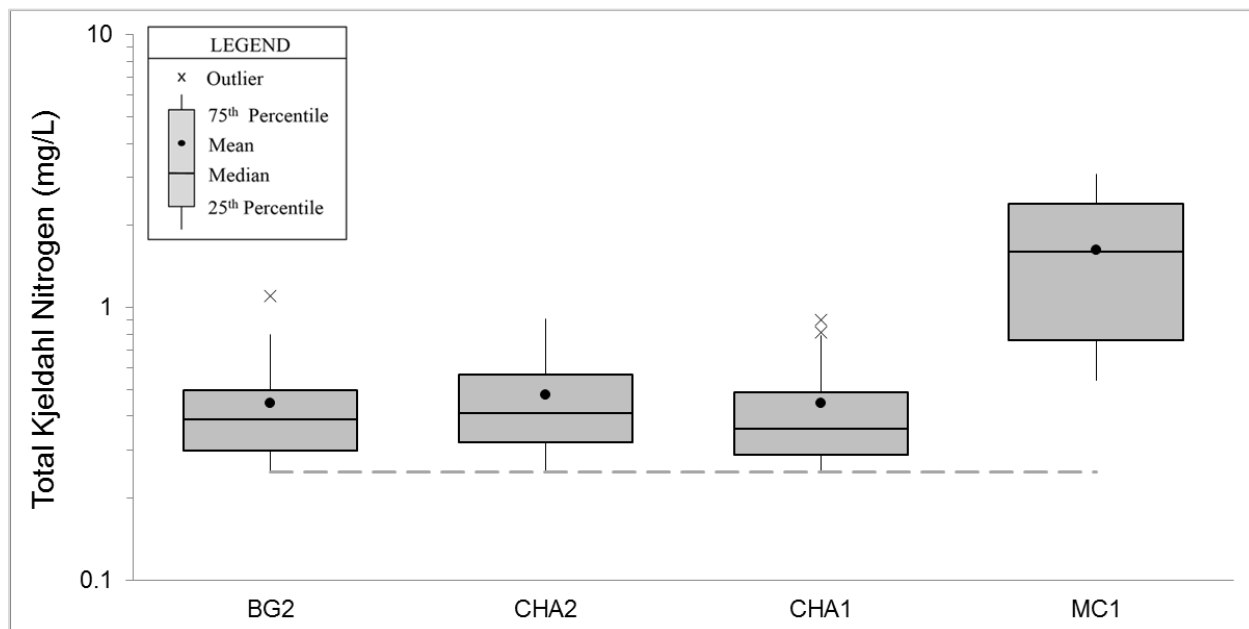


**Figure 29.** Total Kjeldahl nitrogen (TKN) results from Pinnacles National Park, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dashed line represents the laboratory reporting detection limit of 0.25 mg/L.

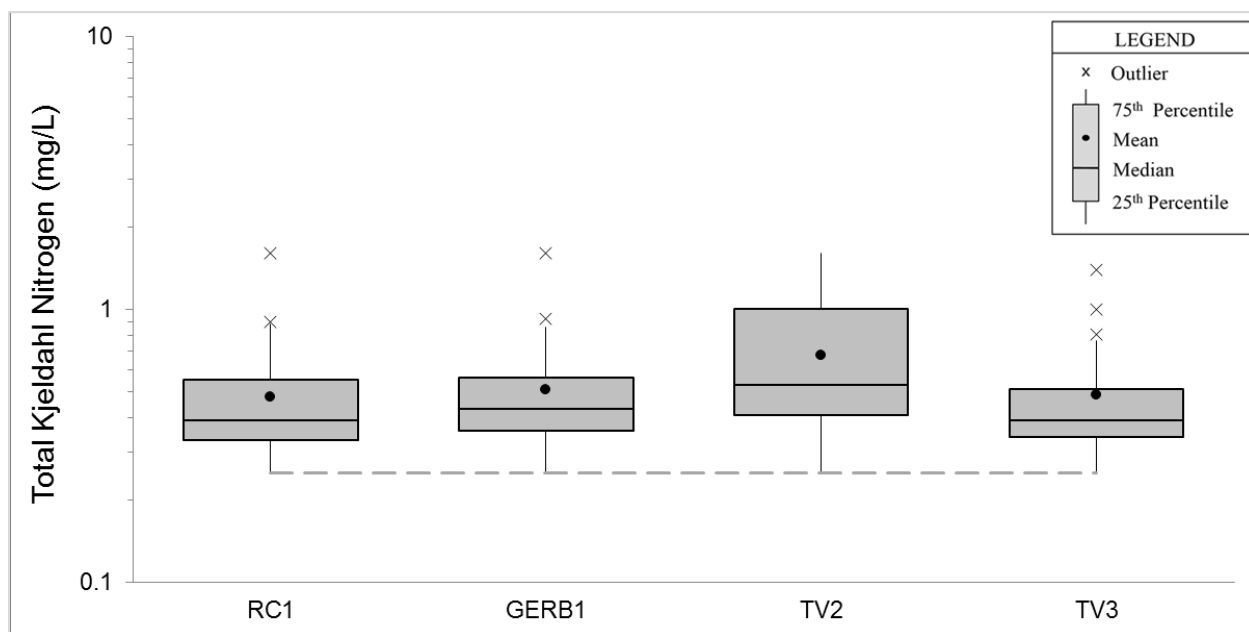


**Figure 30.** Total Kjeldahl nitrogen (TKN) results from Golden Gate National Recreation Area, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dashed line represents the laboratory reporting detection limit of 0.25 mg/L.

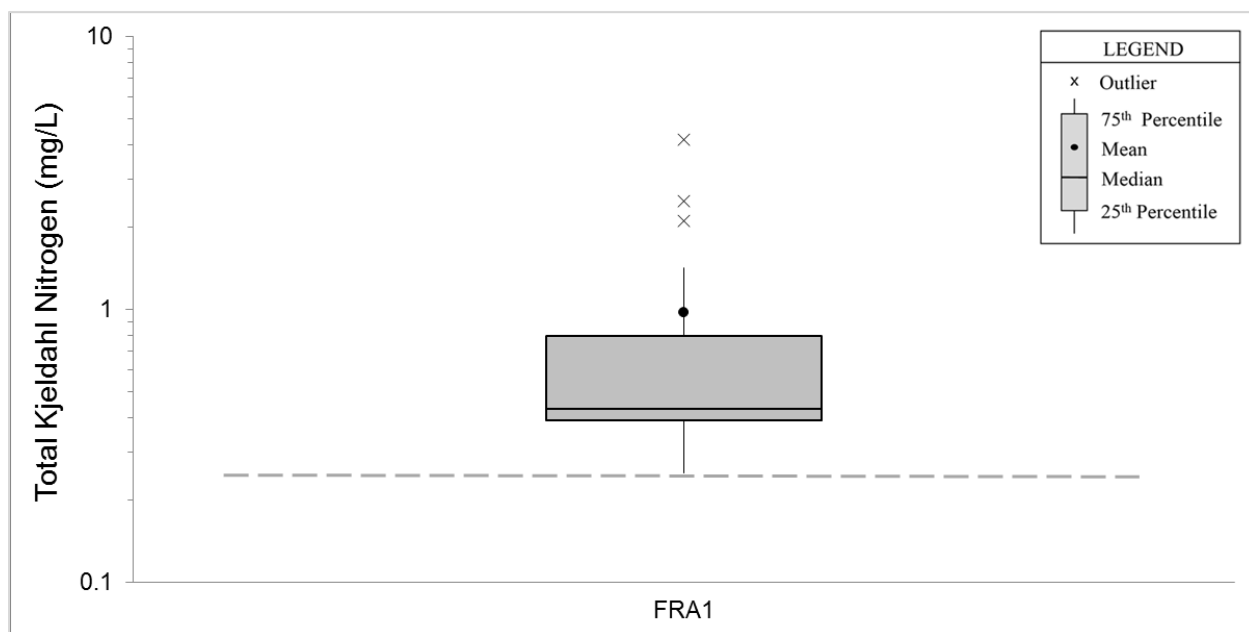


**Figure 31.** Total Kjeldahl nitrogen (TKN) results from John Muir National Historic Site, water years 2015-2016. This boxplot presents the interquartile range of the dataset, and whiskers are drawn to 1.5 times the interquartile range. The dashed line represents the laboratory reporting detection limit of 0.25 mg/L.

