



Pacific Island Network Stream Water Quality Protocol

Version 2.0



The Asan River, Guam, War in the Pacific National Historical Park.

NPS

Pacific Island Network Stream Water Quality Protocol: Version 2.0

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Abstract

Water quality is widely used as an indicator of aquatic resource condition and was identified as a high priority “vital sign” by the Pacific Island Network (PACN). This protocol revision follows guidance set forth by the Inventory and Monitoring Division and is a substantive change to the stream portion of the PACN water quality protocol version one. We revised the sampling design based on power analyses of data collected from 2007–2017 and conducted a full scientific review of the stream portion of the original water quality protocol. Sampling design was modified to cull redundant sampling and increase program efficiency, while meeting or exceeding the original goals of the monitoring protocol. Specific changes include: 1) specifying the magnitude of change the sampling design should, to the degree possible, be able to detect within 10 years; 2) removing the goal of establishing ranges for water quality parameter values; 3) establishing total dissolved nitrogen, total dissolved phosphorus, and nitrate + nitrite as primary analytes; 4) eliminating temporary sites; 5) reducing the total number of fixed sites; and 6) reducing sampling frequency to twice a year. Water sampling methods remain unchanged from the previous protocol version. Additional water quality parameters monitored at each site continue to include pH, temperature, dissolved oxygen, total algae (chlorophyll *a* + phycocyanin), turbidity, and specific conductance. Data will be managed under standard operating procedures that ensure data entered in databases are verified for accuracy and certified as scientifically valid after completing established quality assurance and control procedures. Data are published in the public domain and reported to parks via trend reports, web articles, direct communication, and briefing statements.

List of Acronyms

HALE: Haleakala National Park

IMD: Inventory and Monitoring Division

KALA: Kalaupapa National Historical Park

N: Nitrogen

NO₃⁻: Nitrate

NO₂⁻: Nitrite

NPS: National Park Service

NPSA: National Park of American Samoa

P: Phosphorus

PACN: Pacific Island Network

QAP: Quality Assurance Plan

SOP: Standard Operating Procedure

TDN: Total Dissolved Nitrogen

TDP: Total Dissolved Phosphorus

TN: Total Nitrogen

TP: Total Phosphorus

WAPA: War in the Pacific National Historical Park

Standard Operating Procedures (SOPs)

Twenty-five standard operating procedures are associated with the Pacific Island Network Water Quality Monitoring Protocol. To accommodate frequent changes, each SOP is informally published online through the NPS DataStore (<https://irma.nps.gov/DataStore>). The SOPs can be retrieved from NPS DataStore using the citation or the hyperlinked reference code shown in Table 1 below. Versioning tools in NPS DataStore will offer the most current version from these links.

Table 1. Titles, citations, and NPS DataStore reference codes for all SOPs utilized for this protocol.

Title	Citation	NPS DataStore Reference Code
SOP #1: Safety Protocol	Raikow D. (NPS), Farahi A. (NPS), McCutcheon A. (NPS), and Jones T. (NPS). 2024. SOP #1: Safety Protocol. Version 3.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2312918
SOP #2: General Tasks Prior to Conducting Field Work	Farahi A. (NPS), McCutcheon A. (NPS), Jones T. (NPS), Kudray G. (NPS), and Raikow D. (NPS). 2024. SOP #2: General Tasks Prior to Conducting Field Work. Version 2.04. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313356
SOP #3: Training Observers	Farahi A. (NPS), McCutcheon A. (NPS), Jones T. (NPS), Kudray G. (NPS), and Raikow D. (NPS). 2024. SOP #3: Training Observers. Version 1.04. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313355
SOP #4: Using Garmin GPS Units	Wasser M. (NPS). 2024. SOP #4: Using Garmin GPS Units. Version 2.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313354
SOP #5: Downloading and Uploading Data from/to a Garmin® GPS	Wasser M. (NPS). 2024. SOP #5: Downloading and Uploading Data from/to a Garmin GPS. Version 1.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313353
SOP #6: Using ArcGIS Field Maps Application	Wasser M. (NPS) and Pollvogt B. (NPS). 2024. SOP #6: Using ArcGIS Field Maps Application. Version 1.0. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2312685
SOP #7: Selecting Water Quality Sampling Stations	Wasser M. (NPS). 2024. SOP #7: Selecting Water Quality Sampling Stations. Version 3.05. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313352

Table 1 (continued). Titles, citations, and NPS DataStore reference codes for all SOPs utilized for this protocol.

Title	Citation	NPS DataStore Reference Code
SOP #8: YSI EXO Sonde Operation	Farahi A. (NPS) and McCutcheon A. (NPS). 2024. SOP #8: YSI EXO2 Sonde Operation and Calibration. Version 1.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313351
SOP #9: Collecting Freshwater Samples: General Procedures	Farahi A. (NPS), McCutcheon A. (NPS), Jones T. (NPS), and Raikow D. (NPS). 2024. SOP #9: Collecting Freshwater Samples: General Procedures. Version 2.04. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313349
SOP #10: Collecting Groundwater Samples at KAHO	McCutcheon A. (NPS), Farahi A. (NPS), and Raikow D. (NPS). 2024. SOP #10: Collecting Groundwater Samples at Kaloko-Honokōhau National Historical Park (KAHO). Version 2.05. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313347
SOP #11: Collecting Marine Water Samples	McCutcheon A. (NPS), Farahi A. (NPS), Jones T. (NPS), and Raikow D. (NPS). 2024. SOP #11: Collecting Marine Water Samples. Version 3.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313346
SOP #12: Quality Control When Changing Labs	Raikow D. (NPS), Farahi A. (NPS), and McCutcheon A. (NPS). 2024. SOP#12: Quality Control When Changing Labs. Version 1.01. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313345
SOP #13: Post-field Work Procedures and Equipment Maintenance	Farahi A. (NPS), McCutcheon A. (NPS), Jones T. (NPS), and Raikow D. (NPS). 2024. SOP #13: Post-field Work Procedures and Equipment Maintenance. Version 2.0. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313344
SOP #14: Workspace Setup and Project Records Management	Kozar K. (NPS) and Weisenborn K. (NPS). 2024. SOP #14: Workspace Setup and Project Records Management. Version 2.01. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313343
SOP #15: Datasheet Handling Procedures	Kozar K. (NPS) and Weisenborn K. (NPS). 2024. SOP #15: Datasheet Handling Procedures. Version 2.0. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313342
SOP #16: Managing Photographic Images	Kozar K. (NPS) and Weisenborn K. (NPS). 2024. SOP #16: Managing Photographic Images. Version 2.0. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313341

Table 1 (continued). Titles, citations, and NPS DataStore reference codes for all SOPs utilized for this protocol.

Title	Citation	NPS DataStore Reference Code
SOP #17: Preparing YSI Files for Importing into the Database	Kozar K. (NPS) and Weisenborn K. (NPS)., McCutcheon A., Puig-Santana G., Farahi A. 2024. SOP #17: Preparing YSI Files for Importing into the Database. Version 5.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313337
SOP #18: Data Entry and Verification	Kozar K. (NPS) and Weisenborn K. (NPS). 2024. SOP #18: Data Entry and Verification. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313336
SOP #19: Post-season Data Quality Review Certification	Kozar K. (NPS). 2024. SOP #19: Post-season Data Quality Review and Certification. Version 1.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313335
SOP #20: Metadata Development	Kozar K. (NPS) and Weisenborn K. (NPS). 2021. SOP #20: Metadata Development. Version 1.01. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313334
SOP #21: Sensitive Information Procedures	Kozar K. (NPS) and Weisenborn K. (NPS). 2024. SOP #21: Sensitive Information Procedures. Version 1.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313332
SOP #22: Analysis and Reporting	Raikow D. (NPS), Farahi A. (NPS), McCutcheon A. (NPS), and Jones T. (NPS). 2024. SOP #22: Data Analysis and Reporting. Version 1.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313331
SOP #23: Product Delivery Specifications	Kozar K. (NPS) and Weisenborn K. (NPS). 2024. SOP #23: Product Delivery Specifications. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313329
SOP #24: Product Posting and Distribution	Kozar K. (NPS). 2024. SOP #24: Product Posting and Distribution. Version 1.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313295
SOP #25: Revising the Protocol	Jones T. (NPS). 2024. SOP #25: Revising the Protocol. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawai'i National Park, Hawai'i.	2313293

Executive Summary

The National Park Service (NPS) established the Inventory and Monitoring Division (IMD) in order to monitor physical, chemical, and biological elements and processes of ecosystems that represent overall ecosystem health within parks. Water quality is widely used as an indicator of aquatic resource condition and was identified as a high priority “vital sign,” or physical, chemical, and biological element or process of ecosystems that represent the overall health or condition of park resources, by the Pacific Island Network (PACN). The objectives of this protocol are to collect high-quality spatial and time-series data on the water quality in streams of PACN parks, to analyze these data, and to communicate spatial and temporal patterns of water quality parameters, including statistically identifiable trends, in briefing statements, reports, and publications. This data informs natural resource management decisions made facing environmental threats such as climate change, water diversion, chemical and microbial contamination, nutrient enrichment, invasive species, and sedimentation.

This protocol revision follows guidance set forth by IMD and evaluates recommendations put forth in prior stream water quality trend reporting (e.g., Raikow et al. 2024). It is a substantive change to the stream portion of the PACN water quality protocol version one (Jones et al. 2011a). We revised the sampling design based on power analyses of data collected from 2007–2017 and conducted a full scientific review of the stream portion of the original water quality protocol. Methods were modified to cull redundant sampling and increase program efficiency, while meeting or exceeding the original goals of the monitoring protocol. Specific changes include:

- Modifying the objectives by specifying the magnitude of change the sampling design should, to the degree possible, be able to detect within 10 years, and removing the goal of establishing ranges for water quality parameter values.
- Identifying clearly that total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), and nitrate + nitrite ($\text{NO}_3^- + \text{NO}_2^-$) are primary analytes.
- Removing temporary sites.
- Reducing the total number of fixed sites.
- Sampling twice a year, once during the dry season and once during the wet season, instead of four times per year.
- Reducing the number of replicate subsample bottles analyzed for nutrients from 504 to 144.

Sample sites are established within Alelele Stream, Palikea Stream, and Pīpīwai Stream of Haleakalā National Park (HALE), Waikolu Stream of Kalaupapa National Historical Park (KALA), Fagatuitui Stream, Leafu Stream, Amalau Stream, and Lafuti Stream of National Park of American Samoa (NPSA), and Asan River, and Calacag Stream of War in the Pacific National Historical Park (WAPA). Water quality parameters monitored at each site include TDP, TDN, $\text{NO}_3^- + \text{NO}_2^-$, pH, temperature, dissolved oxygen, total algae (chlorophyll *a* + phycocyanin), turbidity, and specific conductance. Water sampling methods remain unchanged from the previous protocol; three replicate

water subsamples consisting of independent grabs are collected at each site and averaged to determine the parameter value for the site, water samples are filtered for analysis of dissolved nutrients and are kept on ice in a dark container until returning to offices, where they are immediately frozen and stored under these conditions until they are sent to a lab for analysis; and additional parameters are measured by using a sonde in the field.