### 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: “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. Staff collected total coliform and *E. coli* (TC/EC) samples during every site visit of WYs 2015-2016 (including storm sampling visits) and processed the samples at the in-house laboratory at PORE.

During WYs 2015-2016, 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 (CEL Analytical Laboratory) 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 them immediately on ice.

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). During WYs 2015-2016, all TC/EC samples were processed at the standard 10x dilution factor which allows for a quantification range of 10 to 24,190 MPN/100 mL. The fecal coliform results from the contracted laboratory were reported with a minimum quantification limit of 2 MPN/100 mL.

Tables 19, 20, 21, and 22 present summary statistics of all bacteria data collected during WYs 2015-2016, 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 19.** Pathogenic indicator bacteria results from Point Reyes National Seashore, water years 2015-2016.

| Parameter                   | Statistic                             | OLM18  | OLM1  | OLM14 | OLM6A  | OLM11  | OLM10B | PNG3  | PNG4   | PNG2  | PNG1   |
|-----------------------------|---------------------------------------|--------|-------|-------|--------|--------|--------|-------|--------|-------|--------|
| Total coliform (MPN/100 mL) | Minimum                               | 290    | 250   | 800   | 660    | 1,000  | 410    | 220   | 1,600  | 1,900 | 1,100  |
|                             | Maximum                               | >UQL   | >UQL  | >UQL  | 24,000 | >UQL   | >UQL   | >UQL  | 24,000 | >UQL  | >UQL   |
|                             | Mean                                  | 7,100  | 5,100 | 5,500 | 4,800  | 13,000 | 7,200  | 7,300 | 6,200  | 7,500 | 11,000 |
|                             | Median                                | 2,100  | 1,800 | 1,700 | 2,900  | 13,000 | 4,100  | 4,400 | 2,600  | 3,400 | 9,800  |
|                             | Std. dev.                             | 9,100  | 7,200 | 8,100 | 5,700  | 8,000  | 6,400  | 6,000 | 7,900  | 7,300 | 8,400  |
|                             | # censored/<br># results <sup>a</sup> | 6/39   | 1/39  | 4/39  | 0/38   | 8/39   | 7/39   | 4/25  | 0/11   | 1/13  | 4/25   |
| <i>E. coli</i> (MPN/100 mL) | Minimum                               | <10    | <10   | <10   | <10    | 20     | <10    | <10   | 10     | <10   | <10    |
|                             | Maximum                               | 9,200  | 5,800 | 9,800 | 1,000  | 13,000 | 12,000 | 840   | 960    | 1,400 | 4,400  |
|                             | Mean                                  | 525    | 290   | 630   | 110    | 680    | 850    | 150   | 150    | 230   | 460    |
|                             | Median                                | 31     | 20    | 74    | 31     | 180    | 74     | 41    | 20     | 52    | 120    |
|                             | Std. dev.                             | 1,600  | 940   | 1,900 | 190    | 2,100  | 2,400  | 230   | 280    | 410   | 950    |
|                             | # censored/<br># results <sup>b</sup> | 8/38   | 8/39  | 3/39  | 3/38   | 0/39   | 6/39   | 5/25  | 0/11   | 1/13  | 3/25   |
| Fecal coliform (MPN/100 mL) | Minimum                               | <2     | 2     | 2     | 2      | 30     | <2     | –     | –      | –     | –      |
|                             | Maximum                               | 16,000 | 3,000 | 9,000 | 920    | 11,000 | 9,000  | –     | –      | –     | –      |
|                             | Mean                                  | 830    | 170   | 520   | 120    | 660    | 570    | –     | –      | –     | –      |
|                             | Median                                | 30     | 30    | 50    | 33     | 170    | 50     | –     | –      | –     | –      |
|                             | Std. dev.                             | 3,100  | 560   | 1,800 | 230    | 1,900  | 1,700  | –     | –      | –     | –      |
|                             | # censored/<br># results <sup>b</sup> | 3/27   | 0/28  | 0/32  | 0/30   | 0/33   | 1/33   | –     | –      | –     | –      |

<sup>a</sup> These results are above the upper quantification limit (UQL) of 24,190 MPN/100 mL and are shown as a ratio over the total number of results.

<sup>b</sup> These censored results are below the lower quantification limit (LQL) of 10 MPN/100 mL and are shown as a ratio over the total number of results.

**Table 20.** Pathogenic indicator bacteria results from Pinnacles National Park, water years 2015-2016.

| Parameter                   | Statistic                             | BG2    | CHA3   | CHA2  | CHA1   | MC1    | SC3    | SC2    |
|-----------------------------|---------------------------------------|--------|--------|-------|--------|--------|--------|--------|
| Total coliform (MPN/100 mL) | Minimum                               | 410    | 310    | 810   | 230    | 2,400  | 1,200  | 1,900  |
|                             | Maximum                               | 24,000 | 24,000 | >UQL  | 20,000 | >UQL   | 24,000 | >UQL   |
|                             | Mean                                  | 7,200  | 9,300  | 8,500 | 4,000  | 18,000 | 10,000 | 12,000 |
|                             | Median                                | 6,500  | 8,200  | 5,200 | 1,500  | 24,000 | 10,000 | 12,000 |
|                             | Std. dev.                             | 6,200  | 9,600  | 7,900 | 5,000  | 8,800  | 7,900  | 7,800  |
|                             | # censored/<br># results <sup>a</sup> | 0/23   | 0/10   | 1/22  | 0/17   | 6/14   | 0/23   | 1/14   |
| <i>E. coli</i> (MPN/100 mL) | Minimum                               | <10    | <10    | <10   | <10    | 31     | 20     | <10    |
|                             | Maximum                               | 1,600  | 220    | 8,200 | 74     | 3,300  | 2,500  | 1,100  |
|                             | Mean                                  | 200    | 36     | 530   | 17     | 1,100  | 530    | 200    |
|                             | Median                                | 52     | 10     | 31    | 10     | 1,100  | 320    | 160    |
|                             | Std. dev.                             | 370    | 67     | 1,700 | 16     | 1,100  | 660    | 280    |
|                             | # censored/<br># results <sup>b</sup> | 5/23   | 7/10   | 7/22  | 8/17   | 0/14   | 0/23   | 2/14   |

<sup>a</sup> These results are above the upper quantification limit (UQL) of 24,190 MPN/100 mL and are shown as a ratio over the total number of results.

<sup>b</sup> These censored results are below the lower quantification limit (LQL) of 10 MPN/100 mL and are shown as a ratio over the total number of results.

**Table 21.** Pathogenic indicator bacteria results from Golden Gate National Recreation Area, water years 2015-2016.

| Parameter                   | Statistic                             | RC1   | GERB1 | OAK1  | NYH1   | TV1   | TV2   | TV3   |
|-----------------------------|---------------------------------------|-------|-------|-------|--------|-------|-------|-------|
| Total coliform (MPN/100 mL) | Minimum                               | 460   | 350   | 350   | 1,100  | 630   | 1,300 | 790   |
|                             | Maximum                               | >UQL  | >UQL  | >UQL  | >UQL   | >UQL  | >UQL  | >UQL  |
|                             | Mean                                  | 3,200 | 5,700 | 7,300 | 10,000 | 3,600 | 4,800 | 5,300 |
|                             | Median                                | 1,700 | 4,400 | 4,100 | 5,500  | 1,800 | 5,200 | 3,900 |
|                             | Std. dev.                             | 2,900 | 4,600 | 8,400 | 9,300  | 3,200 | 3,200 | 5,100 |
|                             | # censored/<br># results <sup>a</sup> | 2/25  | 2/25  | 2/17  | 4/24   | 1/9   | 1/14  | 1/25  |

<sup>a</sup> These results are above the upper quantification limit (UQL) of 24,190 MPN/100 mL and are shown as a ratio over the total number of results.

<sup>b</sup> These censored results are below the lower quantification limit (LQL) of 10 MPN/100 mL, except for one result from OAK1 that exceeded the upper quantification limit (UQL) of 24,190. The number of censored results are shown as a ratio over the total number of results.

**Table 21 (continued).** Pathogenic indicator bacteria results from Golden Gate National Recreation Area, water years 2015-2016.

| Parameter                          | Statistic                             | RC1   | GERB1 | OAK1  | NYH1   | TV1   | TV2   | TV3   |
|------------------------------------|---------------------------------------|-------|-------|-------|--------|-------|-------|-------|
| <i>E. coli</i><br>(MPN/<br>100 mL) | Minimum                               | <10   | <10   | 31    | 10     | 10    | <10   | <10   |
|                                    | Maximum                               | 4,900 | 1,900 | >UQL  | 17,000 | 1,300 | 2,800 | 3,400 |
|                                    | Mean                                  | 370   | 150   | 730   | 1,200  | 170   | 240   | 190   |
|                                    | Median                                | 110   | 41    | 230   | 120    | 20    | 20    | 31    |
|                                    | Std. dev.                             | 970   | 370   | 1,500 | 3,700  | 430   | 740   | 670   |
|                                    | # censored/<br># results <sup>b</sup> | 2/25  | 5/25  | 1/17  | 0/24   | 0/9   | 5/14  | 2/25  |

<sup>a</sup> These results are above the upper quantification limit (UQL) of 24,190 MPN/100 mL and are shown as a ratio over the total number of results.

<sup>b</sup> These censored results are below the lower quantification limit (LQL) of 10 MPN/100 mL, except for one result from OAK1 that exceeded the upper quantification limit (UQL) of 24,190. The number of censored results are shown as a ratio over the total number of results.

**Table 22.** Pathogenic indicator bacteria results from John Muir National Historic Site, water years 2015-2016.

| Parameter                             | Statistic                             | FRA1   | STR1   | STR2  | STR3  | STR4  | STR5  |
|---------------------------------------|---------------------------------------|--------|--------|-------|-------|-------|-------|
| Total<br>coliform<br>(MPN/<br>100 mL) | Minimum                               | 2,500  | 16,000 | >UQL  | >UQL  | >UQL  | >UQL  |
|                                       | Maximum                               | >UQL   | >UQL   | >UQL  | >UQL  | >UQL  | >UQL  |
|                                       | Mean                                  | 16,000 | 16,000 | –     | –     | –     | –     |
|                                       | Median                                | 20,000 | –      | –     | –     | –     | –     |
|                                       | Std. dev.                             | 6,600  | –      | –     | –     | –     | –     |
|                                       | # censored/<br># results <sup>a</sup> | 5/14   | 1/2    | 2/2   | 2/2   | 2/2   | 1/1   |
| <i>E. coli</i><br>(MPN/<br>100 mL)    | Minimum                               | 110    | 75     | 210   | 270   | 380   | 4,900 |
|                                       | Maximum                               | >UQL   | 570    | 2,000 | 3,700 | 3,900 | 4,900 |
|                                       | Mean                                  | 4,800  | 320    | 1,100 | 2,000 | 2,100 | 4,900 |
|                                       | Median                                | 590    | –      | –     | –     | –     | –     |
|                                       | Std. dev.                             | 7,200  | 350    | 1,300 | 2,400 | 2,500 | –     |
|                                       | # censored/<br># results <sup>b</sup> | 1/14   | 0/2    | 0/2   | 0/2   | 0/2   | 0/1   |

<sup>a</sup> These results are above the upper quantification limit (UQL) of 24,190 MPN/100 mL and are shown as a ratio over the total number of results.

<sup>b</sup> These censored results are below the lower quantification limit (LQL) of 10 MPN/100 mL 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. Total coliform results are summarized below, sorted by NPS unit (Figures 32-34). The NPSTORET database was unable to create a figure for the JOMU dataset.

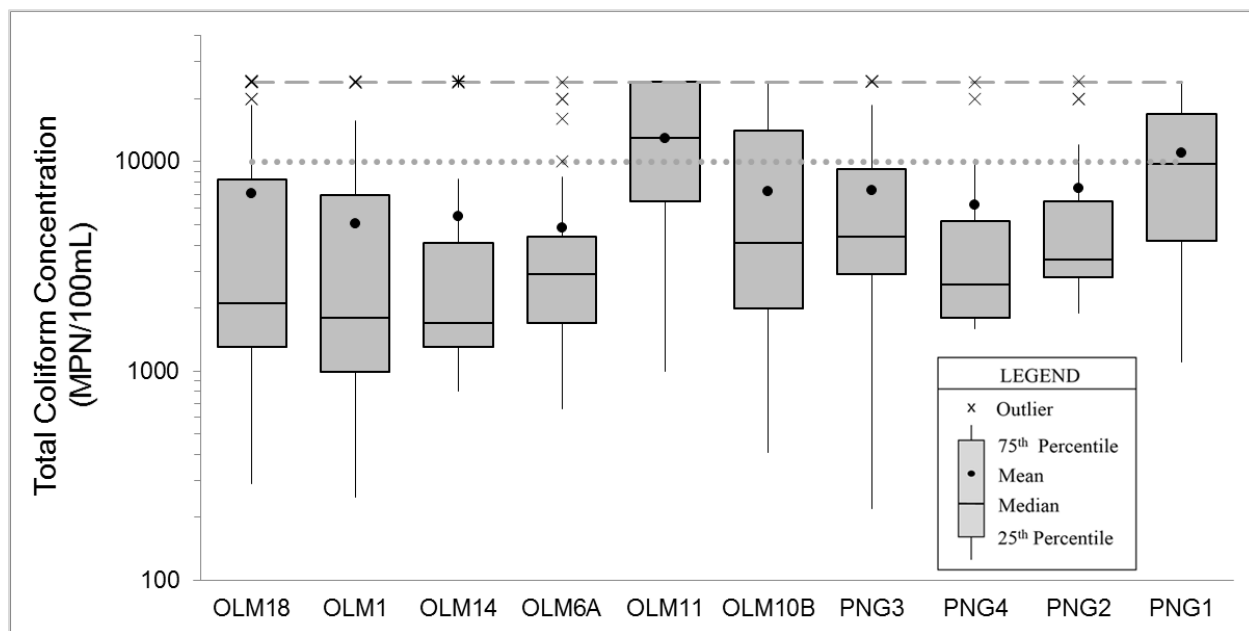


**Figure 32.** Total coliform results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range, unless high censoring prevented computation. The dashed line represents the upper quantification limit of 24,190 MPN/100 mL, and the dotted line represents the water quality objective maximum of 10,000 MPN/100 mL.