Data are managed under standard operating protocols (SOPs) that ensure data entered into databases are verified for accuracy and certified as scientifically valid after completing established quality assurance and control procedures. Data are published in the public domain and reported to parks via trend reports and briefing statements. A trend report or publication will be published to record baseline conditions for each park, then full reports or publications will be issued as needed and peer-reviewed. Full reports or publications generally consist of an introduction; methods; analyses including linear mixed models, Mann-Kendall or other analyses if necessary, and spatial analyses; results; and a discussion that will include interpretation of results, management implications, and suggested improvements to protocol methods, if applicable. Results will be regularly communicated directly to parks using briefs. Trend reports will include a web article. Briefing reports will be published approximately every year and generally consist of annual updates of stream water quality data to parks with no or minimal statistical analyses or interpretation. Operational reviews and updates to SOPs will be conducted annually.

Acknowledgments

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Authorities

- 43 U.S.C. 1451. Establishment of the Department of the Interior. “There shall be at the seat of government an executive department to be known as the Department of the Interior, and a Secretary of the Interior, who shall be the head thereof.”
- 16 U.S.C. 1. National Park Service Organic Act. “...there is hereby created in the Department of the Interior a service to be called the National Park Service.”
- 16 U.S.C. 661-666. Fish and Wildlife Coordination Act. “...the Secretary of the Interior is authorized...to provide assistance to, and cooperate with, Federal, State, and public or private agencies and organizations in the development, protection, rearing, and stocking of all species of wildlife, resources thereof, and their habitat,”
- 16 U.S.C. § 396b. “Effective July 1, 1961, the detached portion of the Hawaii National Park which lies on the island of Maui is established as a separate unit of the national park system to be known as Haleakalā National Park.”
- 33 U.S.C. §1251. Clean Water Act. “The objective of this chapter is to restore and maintain the chemical, physical, and biological integrity of the Nation’s waters.”
- Executive Order 1190. Protection of Wetlands. “Each agency shall provide leadership and shall take action to minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands in carrying out the agency’s responsibilities...”
- Executive Order 11988. Floodplain Management. “Each agency shall provide leadership and shall take action to...restore and preserve the natural and beneficial values served by floodplains in carrying out its responsibilities...”
- Public Law 95-348. An Act to authorize appropriations for certain insular areas of the United States. “...the War in the Pacific National Historical Park is hereby established.”
- Public Law 96-565. An Act to establish the Kalaupapa National Historical Park. “...to provide that the preservation and interpretation of the settlement be managed and performed in management and interpretation of the settlement’s cultural, historical, educational, and scenic resources.”
- Public Law 100-571. An Act to establish the National Park of American Samoa. “...to preserve and protect the tropical forest and...preserve the ecological balance of the Samoan tropical forest.”
- Public Law 105-391. National Parks Omnibus Management Act of 1998. “The Secretary is authorized and directed to assure that management of units of the National Park System is enhanced by the availability and utilization of a broad program of the highest quality science and information... The Secretary shall undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources.”

1 Background and Objectives

The primary mission of the National Park Service (NPS) is to preserve natural and cultural resources unimpaired for future generations, as stated in the Organic Act of 1916 (NPS 1916; Dilsaver 2016). In 1998, the Secretary of the Interior was instructed to monitor long-term trends in natural resources, as stated in the National Parks Omnibus Management Act (NPS 1998). In response, the NPS created a plan to consolidate and expand existing natural resource monitoring programs (NPS 1999). Parks were further mandated to determine the quality of aquatic natural resources and avoid contamination, to “perpetuate surface waters...as integral components of park...systems” (NPS 2006). Subsequently, the Inventory and Monitoring Division (IMD) was created, assigning national park system units to new biogeographically defined programs called networks (Fancy et al. 2009). IMD monitoring was organized around “vital signs,” or physical, chemical, and biological elements and processes of ecosystems that represent the overall health or condition of park resources, stressors, or other important elements. Monitored resources include water, air, geological features, plants, animals, and natural processes. Water quality, widely used as an indicator of aquatic resource condition, was designated as a high priority vital sign in the Pacific Island Network (PACN; HaySmith et al. 2006).

1.1 The Pacific Island Network

A water quality protocol was implemented by PACN in 2007 across 10 national park units on islands in the Pacific Ocean (Figure 1). Four of these parks, including Haleakalā National Park (HALE), Kalaupapa National Historical Park (KALA), War in the Pacific National Historical Park (WAPA), and National Park of American Samoa (NPSA), encompass perennial streams. Potential threats to these streams include climate change, water diversion, chemical and microbial contamination, nutrient enrichment, invasive species, and sedimentation.

Version one of the PACN water quality protocol addressed freshwater, brackish, and saline ecosystems including streams, anchialine pools, lakes, wetlands, and marine nearshore habitats. The original protocol consisted of several published documents, including a narrative (Jones et al. 2011a), Standard Operating Procedures (SOPs; Jones et al. 2011b), and Reference Materials, which were published as a stand-alone appendix (Jones et al. 2011c). Revision of the PACN water quality protocol has been split into three documents covering marine areas (Raikow et al. 2023), streams (this document), and lentic ecosystems (Raikow et al., in prep.). While the original protocol contains useful information, such as conceptual models, this revision replaces the original protocol with respect to stream methodology. In addition, a Quality Assurance Plan (QAP) applicable to all PACN water quality protocols has been published (Raikow and Kozar 2023), along with SOPs made available on the NPS DataStore. There will no longer be a separate, published Reference Materials (Appendix) document.

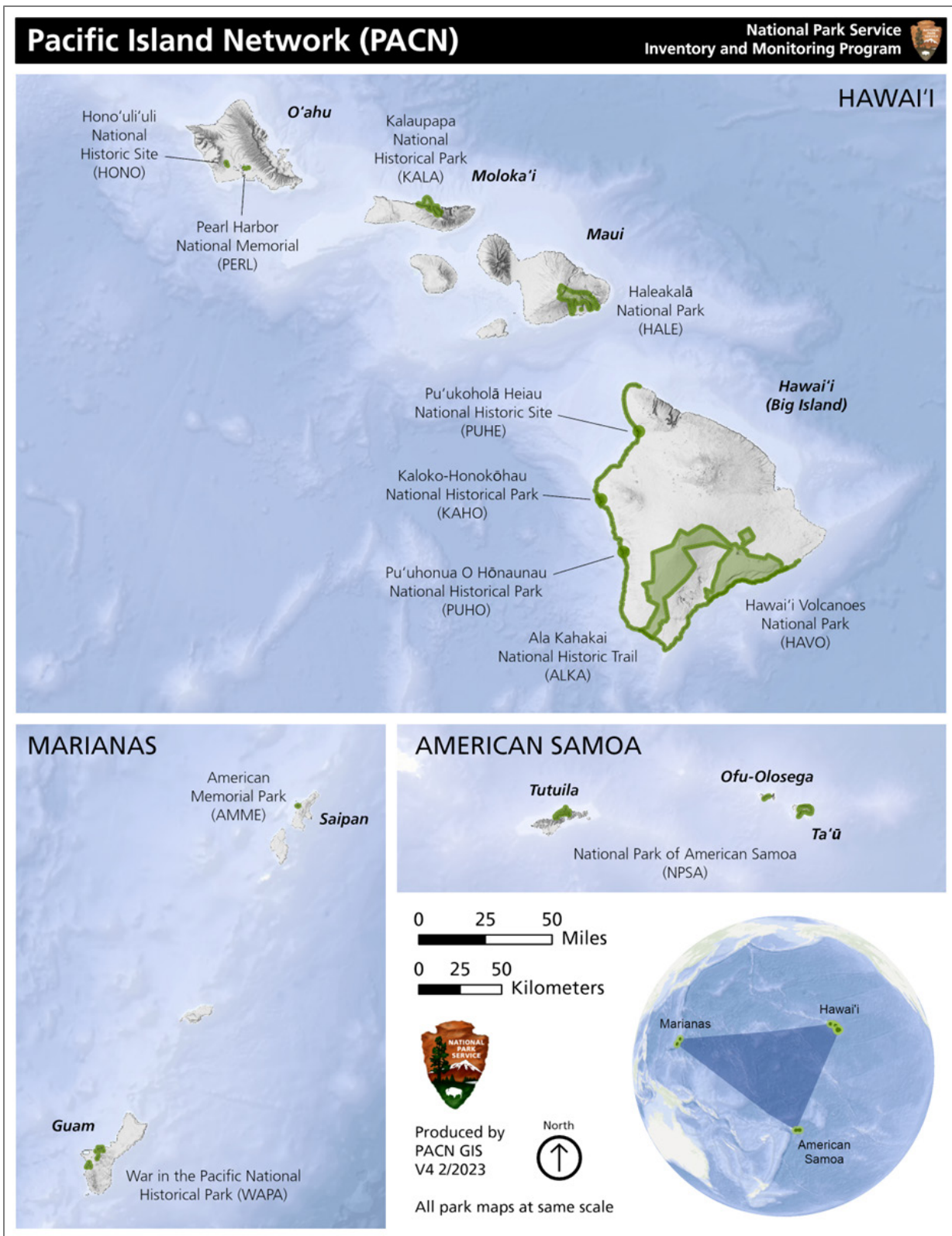


Figure 1. Park units of the Pacific Island Network. Pearl Harbor National Memorial and Hono'uli'uli National Historic Site are not currently monitored by PACN.

NPS

For a general review of monitoring see HaySmith et al. (2006). For justifications of aquatic ecosystem monitoring on Pacific islands see Jones et al. (2011a). For discussions of the El Niño Southern Oscillation, biogeochemistry, and climate change see Raikow et al. (2023). Further information on tropical stream ecology relevant to natural resources monitored by PACN may be found in Raikow et al. (2024). This protocol revision represents a “full scientific protocol review” as outlined by IMD (Mitchell et al. 2018). The review was initiated after completing baseline trend analysis of water quality in Waikolu Stream (Raikow et al. 2024), review of stream water quality data (e.g., Raikow and Farahi 2014, 2015, 2016), and a new power analysis of water quality parameters in streams monitored by PACN (Appendix A).

1.2 Scientific Review Rationale

The purpose of periodic comprehensive scientific review of monitoring protocols is to assess current methods in the light of data collected for 10 years under those methods and determine if major changes to methodology are warranted. Such action is required by both IMD (Mitchell et al. 2018) and the original PACN water quality protocol (Jones et al. 2011a). In contrast, over the course of a long-term monitoring program small adjustments can be made to methodology that do not affect the overall sampling regime, and such adjustments are recorded within SOPs.