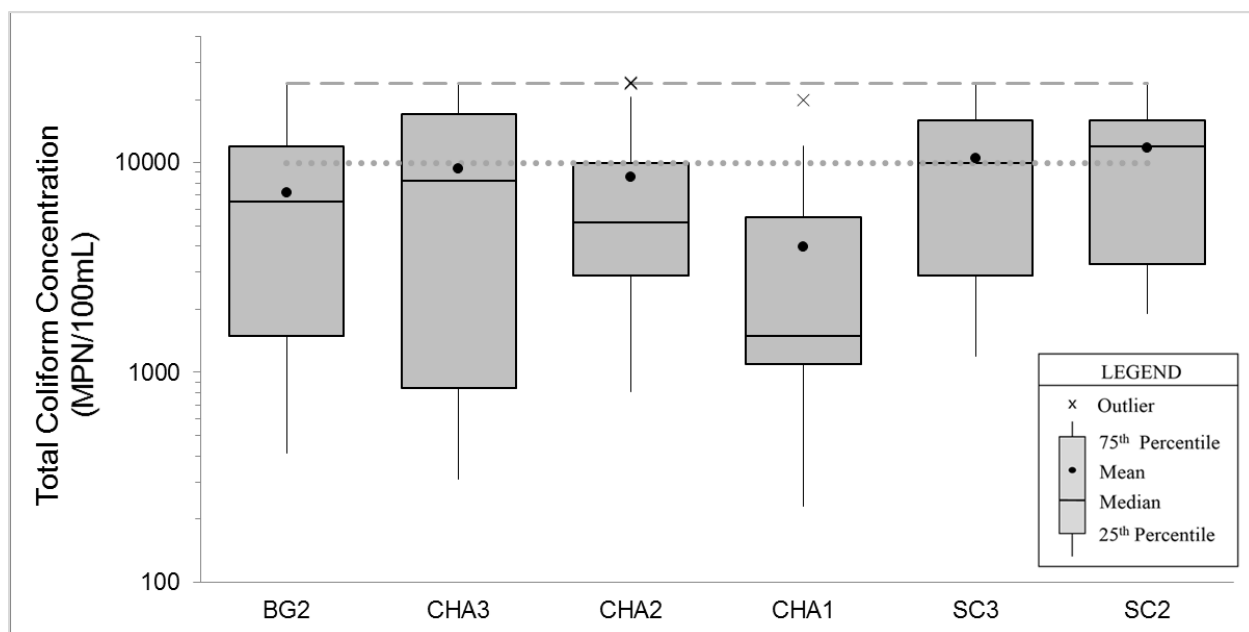


**Figure 33.** Total coliform results from Pinnacles National Park, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dashed line represents the upper quantification limit of 24,190 MPN/100 mL, and the dotted line represents the water quality objective maximum of 10,000 MPN/100 mL.

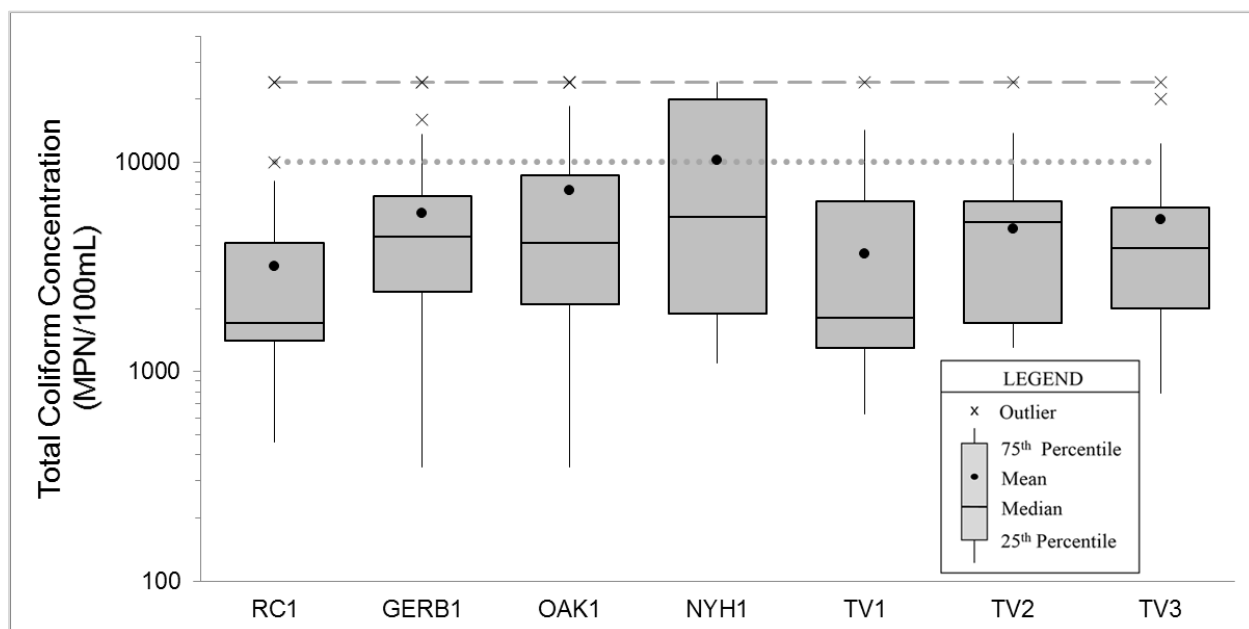


**Figure 34.** Total coliform results from Golden Gate National Recreation Area, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dashed line represents the upper quantification limit of 24,190 MPN/100 mL, and the dotted line represents the water quality objective maximum of 10,000 MPN/100 mL.

### ***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. *E. coli* results are summarized below, sorted by NPS unit (Figures 35-38).

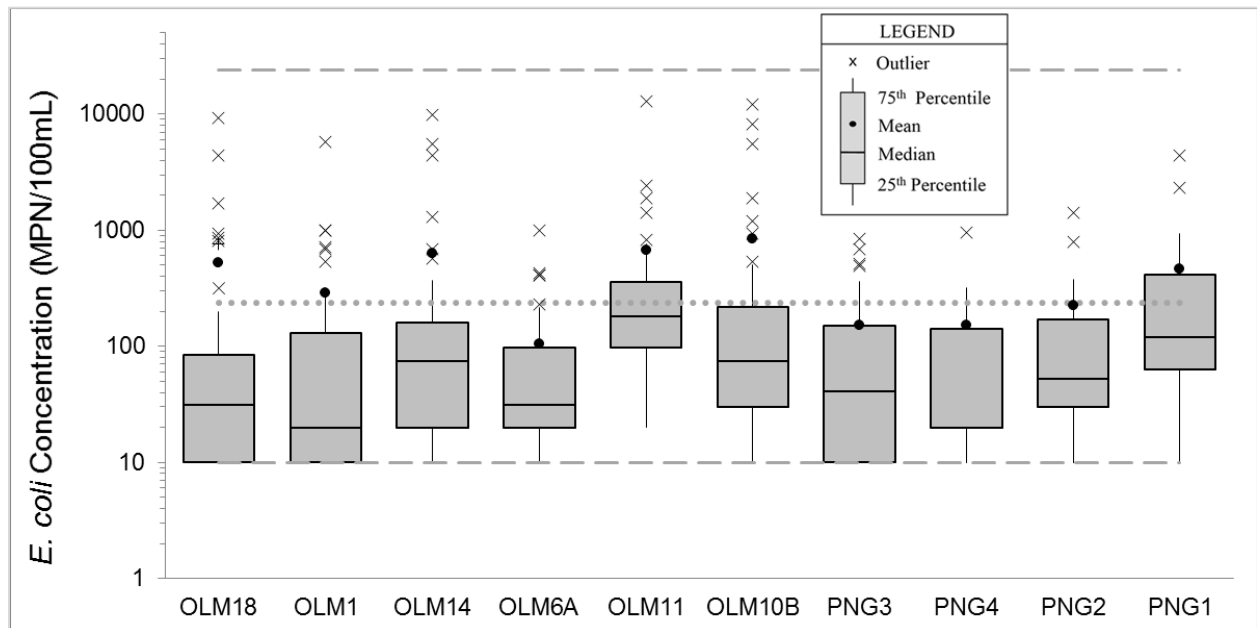


**Figure 35.** *Escherichia coli* results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range, unless high censoring prevented computation. The dashed lines represent the quantifiable range of 10 to 24,190 MPN/100 mL, and the dotted line represents the water quality objective maximum of 235 MPN/100 mL.

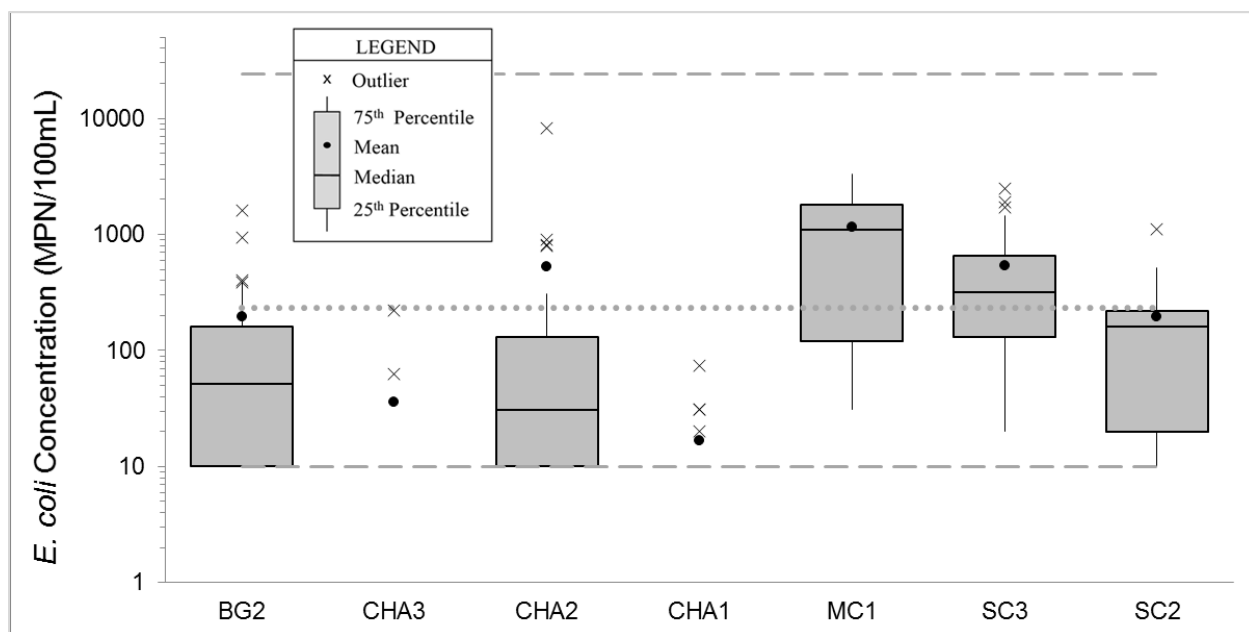


**Figure 36.** *Escherichia coli* results from Pinnacles National Park, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range, unless high censoring prevented computation. The dashed lines represent the quantifiable range of 10 to 24,190 MPN/100 mL, and the dotted line represents the water quality objective maximum of 235 MPN/100 mL.

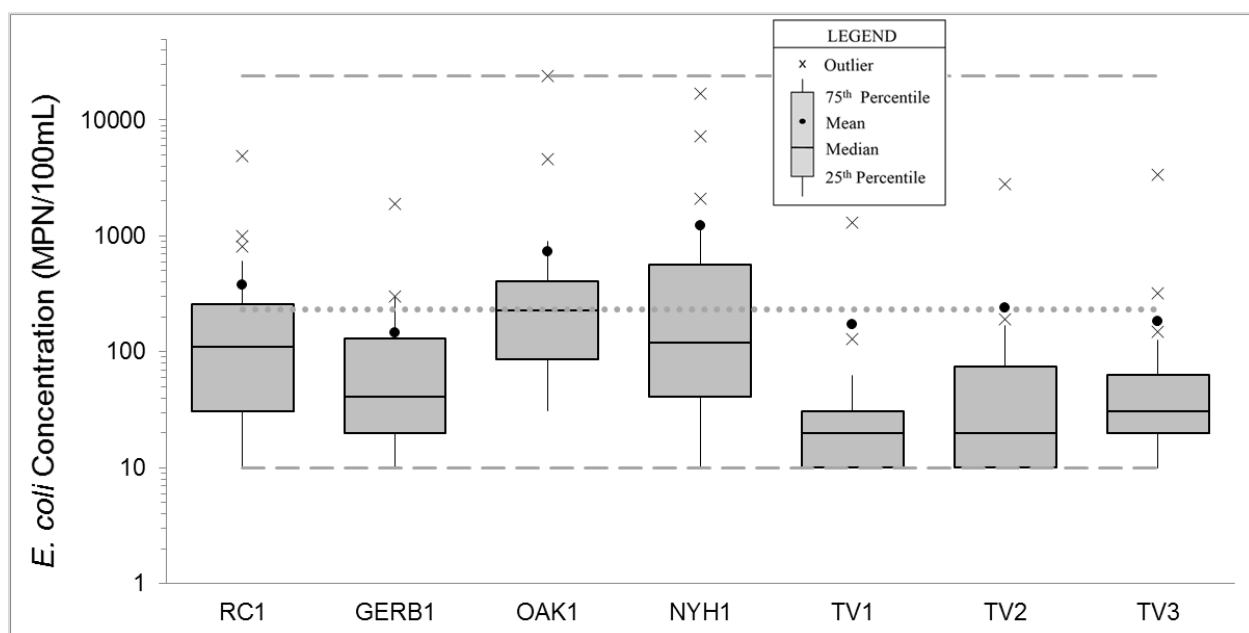


**Figure 37.** *Escherichia coli* results from Golden Gate National Recreation Area, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range, unless high censoring prevented computation. The dashed lines represent the quantifiable range of 10 to 24,190 MPN/100 mL, and the dotted line represents the water quality objective maximum of 235 MPN/100 mL.

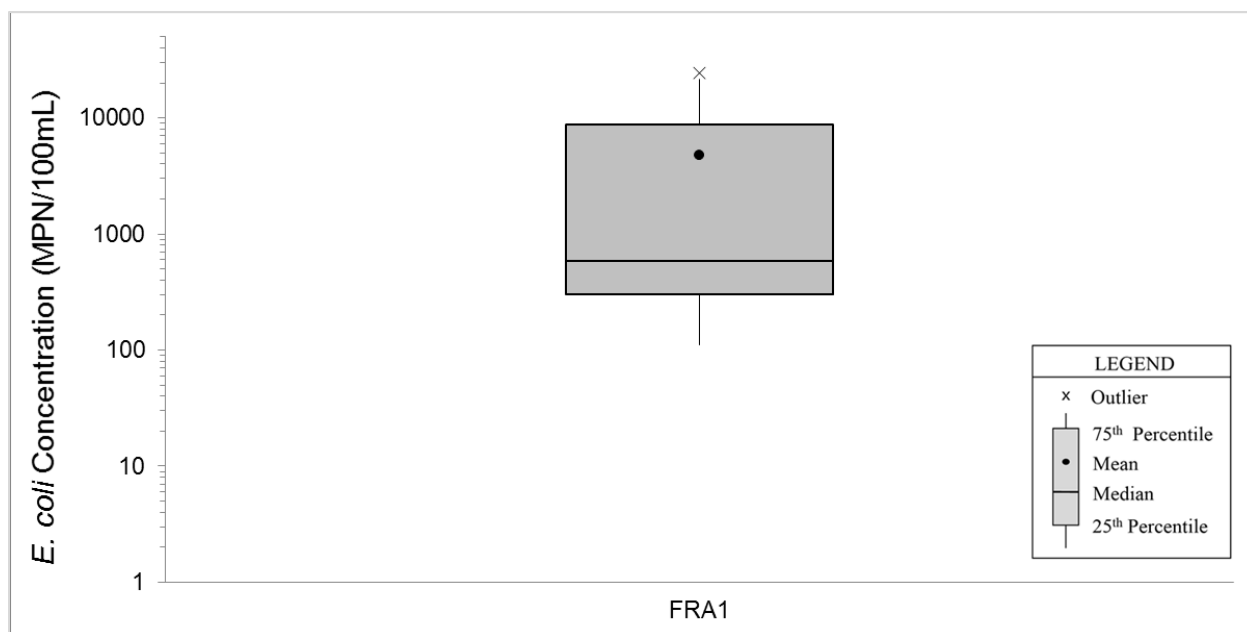


**Figure 38.** *Escherichia coli* results from John Muir National Historic Site, water years 2015-2016. This boxplot presents the interquartile range of the dataset, and whiskers are drawn to 1.5 times the interquartile range.

### ***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 past 12 years, 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. The program had taken a break from monthly sampling, but this ended in December 2014; the 5-week winter series started January 20, 2015 and the normal sampling schedule resumed. During WYs 2015-2016, three of the scheduled sampling days overlapped with storm sampling events. Fecal coliform results are summarized below, sorted by NPS unit (Figures 39).