1.3 Considerations Affecting Protocol Design

Many components are necessary for the overall design of high-quality monitoring protocols, including clear objectives, defined geographic boundaries, and appropriate sampling design (Lindenmayer and Likens 2010). Safety of personnel is also a high priority (see SOP#1: Safety Protocol, for procedures, checklists, and other materials). For example, sampling in the interest of meeting data collection goals that would require putting personnel at unacceptable risk is prohibited. Further factors affecting this revision include logistical constraints, cost limitations, the PACN stream animal monitoring protocol (Brasher et al. 2011), consultation with the NPS Water Resources Division, and analysis of data collected to date. With respect to water quality monitoring in streams, major aspects of the sampling regime that must be evaluated critically include number of sample sites, location of sample sites, and sampling frequency. These considerations must be made within the ecological context of ecosystem structures and processes.

Because of the unique physical characteristic of linear flow, water in streams derived from wide ranging drainage networks is mixed at tributary confluences and amalgamated at stream mouths. Hence, water quality monitoring programs must choose where to place a limited number of sample sites within a branching drainage network made up of nested sub-watersheds. In theory, such a drainage network can be monitored as whole by sampling a single downstream site. However, many statistical evaluations of alternative lotic water quality sample site placement regimes evaluate large river networks thousands of kilometers long (e.g., Dobbie et al. 2008; Park et al. 2006; Stevens and Olsen 2004), or cover huge areas such as entire American states (e.g., Bunn and Smith 2002; Larsen et al. 2008). These sampling designs place sample sites on tributaries to large rivers that integrate nested watersheds that, while smaller than the whole for the river, are themselves frequently thousands of square kilometers in size.

Other approaches to lotic sample site placement consider where the site may be within local geomorphic contexts within the larger drainage network, and with respect to hydrologic processes that can change dramatically with increasing discharge as streams converge to become large rivers (e.g., Montgomery and MacDonald 2002). Such designs account for considerations that could warrant additional monitoring sites, such as the presence of a potential point-source of contamination, differences in land use or land cover within sub-watersheds, and sheer size. While all of the statistical evaluations of alternative sample regimes cited above are perfectly valid and scientifically important, small tropical islands do not fit these models well.

Patterns observed in streams monitored by PACN, e.g., Waikolu Stream in KALA, illustrate the limitation of applying sampling regimes designed for vast areas to small islands. Waikolu Stream drains a 12 km², undeveloped, well-protected watershed with no point-sources of contamination. There are no major land cover differences between the areas drained by tributaries. Analysis of longitudinal water quality spatial patterns showed only minute absolute differences (Raikow et al. 2023). Such patterns were only detectable due to an unusually dense set of sample sites relative to discrete short-term studies, an unintended by-product of the original sampling regime. While scientifically interesting, high-resolution study of subtle ecosystem processes was not within the purview of the protocol. Further, temporal patterns at individual sample sites were highly correlated with time-series data derived from all other sites in the same stream, illustrating little variation among sites, and such patterns were observed at other PACN monitored streams including those of HALE, NPSA, and WAPA (see data in Raikow and Farahi 2014, 2015, 2016). Based on analyses of PACN-monitored streams, it was therefore recommended that the number of sample sites in streams be reduced, e.g., from eight sites sampled four times a year to one site sampled twice a year in Waikolu Stream (Raikow et al. 2023). Further, all streams monitored by PACN were evaluated to examine whether the power to detect change could be maintained with fewer sample sites and fewer sampling events (Appendix A).

Two patterns found in streams monitored by PACN additionally affected modification of protocol methodology: variability of $\text{NO}_3^- + \text{NO}_2^-$, and spatially heterogeneous physical conditions such as forested reaches and reaches within villages. $\text{NO}_3^- + \text{NO}_2^-$ was more variable than TDN or TDP in Waikolu Stream (Raikow et al. 2024), and high variability of $\text{NO}_3^- + \text{NO}_2^-$ was observed in streams of NPSA (Raikow and Farahi 2015), streams of HALE (Raikow and Farahi 2016), and the Asan River of WAPA (Raikow and Farahi 2014). The variability of $\text{NO}_3^- + \text{NO}_2^-$ was reflected in the power analysis by frequently requiring more sites to achieve a designated level of power when compared to TDN or TDP (Appendix A). Hence, the power goal for $\text{NO}_3^- + \text{NO}_2^-$ was defined differently compared to TDN and TDP in the objectives (see below). The considerations below were made concerning the location and number of sample sites and sampling frequency, and it is noted below when these were used as part of the decision making process for the location and number of sites.

- **Practical limitation:** Accessibility to streams monitored by PACN ranges considerably. For example, Fagatuitui Stream in NPSA drains a small watershed of 0.2 km², has a maximum elevation of 343 m, and can be sampled during a day hike. In contrast, Palikea Stream in HALE drains a watershed of 20.6 km², has maximum elevation of 2320 m, and requires

helicopter operations to access heavily forested high altitude reaches. Hence, full channel lengths are not accessible on a regular basis for some streams.

- **Safety:** PACN parks represent safety challenges for PACN operations. In particular, the choice of safe sample sites is limited by the physical environment in the form of dense forest, lack of trails, exceptionally tall waterfalls and cliffs, deep gulches with limited routes of escape, frequent rock falls, flash flooding, limited contingency resources in the form of long response times by distantly located emergency services and potential need for backcountry rescue, and communication limited by radio-dead zones and lack of cell phone coverage.
- **Statistical Power:** Generally, the fewest number of sites needed to achieve desired power was chosen for each stream. In some streams, however, the number of sites required to achieve power varied between parameters (Appendix A). Due to practical limitations, including budget, it was not possible to achieve desired power for all parameters in all streams.
- **Stream size:** Generally, the furthest downstream, safely accessible, fully freshwater site (not under influence of marine inputs as would be found at stream mouths) was selected. Additional locations included sites above a confluence in order to sample a sub-watershed. Small streams with small watersheds generally had fewer sites than large streams. These decisions were supported by power analyses and are outlined below.
- **Special circumstances:** Some streams contained features of special management concern, e.g., Ohelo Gulch on Palikea Stream, warranting additional sample sites.

1.4 Protocol Objectives

The purpose of ecosystem monitoring is to understand patterns, induced naturally or otherwise, over time and space including both gradual and sudden change (NRC 1990). Clear objectives guide protocol development and contribute to the collection of data relevant to managers (Karydis and Kitsiou 2013). Here, monitoring serves the NPS mission by improving understanding of specific ecosystems under management. Change over time, or trends, alert park natural resource managers of the need to adjust broad management policies or acutely intervene in specific cases. Empirically establishing natural or current patterns allows unusual circumstances or aberrant events to be identified. Hence, the overall goal of this protocol is to provide timely, easily understood, and relevant information on stream water quality to park managers and the public. The objectives of this revised protocol remain the same as the first PACN water quality protocol (Jones et al. 2011a), with the exception that determining the ranges of parameter values has been removed because sufficient data to calculate ranges has been collected or baseline reports describing these values are published (e.g., Raikow and Farahi 2014, 2015, 2016). The primary focus of the program is to evaluate change over time, with specific magnitudes of parameter change to be detected, defined, and quantified using updated power analyses.

The scientific objectives of this protocol are:

- To collect high-quality time-series data on TDP, TDN, $\text{NO}_3^- + \text{NO}_2^-$, temperature, pH, dissolved oxygen, specific conductance, chlorophyll, and turbidity in the perennial streams of PACN parks; to analyze spatial and temporal patterns of water quality parameters, including

statistically identifiable trends; and to communicate findings in briefing statements, reports, and publications.

- To be able to detect a 50% change in TDP, 50% change in TDN, 100% change in $\text{NO}_3^- + \text{NO}_2^-$, 10% change in temperature, 0.5 value change in pH, 10% change in oxygen saturation, 400% change in specific conductance, 400% change in chlorophyll, and 400% change in turbidity; over 10 years with at least 80% power, using alpha of 0.05; to the extent possible.

2 Sampling Design

In accordance with IMD protocol revision guidance and the requirement to use data collected under the original protocol to improve future monitoring efforts, this protocol revision includes changes to methodology based on observations and analyses of data collected to date. Proposed approaches to evaluating changes were evaluated in meetings with the PACN Aquatic Ecologist, PACN Program Manager, regional IMD manager, service wide IMD deputy, and NPS Water Resource Division staff. This section defines sampling design elements, describes the original design used and what has been learned from sampling under that design, and describes a modified design created in response to observations and the protocol objectives above. Likewise, data obtained under the present protocol will serve as the empirical basis for future refinements.

2.1 Summary of Methodological Changes

Changes to the protocol and associated justifications are summarized in Table 2. The objectives of the protocol were modified by removing the goal of determining ranges from water quality parameters and specifying how much change (delta, δ , see 2.2.2 Power, below) the methodology should be able to detect to the extent possible. As part of this revised protocol, a power analysis was conducted using 2007–2017 data (Appendix A). Nutrient analytes were specified as dissolved forms as supported by analysis of dissolved and particulate nutrient fractions (Appendix B).

Table 2. Summary of methodological changes made to the original water quality monitoring protocol for Pacific Island Network parks (Jones et al. 2011a).

Topic	Change	Justification
Objectives	Parameter range determination was removed.	Sufficient data has been collected to determine the range of baseline water quality parameters.
Objectives	Water quality parameters no longer list TN and TP, and now list TDN and TDP.	While the objectives of the original protocol listed TN and TP, the protocol narrative used the terms “total” and “total dissolved” nutrients interchangeably, thus did not explicitly define nutrients to be sampled. Further, in practice, the program filtered water samples in the field, producing TDN and TDP from the outset. The PACN Steering Committee decided to preserve the long-term dataset and retain TDN and TDP. In addition, a study of dissolved and particulate nutrient fractions was conducted, and median dissolved fractions of N and P in streams was at least 90% in most parks (Appendix B).
Objectives	The amount of change to be detected (delta) in terms of linear change was specified for each parameter, rather than evaluating potential power based on methodology and presumed variation and added to the objectives.	Deltas were chosen for each parameter separately based on deltas used in the original water quality monitoring protocol (Jones et al. 2011a), deltas used in other IMD networks for aquatic ecosystems (e.g., Gawley et al. 2016; Starceвич 2013), the results of previous power analyses for other aquatic ecosystems monitored by PACN (Raikow et al. 2023), and stream monitoring results (Raikow et al. 2024).

Table 2 (continued). Summary of methodological changes made to the original water quality monitoring protocol for Pacific Island Network parks (Jones et al. 2011a).

Topic	Change	Justification
Sample Site Selection	Sampling at temporary sites was removed.	A new power analysis using 2007–2017 data showed that sampling fewer sites is sufficient to detect change at most locations (see below).
Total Number of Sites	The total number of sample sites was reduced.	A new power analysis using 2007–2017 data showed that sampling fewer sites is sufficient to detect change at most locations (see below).
Sampling Frequency	Sampling frequency was changed from four times a year to two times a year, within wet and dry seasons.	A new power analysis using 2007–2017 data showed that sampling fewer times per year is sufficient to detect change (see below).

2.2 Sampling Regime

2.2.1 Sampling Frame

Using the terminology reviewed in Albert et al. (2010), a stream network within a park can be considered the statistical “target population,” defined in “geographic space.” If the entire area can be sampled, then the “sampling frame” corresponds to the target population. The purpose of clearly defining the sampling frame is to avoid extending inference derived from limited sampling to inapplicable areas. We can extend this concept to “inference space” by limiting applicability to identified ecological contexts (Mueller et al. 2015). There are three major considerations which would limit the sampling frame to a portion of the target population: safety, accessibility, and ecological stratification such as spatial heterogeneity of physical conditions. Here, selected streams within a park are target populations, and safely accessible waters within selected streams of HALE, KALA, NPSA, and WAPA are the sampling frames, as defined by the original protocol (Jones et al. 2011a). At the discretion of the aquatic ecologist, approval of the program manager, and with permission of parks and landowners as needed, sampling may also occur outside the park boundary for specific scientific or management purposes. This revision is also designed to maintain the long-term PACN data set for stream water quality.

2.2.2 Power

The original protocol (Jones et al. 2011a) evaluated the power of alternative sampling regimes, examining change between two datasets by t-test, with arbitrary δ , using uncited data. Unlike for marine areas and anchialine pools, sample sizes needed to estimate the ability to detect a 10%, 25%, and 50% change in parameter values in streams were not evaluated. Hence, the original power analysis was, as noted by the authors, limited by a lack of data from park areas. The original protocol recommended revisiting analysis of power using data collected under the protocol in subsequent years. Pursuant to that recommendation, a new power analysis was conducted using PACN monitoring data from 2007–2017 (Appendix A). In order to be consistent with power analyses in the original protocol $\alpha = 0.05$ and $\beta = 0.20$ were used (T. Jones pers. comm.). Power analyses of trends were modeled by fitting linear regression models to simulated data sets generated iteratively by drawing from the observed independent parameter variance (Bolker 2008). Wilcoxon tests were also

conducted to assess the number of sites needed to detect an anomalous individual outlying event to identify acute conditions requiring a rapid response by park management.

Delta values were chosen for each water quality parameter separately based on monitoring results of the PACN water quality monitoring program obtained from 2007–2017 (e.g., Raikow et al. 2024) as directed by the original protocol (Jones et al. 2011a). A goal of resource management is to avoid change that results in biological impairment, and monitoring is useful if change is detected before impairment occurs. Deltas were set to: $\delta = 50\%$ for TDP, 50% for TDN, 100% for $\text{NO}_2^- + \text{NO}_3^-$, 10% for temperature, 0.5 for pH, 10% for oxygen saturation, 400% for specific conductance, 400% for chlorophyll, and 400% for turbidity. In addition, these deltas reflect that a large percentage change is needed to create a large absolute change in ecosystems where absolute values for parameters are low, as observed in PACN monitored streams. Rationales for these delta values are provided in Appendix A. A power analysis was conducted for each sampling frame separately. Generally, the sampling frame was an individual stream, and at NPSA, the data were further separated into forested and village reaches in Amalau Stream and Leafu Stream; and upstream standing, or “ponded,” reaches and downstream flowing reaches in Lafuti Stream. Data used in the analysis included both fixed and temporary sites.

For all streams, the number of sites required to detect change decreased with sampling frequency and increasing δ (Appendix A). $\text{NO}_2^- + \text{NO}_3^-$ required more sites than did TDN and TDP, reflecting greater variability of $\text{NO}_2^- + \text{NO}_3^-$. Fewer sites were required to detect change in non-nutrient parameters compared to nutrients. In many streams, sufficient power to detect change can be obtained by sampling fewer sites than described under the original protocol.

2.2.3 Sampling Frequency

The original protocol sampled quarterly. The new power analysis showed that sufficient power to detect change over 10 years can be obtained by sampling twice a year for most parameters and locations. In the interest of lowering costs, and with minimal reduction in power, sites will be sampled twice per year. Sample dates will be selected in the wet and dry seasons of parks.

2.2.4 Number of Sample Sites, Site Locations, Site Dispersion

The original protocol used a split-panel design with a panel of four randomly generated then permanently established sites (fixed sites), and four temporary sites (referred to in the original protocol as random sites) randomly generated for each sampling event. These panels were applied to each park regardless of the number or characteristics of streams sampled. This resulted in some streams being sampled with a high density of sites, e.g., Waikolu Stream with eight sites, and some streams sampled with only two sites. Use of this type of split-panel design is intended to balance consistency between sampling events, i.e., the reduction of potentially confounding factors caused by changing site location, with probabilistic sampling. Although the dispersion of sample sites under the original protocol was intended “to make inferences to the entire target population within the sampling frame” (Jones et al. 2011a), analysis of data collected in Waikolu Stream (Raikow et al. 2024) showed that temporary sites were highly correlated with fixed sites. Thus, there was no identified benefit to using temporary sites. There were, however, high monetary, field-effort, and lab costs. This

protocol revision ceases the use of temporary sites. Sample sites in this revision include fixed sites sampled under the original protocol (Table 3, Figures 2–7):

- ***Kalaupapa National Historical Park:*** Two sites were chosen on Waikolu Stream. FKALA03 was the most downstream site that represented the stream as a whole well (Raikow et al. 2024). FKALA10 was chosen to monitor water quality upstream of diversions by the Moloka‘i Irrigation System. This design meets power goals for all parameters.
- ***Haleakalā National Park:*** Two sites were chosen on Alelele Stream. FHALE06 is the most downstream previously existing site not under potential influence of standing water at the mouth created by periodic natural dikes. A new site is being added to monitor standing water at the mouth, representing new monitoring of ecologically stratified conditions in this stream, specifically standing water at the mouth caused by natural dyking and influenced by the sea. Palikea Stream is now divided into an upper reach above the confluence with Pīpīwai Stream and a lower reach below the confluence. Four sites were chosen in the lower reach of Palikea Stream to achieve power goals for all nutrients and to allow spatial evaluation of Ohe‘o Gulch and potential impacts of visitor use. One site was chosen in the upper reach of Palikea representing the most downstream safely accessible location within a deep and steep-sided gulch subject to dangerous flash flooding. The vast majority of Palikea Stream above the confluence is not accessible. One site was chosen on Pīpīwai due to the small 2.2-km² sub-watershed drained by this stream.
- ***National Park of American Samoa:*** At NPSA, Leafu Stream and Amalau Stream are divided into forested and village sections. A forested and a village site were each chosen for Amalau and Leafu Streams on Tutuila, which meets the power goals. One site was chosen on Fagatuitui Stream due to the small 0.2-km² watershed of this stream. Lafuti Stream on Tau is divided into an upper reach that frequently consists of standing pools and a lower reach that typically has flowing water. Two sites were chosen in each of the upstream and downstream sections of Lafuti Stream. It is not possible to achieve power goals for NO₂⁻ + NO₃⁻ in this stream because high variability in this analyte in upper sections would require at least nine replicated subsamples (27 bottles), which is not reasonable.
- ***War in the Pacific National Historical Park:*** Three sites were chosen for the Asan River to evaluate potential change in the upstream channel caused by recent development along the park perimeter, the influence of more established development, and the total output of impacted areas near the mouth on marine waters. It is not possible to achieve power goals for NO₂⁻ + NO₃⁻ in this stream because high variability in this analyte in upper sections would require more than 10 sample sites (more than 30 bottles), which is not reasonable. One site was chosen for Calacag stream, which meets the power goals.

Table 3. Sample sites in PACN-monitored streams.

Park	Stream	# of Sites	Site Names	Note
KALA	Waikolu	2	- FKALA03 - FKALA10	–
HALE	Palikea (lower)	4	- FHALE01 - FHALE02 - FHALE07 - FHALE16	A new fixed site is being added upstream of Ohe'o Gulch to assess changes that may occur in Ohe'o pools.
	Palikea (upper)	1	FHALE09	–
	Pīpīwai	1	FHALE11	–
	Alelele	2	- FHALE06 - FHALE17	A new fixed site is being added in the downstream estuarine pool to assess this area.
NPSA	Amalau (Forested)	1	FTUT08	–
	Amalau (Village)	1	FTUT07	–
	Leafu (Forested)	1	FTUT02	–
	Leafu (village)	1	FTUT01	–
	Fagatuitui	1	FTUT04	–
	Lafuti (upper)	2	- FTAU04 - FTAU03	It is not possible to achieve power goals for nitrate + nitrite at this stream due to high variability of this analyte.
	Lafuti (lower)	2	- FTAU02 - FTAU01	It is not possible to achieve power goals for nitrate + nitrite at this stream due to high variability of this analyte.
WAPA	Asan	4	- FWAPA01 - FWAPA03 - FWAPA07 - FWAPA11	It is not possible to achieve power goals for nitrate + nitrite at this stream due to high variability of this analyte.
	Calacag	1	FWAPA10	–