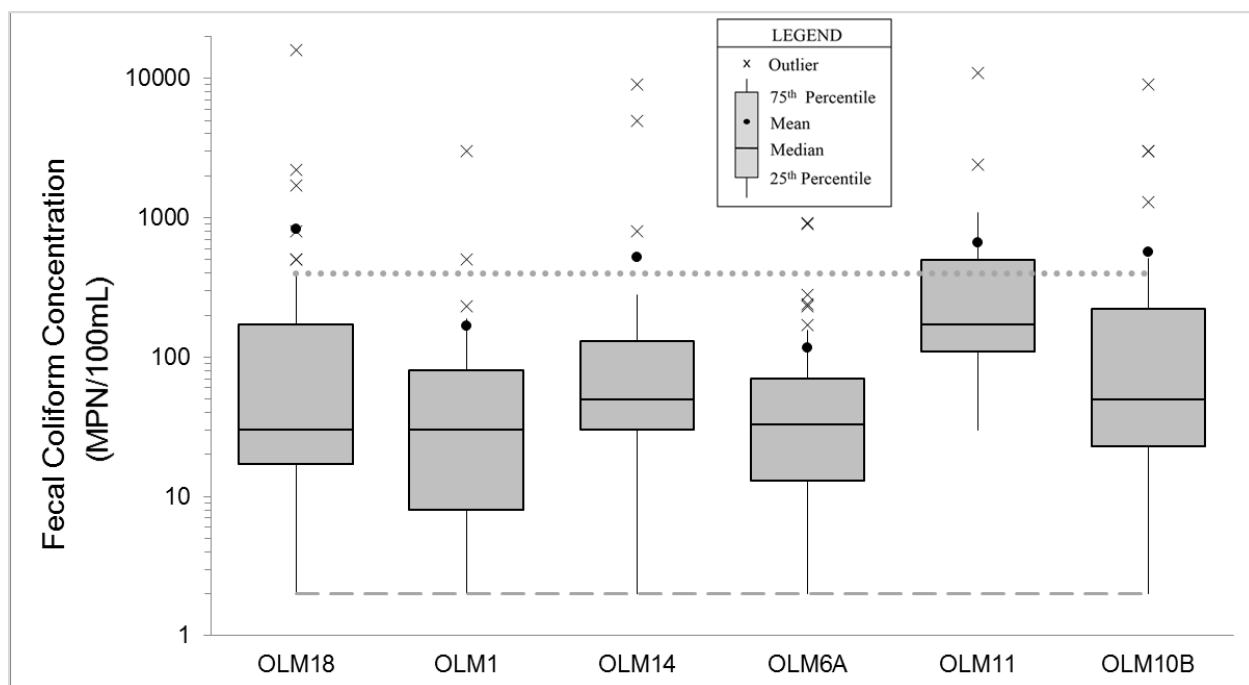


**Figure 39.** Fecal coliform results from Point Reyes National Seashore, water years 2015-2016. Boxplots present the interquartile range of each dataset, and whiskers are drawn to 1.5 times the interquartile range. The dashed line represents the lower quantification limit of 2 MPN/100 mL, and the dotted line represents the water quality objective maximum of 400 MPN/100 mL.

## Discussion of Results

This biennial report presents the freshwater quality results and summary statistics calculated from the SFAN water quality sites monitored during WYs 2015-2016 (October 2014 – September 2016). The discussion below is referring to all results gathered during these two water years alone (including storm samples). NPS staff monitored 30 water quality sites, and the resulting data show that waters commonly met most established water quality objectives (Table 23). Each park produced highly varied failure rates depending on the constituent; overall, the PORE and GOGA results most frequently met their respective objectives, while the PINN and JOMU results exhibited higher failure rates for most monitored parameters. The results are summarized and discussed below, divided by park unit.

**Table 23.** Percentages of results that failed to meet water quality objectives<sup>a</sup>, sorted by NPS unit.

| Parameter               | PORE             | PINN             | GOGA             | JOMU              |
|-------------------------|------------------|------------------|------------------|-------------------|
| Dissolved oxygen        | 19% <sup>b</sup> | 32% <sup>b</sup> | 26% <sup>b</sup> | 7%                |
| pH                      | 10%              | 54% <sup>b</sup> | 3%               | 7%                |
| Specific conductance    | 0%               | 34% <sup>b</sup> | 7%               | 100% <sup>b</sup> |
| Turbidity               | 10%              | 13%              | 17% <sup>b</sup> | 21% <sup>b</sup>  |
| Nitrate (as nitrogen)   | 6%               | 3%               | 0%               | 36% <sup>b</sup>  |
| Total coliform          | 26% <sup>b</sup> | 38% <sup>b</sup> | 14%              | 79% <sup>b</sup>  |
| <i>Escherichia coli</i> | 22% <sup>b</sup> | 29% <sup>b</sup> | 19% <sup>b</sup> | 79% <sup>b</sup>  |
| Fecal coliform          | 15% <sup>b</sup> | n/a              | n/a              | n/a               |

<sup>a</sup> Water quality objectives utilized in this report: > 7 mg/L dissolved oxygen applies to PORE/GOGA/JOMU (CA RWQCB 2010), > 5 mg/L dissolved oxygen applies to PINN (CA RWQCB 2011), 6.5 to 8.5 pH units applies to PORE/GOGA/JOMU (CA RWQCB 2010), 7.0 to 8.5 pH units applies to PINN (CA RWQCB 2011), < 500 µS/cm specific conductance (Behar 1997), < 25 NTU turbidity (Sigler et al. 1984), < 1.1 mg/L nitrate as nitrogen (Crunkilton 2000), < 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).

<sup>b</sup> The parameters of the greatest concern (highlighted in gray) have a failure rate of 15% or higher.

### Point Reyes National Seashore

Field technicians conducted five storm sampling events in PORE during WYs 2015-2016. Three of these events (12/3/2014, 12/21/2015, and 1/5/2016) included both the Pine Gulch and the Olema Creek watershed sites, while two additional storm sampling events (11/22/2014 and 1/19/2016) only included the Olema Creek watershed sites. The datasets discussed below include results from sampling conducted during every month of each water year (from low summer/fall flow conditions to high winter flow and storm events) in order to represent the range of conditions sampled throughout WYs 2015 and 2016. This sampling rotation started while the State Water Board was taking a break from monthly TMDL sampling (See *Clean Water Act Section 303(d) Listed Waters* in the *Methods* section for more info) so fecal coliform was not sampled during the first three months of the rotation (October/November/December 2014). Monthly TMDL sampling resumed in January 2015, in addition to the intensive weekly monitoring events for five consecutive weeks during both the winter and summer of each water year.

There was a change of sites in the middle of this monitoring period. After WY 2015, program staff decided that site PNG2 should no longer be accessed due to safety concerns. The social trail that skirted above this section of Pine Gulch Creek was steep, slippery, and quickly eroding. The last visit to PNG2 was during November 2015, and a new site, PNG4, was added to the rotation the following month. This new site will not retain the same name (even if documenting a location adjustment) because the distance between the two is too great, and there are inputs/tributaries in between.

### **Core Parameters**

During WYs 2015-2016, water temperature exceeded 15.6°C during 12% of site visits (36:307), and all of these were from the warm season (visits between July and October). All results were below 25°C, a temperature known to be lethal to juvenile coho (Moyle 2002). Even the highest result in PORE (18.0°C) was well below this threshold. Water temperature medians generally increased from upstream to downstream.

During WYs 2015-2016 19% of all PORE dissolved oxygen results (49:264) failed to meet the dissolved oxygen minimum objective of 7 mg/L. All failures were from the Olema Creek watershed sites (none from Pine Gulch), and the majority of them were from three specific sites: the farthest downstream site that often becomes stagnant (OLM10B), and two upstream sites that regularly become disconnected and pooled during low flow conditions (OLM1 and OLM18). The two lowest readings (program-wide) from WYs 2015-2016 were both recorded during October 2015 (0.11 mg/L at OLM10B & 0.58 mg/L at OLM18) when water was stagnant, black in color, and disconnected into smaller pools (Figure 40). The three highest individual dissolved oxygen readings recorded at PORE sites were all from Davis Boucher (OLM6A) during the winter months; this site also produced the highest median of all SFAN sites (10.34 mg/L).

Ten percent of the PORE pH results (30:307) fell below the minimum objective of 6.5 pH units, while no results exceeded the upper end of the objective (8.5 pH units). Every PORE pH failure was from one of the upper Olema Creek watershed sites (OLM18, OLM1, and OLM14); these three sites also produced the three lowest median pH values in the PORE dataset. Both the lowest and highest pH medians in the SFAN were found in PORE (6.50 at OLM18 and 7.76 at PNG3).

The six lowest specific conductance results (program-wide) were all from Olema Creek sites during storm events. The PORE sites generally had the lowest specific conductance readings compared to the other parks; none of the PORE results exceeded the ecological objective of 500  $\mu\text{S}/\text{cm}$ .

The PORE turbidity dataset had the lowest failure rate compared to the other parks; only 10% of results (29:305) exceeded the ecological objective maximum of 25 NTU. The lowest median turbidity value in the SFAN was also from the PORE dataset (0.97 at site PNG2). The highest turbidity values (top 27 results) in PORE were all collected during storm sampling events.



**Figure 40.** The farthest upstream water quality site in the Olema Creek Watershed, shown during low flow conditions when the site is disconnected, full of leaves, and nearly anoxic.

### ***Nutrient Parameters***

The PORE nitrate dataset had one of the lowest failure rates, second to PINN; six percent of samples (14:230) failed to meet the ecological objective maximum of 1.1 mg/L. There were many low results, and 29% of the PORE samples were reported as non-detect (below the 0.15 mg/L detection limit). The highest PORE nitrate results (top 18) were all collected during storm sampling events.

PORE had the highest percentage of undetectable TKN levels; 25% of samples (58:230) were reported as non-detect (below the 0.25 mg/L laboratory detection limit). The three highest TKN results from the PORE dataset were from samples collected during storm sampling in December 2014, and the highest individual result was 3.7 mg/L from site PNG1, when the creek had topped its banks and was flowing out into the nearby plant nursery and farmland (Figures 41 and 42).



**Figure 41.** Pine Gulch Creek at site PNG1 during storm sampling in December 2014. This perspective is facing the left bank (at top of frame) and shows the creek overtopping its banks and flowing perpendicular to the stream channel, out into the surrounding farmland.



**Figure 42.** Pine Gulch Creek at site PNG1 during storm sampling in December 2014. This perspective is from the right bank (facing away from the creek), showing the creek overtopping its banks and flowing perpendicular to the stream channel, out into the surrounding farmland.

### ***Pathogenic Indicator Bacteria***

Twenty-six percent of the PORE bacteria samples (79:307) exceeded the objective maximum of 10,000 MPN/100 mL total coliform. Every PORE sample collected during a storm sampling event failed to meet this objective. The lowest and highest median values in PORE were both from mainstem Olema Creek sites; the lowest was from site OLM14 near Five Brooks, while the highest median was calculated from OLM11, downstream at the Bear Valley Road Bridge.

PORE had a similar *E. coli* failure rate to PINN and GOGA; 22% of samples (67:306) exceeded the objective maximum of 235 MPN/100 mL. The highest *E. coli* results (top 8) in the PORE dataset were all from samples collected during storm events. The highest individual result (13,000 MPN/100 mL) was from site OLM11 at the Bear Valley Road Bridge during a storm in January 2016. Site OLM11 also produced the highest median *E. coli* and fecal coliform values in PORE. The highest fecal coliform result (16,000 MPN/100 mL) was also recorded during the January 2016 storm sampling event, but was collected from the farthest upstream site near the Randall House (OLM18). Fecal coliform samples were collected at the six Olema Creek watershed sites (unless disconnected/stagnant), and not at any of the Pine Gulch watershed sites (See *Clean Water Act Section 303(d) Listed Waters* in the *Methods* section for more info). Fifteen percent of the fecal coliform results (27:183) exceeded the contact recreation maximum of 400 MPN/100 mL.

## **Pinnacles National Park**

Field technicians were unable to capture storm sampling events in PINN during WYs 2015-2016. Some field visits were within a few days of rain events (and one visit immediately followed precipitation), but the streams were not affected to the point that these could be considered true storm sampling events. The datasets discussed below include results from sampling conducted during every month of each water year (from low summer/fall flow conditions to winter sampling after rain events) in order to represent the range of conditions sampled throughout WYs 2015 and 2016. The farthest downstream water quality site in Sandy Creek (SC1) was dry on every monthly visit of WY 2015 and 2016, so the PINN dataset is comprised of seven sites (instead of eight) during this reporting period. Core parameters and pathogenic bacteria samples were collected on every site visit, while nutrient samples were only collected from the four primary sites (BG2, CHA1, CHA2, and MC1).

### **Core Parameters**

The highest and lowest water temperature medians in the program were found in the PINN dataset; site SC2 and site CHA3 both had median values of 10.8 °C, while the highest SFAN median was from site CHA1 (14.9 °C).

During WYs 2015-2016, 32% of PINN dissolved oxygen results (36:111) failed to meet the minimum objective of 5 mg/L. The other three parks had lower failure rates (even though they have a stricter objective of 7 mg/L). The three lowest values in PINN (0.86, 1.03, and 1.07 mg/L), and the lowest median program-wide (2.54 mg/L) were all measured at site SC2 in Sandy Creek during the late spring. This site is located in the far loop of the campground near bathrooms and often becomes pooled, stagnant, and full of algae and vegetation.

The PINN pH dataset had the highest failure rate compared to the other SFAN units; 54% of results (67:123) fell below the pH objective minimum of 7 pH units, while no results exceeded 8.5 pH units (the upper end of the objective range). The Bear Gulch site, BG2, produced the four lowest pH results in PINN, and four of the five lowest pH results in the SFAN.

Approximately one third (42:123) of the PINN results exceeded the specific conductance ecological objective of 500  $\mu\text{S}/\text{cm}$ . The ten highest specific conductance results in the SFAN were all from Sandy Creek sites, and the highest median program-wide (1,518.0  $\mu\text{S}/\text{cm}$ ) was from site SC2 in Sandy Creek.

The PINN turbidity dataset had a relatively low failure rate; only 13% of results (16:122) exceeded the ecological objective of 25 NTU. Instead of turbidity exceedances taking place during and after storm events (which happens at the rest of the SFAN sites), the highest turbidity results in PINN took place during the dry season. The six highest values were from MC1 (McCabe Canyon) samples collected during the summer. This site also produced the highest median value program-wide (47.6 NTU). The streambed in this area is full of extremely fine sediments and is often trampled upstream.

**Nutrient Parameters**

PINN had one of the lowest nitrate failure rates in the network; only 3% of nitrate samples (2:76) exceeded the ecological objective of 1.1 mg/L. These two nitrate exceedances were from samples collected on the same day (following a storm event in December 2014) at sites BG2 and CHA2.

The PINN sites had relatively low TKN results, except for site MC1 in McCabe Canyon which had the highest results in PINN (top 9) and also produced the highest median value in the SFAN Program.

**Pathogenic Indicator Bacteria**

Thirty-eight percent of the total coliform results from PINN (47:123) exceeded the objective maximum of 10,000 MPN/100 mL. Eight individual results exceeded the quantification limit of 24,190 MPN/100 mL, and most of these (6:8) were from site MC1 in McCabe Canyon. The most extreme median values in the SFAN bacteria dataset were all calculated from PINN sites; CHA1 produced the lowest total coliform and *E. coli* medians (1,500 and 10 MPN/100mL, respectively), while site MC1 in McCabe Canyon produced the highest total coliform and *E. coli* medians in the SFAN (24,000 and 1,100 MPN/100 mL, respectively). Twenty-nine percent of the PINN bacteria results (26:123) exceeded the *E. coli* objective maximum of 235 MPN/100 mL. The highest individual *E. coli* concentration in PINN (8,200 MPN/100 mL) was sampled from site CHA2 during September 2015 when the reach was disconnected into scattered pools (Figure 43).