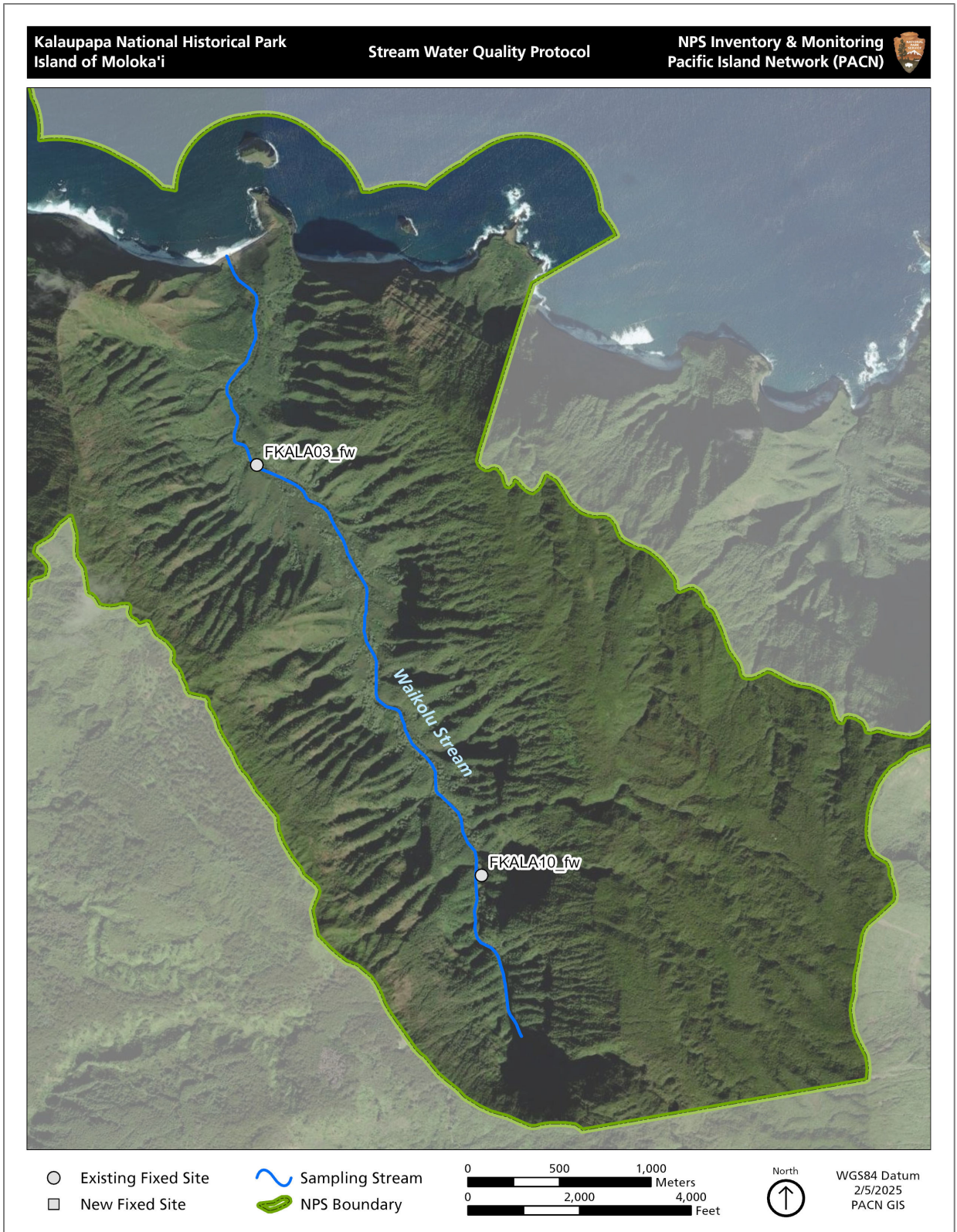


Figure 2. Sample sites in Waikolu Stream, Kalaupapa National Park.
NPS



Figure 3. Sample sites in Alelele Stream, Haleakalā National Park.

NPS



Figure 4. Sample sites in Palikea Stream and Pīpīwai Stream, Haleakala National Park.
 NPS



- Existing Fixed Site
- New Fixed Site
- ~ Sampling Stream
- NPS Boundary



North
WG584 Datum
2/10/2025
PACN GIS

Figure 5. Sample sites in Amalau, Leafu, and Fagatuitui Streams on the island of Tutuila, National Park of American Samoa.
NPS

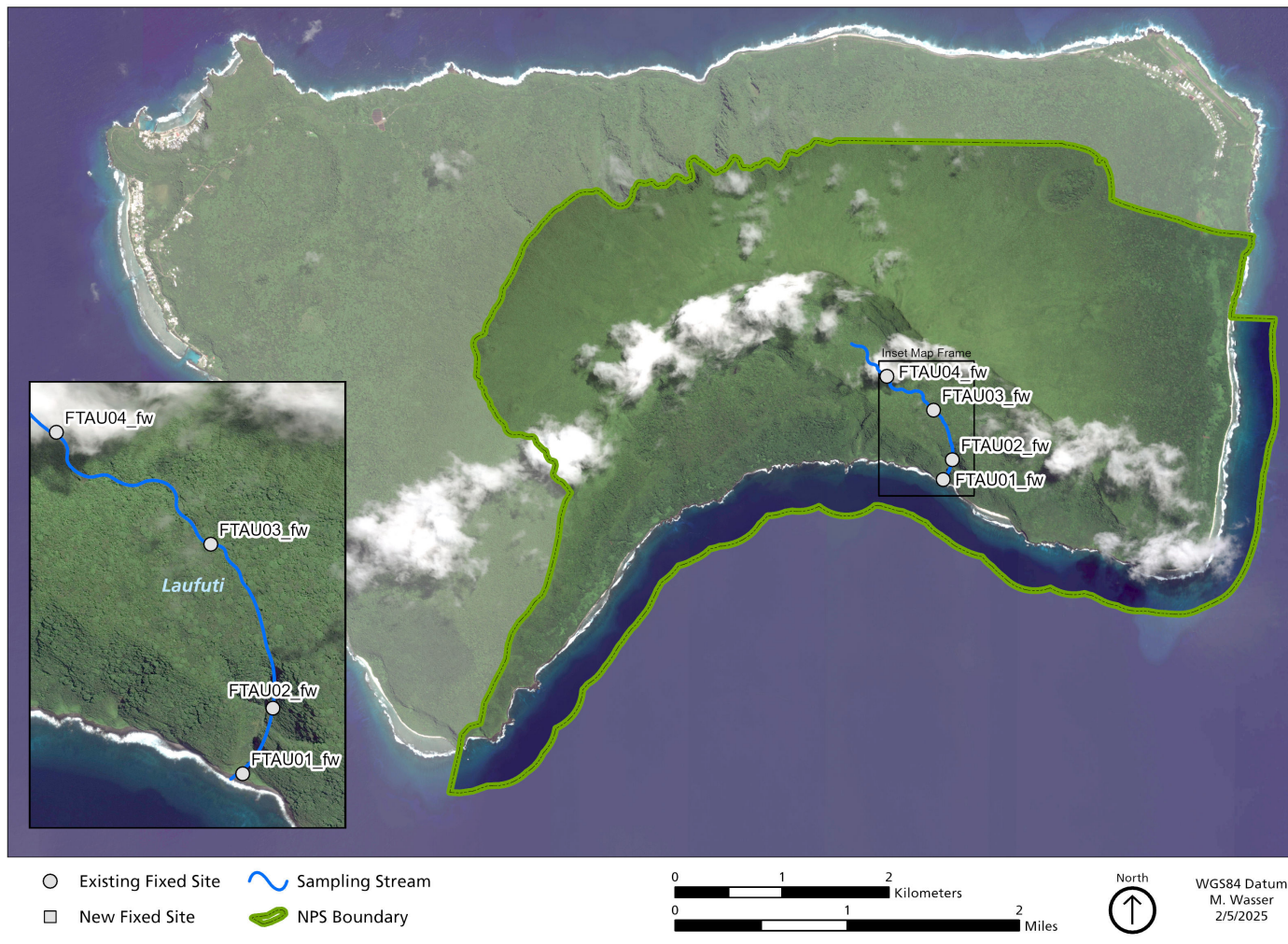


Figure 6. Sample sites in Laufuti Stream on the island of Ta'u, National Park of American Samoa.
NPS



Figure 7. Sample sites in Asan River and Calacag Stream, War in the Pacific National Historical Park.
NPS

2.2.5 Water Quality Parameters

Total phosphorus (TP) and total nitrogen (TN) are measures of all the phosphorus and nitrogen in a sample, in all particulate and dissolved chemical forms, which are called “nutrient species.” Water samples must be filtered to remove particulates to measure total dissolved phosphorus (TDP) and total dissolved nitrogen (TDN). The original protocol was not clear with respect to analyzing TN and TP or TDN and TDP. For example, the executive summary lists TDP and TDN (Jones et al. 2011a, p. xix), while the objectives list TP and TN (p. 20). In practice, the program switched from not filtering samples in the field, which would allow TP and TN to be analyzed, to filtering samples in the field, which would force TDP and TDN to be analyzed, very early on (A. Farahi pers. comm.). Results from the analytical lab contractor as well as the database were labeled TP and TN when the data reflected TDP and TDN (observed by D. Raikow). At least one member of the steering committee believed that TP and TN were being analyzed, when the data were TDP and TDN (observed by D. Raikow). This issue was brought to the attention of the steering committee in 2013, which decided that it was better to preserve the integrity of the long-term data set and continue to measure TDP and TDN, rather than end the time series and change analytes.

A study of dissolved and particulate nutrient fractions was subsequently conducted to assess the proportion of nutrients in dissolved form (Appendix B). The purposes of the study were to measure the proportion of total P and N that is captured by TDP and TDN, determine the best measure for use in this protocol, and maintain the long-term dataset. Results showed that median proportions of dissolved N and P constituted at least 90% of nutrients present in streams of all parks at baseflow, when sampling under this protocol is targeted. Such results should not be surprising because sampling is mandated to occur when field conditions are safe. In the case of Pacific Island streams, sampling at baseflow is generally safe, while high flow conditions are very dangerous. Thus, the original protocol, as well as this revision, specifically target field sampling when particulates are not expected to be present.

Water quality parameters previously monitored at each site remain unchanged and include TDP, TDN, $\text{NO}_3^- + \text{NO}_2^-$, total algae (chlorophyll *a* + phycocyanin), pH, temperature, oxygen (reported by the sonde as both dissolved concentration and saturation), turbidity, and specific conductance. Note that the YSI EXO sonde currently in use by PACN employs a total-algae probe rather than the chlorophyll *a* probe used in the previous YSI 6600 sonde model. Chlorophyll *a* can be calculated from total algae and is comparable to previously collected data. Additional parameters, including TP and TN, may be monitored at the discretion of the aquatic ecologist or program manager. In particular, flood events can be sampled from a safe location in some streams at some times, in which case both filtered and unfiltered samples could be taken to allow evaluation of particulate loads during spates.

3 Field Methods, Data Analysis, Handling, and Reporting

3.1 Planning and Equipment.

Multi-parameter sondes will be used in the field for non-nutrient parameters; currently, these are YSI EXO Sondes. For detailed methods consult SOP #2: General Tasks Prior to Conducting Fieldwork for travel cost accounting, scheduling, field information binder, trip preparation checklist, and master gear list guidance; and SOP #3: Training Observers for guidance on required training for field crew.

3.2 Sonde Operation

Sondes will be calibrated in the lab prior to every sampling trip. Briefly, specific conductance, dissolved oxygen, total algae, turbidity, and pH are calibrated, and calibration results are tabulated in a notebook or through software. See SOP #8: YSI EXO Sonde Basic Operation and Calibration for general procedures.

3.3 Collecting Water Samples

Three replicate subsamples will be collected at each site just below the surface. Each replicate will consist of an independent grab sample. These subsamples are averaged to determine a parameter value for the site. Standard water samples will be filtered for analysis of dissolved nutrients using acid-washed filter towers, currently “Thermo Scientific Nalgene Reusable Filter Holders with Receiver.” Filtration should occur in the field. Water will be filtered using industry-standard 0.47- μ m glass microfiber GF/F filters. Other industry-standard means of filtration, such as in-line 0.47- μ m glass microfiber GF/F filters and syringes, may be used in place of towers when necessary. Immediately after collection and filtration, samples will be kept on ice in a dark container until returning to offices and then immediately frozen. Samples are to be sent to a lab for analysis as soon as possible. Unfiltered samples may be collected for additional studies at the discretion of the aquatic ecologist. Stream water collection procedures are described in detail in SOP #9: Collecting Freshwater Samples.

Other procedures of note include recording GPS locations, navigation directions, and site descriptions, and taking images of sites. No permanent markers are used, but if needed they will be established by PACN via a research permit with the park(s). Consult SOP #4: Using Garmin® GPS Units for guidance on Global Positioning System (GPS) receivers and GPS transfer software. Consult SOP #5: Downloading and Uploading Data from/to a Garmin® GPS, for guidance on uploading field site locations prior to leaving for the field. Additional studies may be conducted to strengthen the water quality dataset, including, but not limited to comparison of filtering methods, field filtering vs. lab filtering, and quality control studies. Filtering equipment and sample bottles will be acid-washed after use.

4 Data Analysis, Handling, and Reporting

Data management, analysis, and reporting are treated as three interrelated steps in managing water quality monitoring information. Additional details and context for this chapter may be found in the PACN Data Management Plan (Dicus 2006), which describes the overall information management strategy for the network, and SOPs #14–24.

4.1 Project Information Management Overview

Project information management is a cyclic process. Specific annual information management tasks for this project and their timing are described in Table 4. Readers may also refer to each respective chapter section below for additional guidance and instructions. The stages of this cycle are described in greater depth in later sections of this chapter, but can be briefly summarized as follows:

- **Preparation:** Training, logistics planning, printing forms and maps.
- **Data acquisition:** Field trips to acquire data.
- **Data entry & processing:** Data entry and uploads into the working copy of the database, YSI data processing, etc.
- **Data verification:** Data in databases is checked against field datasheets to ensure correct entry.
- **Quality review:** Data are reviewed within the database for quality and logical consistency.
- **Metadata:** Documentation of the year's data collection and results of the quality review.
- **Data approval (i.e., certification):** Newly collected data are reviewed within the context of the complete dataset, and sampling events are randomly chosen for further review.
- **Data delivery:** Certified data are delivered for archiving and uploaded to the master project database.
- **Data analysis:** Data are summarized, explored, and statistically analyzed.
- **Product development:** Reports, maps, and other products are generated.
- **Product review:** Reports and other products (e.g., annual briefings) are provided to parks and a peer review manager for the appropriate level of external and internal peer review, and revisions or responses made.
- **Posting & distribution:** Products are published in the Water Quality Portal and NPS DataStore (data is typically published as soon as the data is approved).
- **Archival & records management:** Review analog and digital files for retention (or destruction) according to NPS Director's Order 19 (NPS 2001). Retained files are renamed and stored as needed.
- **Season close-out:** Review and document needed improvements to project procedures or infrastructure, complete administrative reports, develop work plans for the coming season.

Table 4. Annual information management tasks.

Project Stage	Task Description	Responsibility	Timing
Preparation	Notify PACN Data Manager and PACN GIS Specialist of needs for the coming season (field maps, GPS support, training)	PACN Aquatic Ecologist	By Dec 1
	Plan schedule and logistics, including ordering any needed equipment and supplies (SOP #2 General Tasks Prior to Conducting Field Work)	PACN Aquatic Ecologist, PACN Lead Aquatic Biological Science Technician	Continuous
	Prepare and print field maps	PACN GIS Specialist, PACN Lead Aquatic Biological Science Technician	Jan
	Load data dictionary, background maps, and target coordinates into GPS units (SOP #5 Downloading and Uploading Data from/to a Garmin® GPS)	PACN GIS Specialist, PACN Lead Aquatic Biological Science Technician, Technicians	Before each tour
	Ensure that project workspace for the upcoming year is ready for use (SOP #14 Workspace Setup and Project Records Management)	PACN Data Manager	By February 1
	Implement working database copies for each park/set of parks	PACN Data Manager	By February 1
	Provide database/GPS training as needed	PACN Data Manager, PACN GIS Specialist	Continuous
	Train field crew in sampling protocols and safety (SOP #1 Safety Protocol)	PACN Lead Aquatic Biological Science Technician, Technicians	As needed
Data Acquisition	Notify Park Biologist and PACN Aquatic Ecologist of tour itinerary	Technicians	Before each tour
	Collect field observations and position data during field trips	Technicians	During tour
	Review datasheets after each day	Technicians	Daily
Data Entry & Processing	Download GPS data and upload to project workspace on the server (SOP #5 Downloading and Uploading Data from/to a Garmin® GPS)	Technicians	After each tour
	Scan datasheets and upload to project workspace on the server (SOP #15 Datasheet Handling Procedures)	Technicians	After each tour

^A The PACN Monitoring Archive SharePoint site is a hierarchical digital filing system. Staff have read-only access to these files, except where information sensitivity may preclude general access.

^B The NPS DataStore is the online repository of documents and datasets about natural and cultural resources in the parks. Only non-sensitive information is posted to NPS DataStore.

Table 4 (continued). Annual information management tasks.

Project Stage	Task Description	Responsibility	Timing
Data Entry & Processing (continued)	Download and process digital images, store in project workspace on the server (SOP #16 Managing Photographic Images)	Technicians	After each tour
	Download and process YSI files, store in project workspace on the server (SOP #17 Preparing YSI Files for Importing into the Database)	Technicians	After each tour
	Enter data into working copy of the database (SOP #18 Data Entry and Verification)	Technicians	After each tour
	Verification of accurate transcription as data are entered (SOP #18 Data Entry and Verification)	Technicians	After each tour
Quality Review	Quality review and data validation using database tools for verified data (SOP #19 Post-season Data Quality Review Approval)	PACN Lead Aquatic Biological Science Technician, PACN Data Manager	Jan–Mar
	Prepare station coordinate summaries and send to PACN GIS Specialist for spatial data review	PACN Data Manager, PACN GIS Specialist	Jan–Mar
Metadata	Identify any sensitive information contained in the data set (SOP #21 Sensitive Information Procedures)	PACN Aquatic Ecologist, Technicians	Jan–Mar
	Update project metadata records (SOP #20 Metadata Development)	PACN Data Manager	Jan–Mar
Data Certification & Delivery	Certify the season's data and complete the certification report; send certification report to PACN Data Manager (SOP #23 Product Delivery Specifications)	PACN Aquatic Ecologist	April–May
	Upload certified data into master project database, store data files in the PACN Monitoring Archive SharePoint site (SOP #24 Product Posting and Distribution) ^A	PACN Data Manager	May–June
	Finalize and parse metadata records, store in the PACN Monitoring Archive SharePoint site ^A	PACN Data Manager	May–June

^A The PACN Monitoring Archive SharePoint site is a hierarchical digital filing system. Staff have read-only access to these files, except where information sensitivity may preclude general access.

^B The NPS DataStore is the online repository of documents and datasets about natural and cultural resources in the parks. Only non-sensitive information is posted to NPS DataStore.

Table 4 (continued). Annual information management tasks.

Project Stage	Task Description	Responsibility	Timing
Data Certification & Delivery (continued)	Update project GIS datasets and associated metadata records, store in the Monitoring Archive SharePoint site ^A	PACN GIS Specialist	May–June
	Upload dataset to local NPSTORET database and send to WRD	PACN Data Manager	July–August
Data Analysis & Reporting	Plot data for analysis following delivery from lab, plot data for certification, prepare figures for reports	Technicians	As needed
	Examine data for spatial and temporal status and trends (SOP #22 Data Analysis and Reporting)	PACN Aquatic Ecologist	Continuous
	Generate report-quality map output for reports	PACN GIS Specialist	As needed
	Screen all reports and data products for sensitive information (SOP #21 Sensitive Information Procedures)	PACN Aquatic Ecologist, Technicians	As needed
	Prepare draft report and distribute to PACN Program Manager for preliminary review	PACN Aquatic Ecologist	As available
Product Delivery	Submit draft I&M report to Network Program Manager for review	PACN Aquatic Ecologist	As available
	Upload completed report to PACN Monitoring Archive SharePoint site ^A (SOP #23 Product Delivery Specifications)	PACN Aquatic Ecologist or PACN Data Manager	Upon approval
	Deliver other products according to the delivery schedule and instructions (SOP #23 Product Delivery Specifications)	PACN Aquatic Ecologist	Upon completion
Posting & Distribution	Upload certified dataset, metadata, and reports to the NPS DataStore ^B (SOP #24 Product Posting and Distribution)	PACN Data Manager	Upon completion
Archival & Records Management	Store finalized products in the Monitoring Archive SharePoint site ^A	PACN Data Manager	Upon receipt
Season Close-out	Inventory equipment and supplies	PACN Aquatic Ecologist and Technicians	Oct
	Annual operational review to discuss and document needed changes to fieldwork, safety, analysis and reporting procedures	PACN Aquatic Ecologist, Technicians, PACN Data Manager, PACN Program Manager	Dec–Jan

^A The PACN Monitoring Archive SharePoint site is a hierarchical digital filing system. Staff have read-only access to these files, except where information sensitivity may preclude general access.

^B The NPS DataStore is the online repository of documents and datasets about natural and cultural resources in the parks. Only non-sensitive information is posted to NPS DataStore.

4.2 Pre-Season Preparations for Information Management

4.2.1 Set Up of Project Workspace

A section of the PACN SharePoint site is reserved for this protocol, and access permissions are established so that project staff members have access to needed files within this workspace. The PACN aquatic ecologist should make sure that network accounts are established for each new staff member, and that the Data Manager is notified to ensure access to the project workspace and databases. Individual staff members should set up a workspace on their own workstation, with periodic data transfer to the PACN SharePoint site. Backups of the workstation to OneDrive will ensure that no data are lost. Additional details may be found in SOP #14: Workspace Setup and Project Records Management.

4.2.2 GPS Loading and Preparation

The GIS Specialist and PACN Aquatic Ecologist should work together to ensure that target coordinates and data dictionaries are loaded into the GPS units prior to the onset of field work, and that GPS download software is available and ready for use. Additional details on GPS use and GPS data handling may be found in SOP #4: Using Garmin® GPS Units and SOP #5: Downloading and Uploading Data from/to a Garmin® GPS.

4.2.3 Implementation of Working Database Copy

The Data Manager will issue working copies of the database for each park or set of parks and ensure proper access on the part of the project staff. Refer to 4.3 Overview for Database Design for additional information about the database design and implementation strategy.

4.3 Overview of Database Design

The PACN water quality database was created based on the NPSTORET desktop database application, but is modified and condensed to deal specifically with PACN water quality needs. NPSTORET is a Microsoft Access database designed around a series of templates that allow users to describe physical, chemical, and biological water quality monitoring activities in a format compatible with the EPA's STORET Import Module (SIM v.2). PACN data management staff designed the PACN water quality database following the hierarchical data table organization of the Natural Resource Database Template. The PACN data management staff is responsible for development and maintenance of the database, including customization of data summarization and export routines. The PACN water quality database has built in functionality for converting data into the correct format for importation into NPSTORET.

The database consists of two components: one for entering, editing and error-checking data for the current season (working database copy), and one that contains the complete set of certified data for the monitoring project (master project database). Each of these components is based on an identical underlying data structure. The working database is implemented in Microsoft Access.