**Figure 43.** Site CHA2 on Chalone Creek during sampling in September 2015 when the reach was disconnected into smaller, stagnant pools.

### **Golden Gate National Recreation Area**

Field technicians conducted two storm sampling events in GOGA during WYs 2015-2016 (one during each water year). The datasets discussed below include results from sampling conducted during every month of each water year (from low summer/fall flow conditions to high winter flow and storm events) in order to represent the range of conditions sampled throughout WYs 2015 and 2016. Staff collected core parameters and pathogenic bacteria samples on every site visit, while nutrient samples were only collected from the four primary sites (RC1, GERB1, TV2, and TV3).

### **Core Parameters**

The Oakwood Creek site has little canopy cover and often becomes disconnected in the late summer months; not surprisingly, this site produced the three highest temperature readings program-wide (even higher than any summer sampling event in PINN). Despite this, only eight percent of GOGA results exceeded the ecological objective of 15.6°C.

About one quarter of the GOGA results (37:140) failed to meet the dissolved oxygen minimum objective of 7 mg/L. The five lowest results in GOGA were all measured at site TV2 near the Tennessee Valley Trailhead; each of these failures was found during April, May, or June when thick, orange, iron-rich floc was present in the channel (Figure 44).



**Figure 44.** Site TV2 in Tennessee Valley Creek, shown during low flow conditions when the channel fills with iron-rich floc. These conditions usually correspond with low dissolved oxygen levels.

Compared to the three other parks, the GOGA pH dataset produced the lowest failure rate; just two percent of samples (3:140) fell below the minimum of 6.5 pH units, and just one individual result fell above the maximum of 8.5 pH units (also the only exceedance program-wide). These four failures (three below and one above the objective range) all occurred at the Rodeo Creek site, RC1.

The GOGA results rarely exceeded the specific conductance ecological objective maximum of 500  $\mu\text{S}/\text{cm}$ ; only seven percent of measurements (10:140) were above this threshold. The lowest median value program-wide was from site TV1 in the upstream reach of Tennessee Valley Creek. Site TV1 produced some of the lowest individual conductance results, while site NYH1 in Nyhan Creek produced some of the highest individual results as well as the highest median in GOGA.

Seventeen percent of the GOGA turbidity samples exceeded the ecological objective maximum of 25 NTU, and the highest values (top 12) were all from samples collected during storm events. Site NYH1 in Nyhan Creek produced the lowest median result in GOGA as well as some of the lowest individual results.

### ***Nutrient Parameters***

GOGA was the only SFAN unit which did not produce any nitrate results that exceeded the ecological objective maximum of 1.1 mg/L. GOGA also had the highest percentage of results reported as non-detect (75% of results fell below the 0.15 mg/L detection limit). Even the highest individual GOGA result was moderate (0.70 mg/L from site RC1 in Rodeo Creek).

One of the highest individual TKN results from the GOGA samples was from site TV2 during June 2016 when the channel was thick with orange floc. The other results with similarly high concentrations (1.3 - 1.6 mg/L) were from samples collected during storm sampling in February 2015.

### ***Pathogenic Indicator Bacteria***

Compared to the other SFAN units, the GOGA dataset had the lowest failure rates for pathogenic indicator bacteria. Just 14% of bacteria samples exceeded the total coliform objective maximum of 10,000 MPN/100 mL (half of which took place during storm events), and just 19% of samples exceeded the *E. coli* objective maximum of 235 MPN/100 mL. The Oakwood Creek site, OAK1, produced the highest median *E. coli* value in GOGA (230 MPN/100 mL). One of the highest individual concentrations of *E. coli* program-wide was also found at OAK1 (during November 2015); this sample exceeded the upper quantification limit of the laboratory method and was reported as >24,190 MPN/100 mL. The next two highest-concentration *E. coli* samples were from site NYH1 in Nyhan Creek during base flow conditions, and the next seven highest results were from storm samples.

### **John Muir National Historic Site**

Field technicians conducted three storm sampling events in JOMU during WYs 2015-2016. Two of these events (12/15/2014 and 3/7/2016) included both the Franklin Creek site and the Strentzel Creek watershed sites, while one additional storm sampling event (on 2/8/2015) only included the Franklin Creek site. The Strentzel Creek storm sampling results are included in the summary tables, but are excluded from this discussion. Including data from these sites (that are only monitored once per year during a storm event) would skew the dataset for each constituent. Results discussed below are only from the Franklin Creek site, FRA1, because this is the only JOMU site that field staff visit monthly and is listed as 'primary' in the SFAN Freshwater Quality Monitoring Protocol. The datasets discussed below include results from sampling conducted during every month of each water year (from low summer/fall flow conditions to high winter flow and storm events) in order to represent the range of conditions sampled at Franklin Creek throughout WYs 2015 and 2016.

### ***Core Parameters***

Compared to all other SFAN units, the JOMU dissolved oxygen results most frequently met the established objective (only one [of 14] results fell below 7 mg/L). This Franklin Creek site also

produced the highest individual dissolved oxygen reading in the program: 13.15 mg/L during a period of super-saturation in May of 2015 when the channel was full of algae (Figure 45). The algae probably started decomposing shortly after this visit, because the lowest JOMU result was recorded during the following visit in June 2015 (5.17 mg/L).



**Figure 45.** Site FRA1 on Franklin Creek during an algae bloom in May 2015. This site visit produced the highest individual dissolved oxygen reading of all sites monitored during water years 2015-2016.

Only one Franklin Creek result fell below the pH objective minimum of 6.5 pH units. The two lowest pH results were recorded during June of each water year, while some of the highest pH results were recorded during storms and winter sampling events.

Every individual specific conductance reading from Franklin Creek exceeded the ecological objective maximum of 500  $\mu\text{S}/\text{cm}$ , which can be more common in urban watersheds; this was the highest exceedance rate (program-wide) calculated during WYs 2015-2016.

The JOMU turbidity dataset produced the highest percentage of results that failed to meet the ecological objective of 25 NTU (21% of samples). The three highest turbidity values were collected during storm events. The highest turbidity result program-wide was found in Franklin Creek; it even exceeded the Strentzel Creek storm samples, which are notoriously high. This sample was collected during storm sampling in February of 2015 and was the only sample program-wide that exceeded the quantification range of the laboratory equipment (it was reported as  $>1,000$  NTU). This same storm sampling event also produced the highest TKN result in the program (4.2 mg/L).

### ***Nutrient Parameters***

Franklin Creek produced the highest rate of nitrate objective failures in the SFAN. Thirty-six percent of the nitrate samples (5:14) exceeded the ecological objective maximum of 1.1 mg/L. The highest

individual result (2.5 mg/L during storm sampling in December 2014) and the highest nitrate median value in the SFAN (0.80 mg/L) were both from the Franklin Creek site.

### ***Pathogenic Indicator Bacteria***

In addition to the turbidity, specific conductance, and nitrate datasets, Franklin Creek also produced the highest rate of exceedance in the SFAN for total coliform and *E. coli*. Seventy-nine percent of the Franklin Creek results (11:14) exceeded the total coliform objective maximum of 10,000 MPN/100 mL and the *E. coli* objective maximum of 235 MPN/100 mL. Two of the highest *E. coli* results in the program were from Franklin Creek samples (>24,190 in February 2015 and 20,000 in June 2015).

### **Conclusion**

The data presented in this report summarize the ninth and tenth years of monitoring under the SFAN Freshwater Quality Monitoring Protocol (Coopridge and Carson 2006). Due to the rotating basin design, ten years of monitoring results in just six years of data for the first rotation, and four years of data for the second. SFAN staff conducted a preliminary trends analysis, but determined that there are not yet enough data to detect trends for most SFAN sites/parameters.

This two-year rotation (WYs 2015-2016) included routine monitoring of 30 different sites in four SFAN parks (PINN, JOMU, GOGA, and PORE) and it will be repeated in WYs 2019-2020. WYs 2017-2018 will repeat the sampling routine of the alternate rotation, which includes 25 sites in three major watersheds (Table 9). During WYs 2015 and 2016, 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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