Both components have an associated front-end database application ("user interface" with forms and queries) implemented in Microsoft Access. The working database application has separate screens for data entry, data review, and quality validation tools. The master database application contains the

analysis and summarization tools, including pre-formatted report output and exports to other software (e.g., for analysis and graphics production). This front-end application arrangement allows for modification and update of the user interface with no disruption to data entry continuity. The improved front-end file can be distributed to data entry staff, who link it to the back-end file, discard the outdated front-end file, and proceed with their data entry work. Under this arrangement, data entry staff has no need to open the back-end file, thereby reducing the risk of improper deletions or other inadvertent data loss occurring within the protocol-specific data tables. In addition, a multi-user environment can be accommodated by storing the back-end file on a server available to all users via a computer network.

During the field season, each project crew will be provided with their own copy of a working database into which they enter, process, and quality-check data for the current season. Once data for the field season have been certified, they will be uploaded into the master database, which is then used to inform all reporting and analysis. This upload process is performed by the Data Manager, using a series of pre-built append queries.

4.4 Data Entry and Processing

The components of entering data into the working database are described in SOP #18: Data Entry and Verification. Each data entry form has built-in quality assurance components such as pick lists and validation rules to test for missing data or illogical combinations. All described data procedures have user manuals that are included in the SOPs associated with this protocol.

4.4.1 Regular Data Backups

Upon opening the working database, the user will be prompted to make a backup of the underlying data. It is recommended that this be done on a regular basis, perhaps every day that new data are entered, to save time in case of mistakes or database file corruption. All such backups may be deleted after the data have passed the quality review and been certified.

4.4.2 Data Verification

Data verification is a quality assurance measure to ensure data have been properly entered into databases and consists of checking original datasheets against database entries. This will be done for all data entered into the database.

Analyses performed to detect trends require data that are recorded properly and have acceptable precision and minimal bias. Poor quality data can limit detection of subtle changes in ecosystem patterns and processes and may lead to incorrect conclusions. Quality assurance/quality control (QA/QC) procedures applied to ecological data include four procedural areas (or activities), ranging from simple to sophisticated, and inexpensive to costly:

- Defining and enforcing standards for electronic formats, locally defined codes, measurement units, and metadata.
- Checking for unusual or unreasonable patterns in data.
- Checking for comparability of values between data sets.

- Assessing overall data quality.

To the greatest extent possible, the water quality database application incorporates QA/QC strategies involving the first activity (defining and enforcing standards). The database design and the allowable value ranges assigned to individual fields within the data tables help to minimize the potential for data entry errors and/or the transcription of erroneously recorded data. The other activities are integrated in the quality review phase (for more details, see section 4.5, Data Quality Review, and SOP #19: Data Quality Review and Certification).

4.4.3 Field Form Handling Procedures

As the field data forms are part of the permanent record for project data, they should be handled in a way that preserves their future interpretability and information content. To minimize the possibility of data loss, hardcopy data forms and field notebooks should be stored in a well-organized fashion in a secure location, with scanned data forms stored on the PACN data server (for more details see SOP #13: Field Form Handling Procedures).

4.4.4 Image Handling Procedures

Photographic images document changes over time to sampling sites and are an important part of the data record. Procedures for downloading and processing photographic images collected by project staff or volunteers while conducting water quality monitoring are described in SOP #16: Managing Photographic Images.

4.4.5 GPS Data Procedures

GPS data should be downloaded by the field crew from the units at the end of each field trip and stored in the project workspace (SOP #14: Workspace Setup and Project Records Management). The Field Lead should periodically review the processed GPS data to make sure that any problems are identified early on in the data collection process.

4.5 Data Quality Review

4.5.1 Quality Review Tool

The database has a Quality Review tool that contains queries that check for unusual or unreasonable patterns in data and the comparability of values between data sets, and assess overall data quality. The Field Lead should run this tool and fix any errors that are detected, flag data, or notate why the records are correct. A Quality Review Report can be generated and will be submitted as metadata for data quality.

4.5.2 Geospatial Data

The Data Manager and GIS Specialist will work together to review the surveyed coordinates and other geospatial data for accuracy. The purpose of this joint review is to make sure that geospatial data are complete and reasonably accurate, and to determine which coordinates will be used for subsequent mapping and field work.

4.6 Metadata Procedures

Data documentation is a critical step toward ensuring that data sets are usable for their intended purposes well into the future. This involves the development of metadata, which can be defined as structured information about the content, quality, condition, and other characteristics of a given data set, both tabular and spatial. Additionally, metadata provide the means to catalog and search among data sets, thus making them available to a broad range of potential data users. Metadata for all PACN monitoring data will conform to Ecological Metadata Language (EML) guidelines and will contain all components of supporting information such that the data may be confidently manipulated, analyzed, and synthesized. The Data Manager will develop and parse the metadata and it will be published in NPS Data Store along with the data package. For specific instructions, refer to SOP #20: Metadata Development.

4.7 Data Certification and Delivery

After the data have been entered and verified, they need to be certified by the PACN aquatic ecologist for quality, completeness, and logical consistency. Data certification is a benchmark in the project information management process that indicates that: 1) the data are complete for the period of record; 2) they have undergone and passed automated database quality assurance checks (Quality Review); and 3) they are appropriately documented and in a condition for archiving, posting and distribution as appropriate. Data certification consists of checking 10% of data records for accuracy whereby less than 90% accuracy triggers further review, and visual data exploration to identify potentially anomalous results. Certification is not intended to imply that the data are completely free of errors or inconsistencies, which may or may not have been detected during quality assurance reviews.

To ensure that only quality data are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. The PACN aquatic ecologist is primarily responsible for completing a PACN Project Data Certification Form, available in Appendix 21b in SOP# 23: Product Delivery Specifications. This brief form should be submitted with the certified data.

4.7.1 Data Edits After Certification

Due to the high volume of data changes and/or corrections during data entry, it is not efficient to log all changes until after data are certified and uploaded into the master database. Prior to certification, daily backups of the working database provide a crude means of restoring data to the previous day's state. After certification, all data edits in the master database are tracked in an edit log so that future data users will be aware of changes made after certification. In case future users need to restore data to the certified version, we also retain a separate, read-only copy of the original, certified data for each year in the PACN Monitoring Archive SharePoint site.

4.8 Data Analysis

For a review of trend analysis of water quality data see Raikow et al. (2023).

Different temporal patterns qualify as trends. An abrupt change in a parameter across a short time period as the result of a discrete event is often called a “step-change” or “intervention”. Consistent monotonic change in the parameter over a qualitatively extended time period, either positive or negative, is a trend, while a correlation describes the degree of linear association between two parameters. Some statistical correlation values form the basis of a trend test, such as the non-parametric correlation coefficient Mann-Kendall Tau. Specification of a model describing relationships between predictors and an outcome of interest is a regression. Regression of a time variable on an outcome of interest is the basis for a Wald test of trend. The narrative section of this protocol is written to be sufficiently broad concerning trend analyses to allow the assessment and use of new methods as they emerge and allow expansion of methods as datasets increase in size. Specific statistical procedures are described in detail, and updated as necessary, in the SOPs (e.g., SOP #22: Analysis and Reporting). In general, statistical analyses should conform to accepted scientific practices. The goals of trend analysis here are to describe data distribution, identify outliers, assess seasonality, and describe trends. Future analyses may include forecasting and other time series analyses.

Data should be excluded from analyses if they are affected by instrumentation or procedural error. Outliers should be evaluated for exclusion from trend analyses if caused by environmental conditions not normally encountered, or by “identifiable disturbances” (Mueller et al. 2015). Such data may be true measurements of ecosystem conditions, and may provide important insights into ecosystem processes, and therefore should be reported. Care must be taken, however, when deciding whether such data should be included in temporal trend analyses, as they could represent conditions not present during other sampling and misrepresent the error term. Moreover, quarterly or bi-annual sampling rates cannot be expected to capture the entire range of naturally occurring hydrological conditions. This means that inference spaces must be clearly defined in analyses, especially reflecting the hydrological regime sampled. Naturally occurring outliers should be plotted with other data if identified as different and not included in correlations and regressions, because they are outside the inference space, but still represent important data. Databases allow for flagging of data as either rejected due to instrument or procedural error, or representative of ecosystem conditions, but excluded from trend analysis.

Distributional assumptions are needed for some statistical analysis approaches. Normality assessment allows proper selection of parametric or non-parametric tests. Distributions will be assessed for left-censorship due to detection limits for some parameters. Here, non-detects are treated as the detection limit for statistical purposes. Right-skewness may be present, even with exclusion of naturally occurring outliers. Right-skewness in water quality parameters can be caused by infrequent but natural events for continuous or daily measurements.

Thus, is it possible that water quality parameters measured here may display less, or no, right-skewness. Such factors affecting parameter value distributions must be expressed when reporting results. Such factors must also be considered when using data distributions used to establish ranges of “expected” values for use in evaluating future data. Future parameter values that deviate from

ranges established by past data might signal a disturbance or the beginning of a trend, if outliers are properly identified.

Choice of statistical tests is subject to data quality. Censoring, or the limitation of possible values due to detection limits or a lower limit of zero, can cause datasets to be non-normal by truncating the distribution. For example, TDP, chlorophyll, and turbidity were regularly censored in marine PACN waters from 2009–2015 because values were below detection limits (Raikow et al. 2021). No trend analysis will be conducted for instances where more than 50% of the entire parameter dataset is censored (after Weissinger and Sharrow 2018). The non-parametric Mann-Kendall Tau will be used to assess trend in nutrients, chlorophyll, and turbidity due to truncation of distributions by censoring. Trends in non-censored parameters will be analyzed by linear mixed model (VanLeeuwen et al. 1996). Data analysis will be completed using the latest version of R (e.g., R Core Team 2020). Mann-Kendall tests will be evaluated using the *EnvStats* package for R (Millard 2013). Mixed models will be evaluated with the *lmerTest* package (Kuznetsova et al. 2016) or appropriate replacement as new, more efficient packages are developed. Guidelines for statistical analysis are described in SOP #22: Data Analysis and Reporting.

4.9 Reporting and Product Development

Reports are to follow standard NPS formats. A short internal NPS communique will be issued to parks when an important trend or acute event is discovered. Annual briefs are issued to parks to summarize newly certified data. All certified data, including data newly certified, are presented in briefs with time-series graphs. A list of important results is presented, but the brief does not contain statistical analyses or in-depth interpretations. A trend report or publication will be issued for each park to establish baseline conditions, and subsequent reports or publications issued as needed; e.g., if unusual ecological conditions occur. Trend reports are externally reviewed NPS Science Reports (SR); see SOP #22: Statistical Analysis and Reporting. Results will be regularly communicated directly to parks and any trend reports will include a web article.

4.10 Product Delivery, Posting and Distribution

Refer to SOP #23: Product Delivery Specifications for the complete schedule for project deliverables and the people responsible for them, and for detailed instructions on how to deliver final products. Final products will be available from the NPS Integrated Resource Management Applications Portal (For more information, refer to SOP #24: Product Posting and Distribution).

4.10.1 STORET

The EPA has developed and maintained STORET as a database to house ambient water quality data collected by states, federal agencies, volunteer monitoring groups, and other entities. The Natural Resources Management Guideline (NPS-77) states that the NPS should provide water quality monitoring data to STORET as the national water quality repository. These archived data are then accessible to the public. Archiving PACN water quality data in STORET on an annual basis is a requirement in order to receive water quality vital signs funding from the Water Resources Division.

The NPS STORET database is maintained by the NPS Water Resources Division (WRD). To facilitate archiving NPS data in STORET, the WRD has developed a series of Access-based templates (called NPSTORET), patterned after the Natural Resource Data Templates, for Networks to use to enter their water quality data in a STORET-compatible format ([DataStore - NPSTORET v.2.3](#))

All water quality data collected by PACN will be managed according to guidelines from the WRD. The PACN water quality database was created based on the NPSTORET desktop database application, but is modified and condensed to deal specifically with PACN water quality needs. PACN data management staff will maintain a desktop copy of NPSTORET, which will be populated from the PACN water quality database annually after verification and certification of the dataset has occurred. PACN's NPSTORET contents will be transferred annually to NPS Water Resource Division for uploads to the STORET National Data Warehouse. Although WRD's data dissemination needs dictate a monthly schedule for uploads to their data warehouse, PACN data collection and summation activities will be on an annual schedule requiring data uploads to the master WRD database only once a year.

Data from the STORET Data Warehouse are available to the public through the National Water Quality Monitoring Council's Water Quality Portal (<https://www.waterqualitydata.us/>). The Water Quality Portal is a distribution portal that, in addition to providing data from the STORET Data Warehouse, also serves up the U.S. Geological Survey's National Water Information System data and the U.S. Department of Agriculture's STEWARDS data (<https://www.waterqualitydata.us/orgs/>). It is a "one-stop-shop" for readily available water quality data provided in a common format for anywhere in the country.

4.10.2 Special Procedures for Sensitive Information

Products that have been identified upon submission by the PACN aquatic ecologist as containing sensitive information will either be revised into a form that does not disclose the locations of sensitive resources or withheld from posting and distribution. When requests for distribution of the unedited version of products are initiated by the NPS, by another federal agency, or by another partner organization (e.g., a research scientist at a university), the unedited product (e.g., the full data set that includes protected information) may only be shared after a confidentiality agreement is established between NPS and the other organization. For more information, refer to SOP #21: Sensitive Information Procedures.

All official Freedom of Information Act (FOIA) requests will be handled according to NPS policy. The PACN aquatic ecologist will work with the Data Manager and the FOIA representative(s) of the park(s) for which the request applies.

4.11 Archival and Records Management

All project files should be reviewed and organized by the PACN aquatic ecologist on a regular basis. Decisions on what to retain and what to destroy should be made following guidelines stipulated in NPS Director's Order 19, which provides a schedule indicating the amount of time that the various

kinds of records should be retained (refer to SOP #14: Workspace Setup and Project Records Management). Operational reviews and SOP updates will be conducted annually and uploaded to NPS DataStore.

4.12 Season Close Out

After the conclusion of the field season, the PACN aquatic ecologist, Data Manager, and GIS Specialist should meet to discuss the recent field season, and to document any needed changes to the field sampling protocols, the working database application, or to any of the SOPs associated with the protocol. Refer to the section on Data Entry and Verification for additional close-out procedures not specifically related to project information management.

4.13 Changing Laboratory Contracts

Nutrient analyses are conducted by labs under an agreement or contract to NPS. Lab quality control standards defined by NPS are used to determine eligibility to bid on laboratory analysis contracts. Should a new laboratory be contracted during the course of monitoring, consult SOP #10: Quality Control When Changing Labs.

4.14 Modifying the Protocol

Generally, small changes to field, data management, or other procedures are documented in the SOPs, which are updated annually. Operational reviews will occur annually and precede SOP edits, as the PACN program manager and aquatic ecologist will determine what level of revisions and scientific review are required, as outlined in Mitchell et al. (2018) and/or subsequent updates from the IMD program.

5 Operational Requirements

5.1 Facilities and Equipment

Facility support, office space, data management, GIS services, and supply requirements will be coordinated through the PACN program manager, in consultation with the aquatic ecologist. In some instances, parks will provide space for long-term storage of field gear. Analytical laboratory services are required through an agreement or contract. Significant equipment is needed to maintain all water quality activities, including sondes and probes. Maintenance and repairs are required for sondes and probes, and the estimate in Table 5 is based on estimated average annual cost of maintenance over the expected life of the device. Supplies include calibration chemicals, sample bottles, filter towers, and filters.

Table 5. Protocol expenses.

Staff ^A	Daily Salary and Benefits (\$)	Prep Work (days)	Full-rate Travel (days)	In-Transit Travel (days)	Data Tasks (days)	Non-Travel Field (days)	Total Work (days)	Total Salary (\$)	M&IE Full Rate (\$) ^{B,C}	M&IE in Transit (\$) ^{B,D}	Lodging (\$) ^{B,E}	Total Travel (\$)	Total Costs (\$)
Program Manager	558	–	–	–	7	–	7	3,906	–	–	–	–	3,906
Aquatic Ecologist	483	–	–	–	7	–	7	3,381	–	–	–	–	3,381
Data Manager	470	–	–	–	7	–	7	3,290	–	–	–	–	3,290
Lead Biotech	356	2	2	2	4	4	14	4,984	244	183	1,416	1,889	6,827
KAHO Biotech	356	2	2	2	7	4	17	6,052	244	183	1,416	1,889	6,480
KALA Biotech	356	2	–	–	2	1	5	1,780	–	–	–	–	1,780
NPSA Biotech ^F	356	8	6	4	–	6	24	8,544	–	–	–	–	8,544
Analytical costs ^G	–	–	–	–	–	–	–	–	–	–	–	–	6,439
Calibration Supplies ^H	–	–	–	–	–	–	–	–	–	–	–	–	4,000
Sondes ^I	–	–	–	–	–	–	–	–	–	–	–	–	10,000
Grand total (\$)	–	–	–	–	–	–	–	–	–	–	–	–	54,647

^A Salary and benefits estimated for a GS-13 step 1, GS-11 step 8, GS-12 step 1, and GS-9 step 4, in Hawaii, 2025; also assumes no WAPA biotech support.

^B “Isle of Hawai’i: other”. Travel for stream animal monitoring trips, during which water quality sampling is done, is not included in this table.

^C \$122 M&IE, for Maui 2025.

^D 75% of full M&IE rate.

^E \$354, maximum lodging for Maui.

^F Total for two biotechs, stream water quality sampling only.

^G 144 sample bottles at UH Hilo 2025 price schedule, including bottle and tower washing.

^H Calibration supplies for the stream portion of all PACN water quality monitoring.

^I Four full sonde set-ups including probes at \$25,000 each, divided by ten to arrive at average annual cost and assuming a ten-year lifespan.

5.2 Start-Up Costs

Start-up costs are enumerated separately from annual monitoring and related maintenance expenses. As this protocol is already underway, there are no new start-up costs.

5.3 Annual Budget

Expenses are based on calculating the cost per day of staff, with one lead full-time PACN technician stationed at HAVO, one technician stationed at KAHO, and technicians partially funded by PACN and stationed at other parks (Table 5). Travel costs are based on the “Isle of Hawai‘i: other” per-diem category. As this protocol, sample design, field visit schedule, safety and other considerations evolve this budget will also evolve. Expenses include salary (with COLA and benefits), travel, and supplies. Existing funds will be used to support salaries, supplies, travel, and training expenses.

5.4 Support Provided by Parks

Technicians at outlying parks are funded by PACN and the host park. Park staff, interns, and volunteers will assist a PACN field lead in conducting fieldwork as required by the park’s specific safety protocols.

6 Personnel Requirements and Training

Responsibilities of the PACN aquatic ecologist include:

- Managing protocol implementation.
- Serving as project point-of-contact.
- Formally supervising technicians.
- Ensuring that all safety policies, procedures, and training requirements are met.
- Tracking project progress.
- Initiating and coordinating methodological, safety, and budgetary improvements.
- Participating in fieldwork and training.
- Directly performing, delegating, and/or coordinating data analysis.
- Maintaining project record archives.
- Monitoring project spending.
- Certifying data.
- Analyzing data.
- Writing data, analytical, and other reports.
- Producing a web article with any report and communicating directly with parks to inform them of results.
- Reporting project status to the program manager.

PACN biological technicians and park staff will shoulder most day-to-day tasks. Responsibilities of technicians include:

- Having primary responsibility for logistical and travel planning, preparation for execution of fieldwork, and post-field procedures.
- Training field personnel.
- Ensuring adherence to safety procedures by other field crew members.
- Acquiring and maintaining equipment.
- Analyzing data.
- Recording, entering, and verifying data.
- Writing required field and other reports.

Other relevant PACN personnel include the data manager, GIS specialist, and program manager.

Literature Cited

- Albert, C.H., N.G. Yoccoz, T.C. Edwards Jr., C.H. Graham, N.E. Zimmermann, and W. Thuiller. 2010. Sampling in ecology and evolution—bridging the gap between theory and practice. *Ecography*, 33(6), 1028–1037.
- Bolker, B.M. 2008. *Ecological Models and Data in R*. Princeton University Press, Princeton, New Jersey.
- Brasher, A.M.D., T. Jones, A.C. Farahi, M.P. Miller, and K. Kozar. 2011. Stream monitoring protocol: fish, shrimp, and snails; Pacific Island Network. Natural Resource Report NPS/PACN/NRR—2011/468. National Park Service, Fort Collins, Colorado.
- Bunn, S.E., and M.J. Smith. 2002. Design and implementation of an ecosystem health monitoring program for streams and rivers in Southeast Queensland, Australia: an overview. *Bulletin of the North American Benthological Society* 1:1–17.
- Dicus, G.H. 2006. Data management plan for the Pacific Island Network. National Park Service, Pacific Island Network, Hawaii National Park, Hawaii.
- Dilsaver, L.M. 2016. *America's National Park System: The critical documents*, second edition. Rowman and Littlefield Publishers, Lanham, Maryland.
- Dobbie, M.J., B.L. Henderson, and D.L. Stevens Jr. 2008. Sparse sampling: spatial design for monitoring stream networks. *Statistics Surveys* 2:113–153.
- Fancy, S.G., J.E. Gross, and S.L. Carter. 2009. Monitoring the condition of natural resources in US national parks. *Environmental Monitoring and Assessment* 151:161–174.
- Gawley, W.G., B.R. Mitchell, and E.A. Arsenault. 2016. Northeast Temperate Network lakes, ponds, and streams monitoring protocol: 2015 revision. Natural Resource Report NPS/NETN/NRR—2016/1225. National Park Service, Fort Collins, CO.
- HaySmith, L., F.L. Klasner, S.H. Stephens, and G.H. Dicus. 2006. Pacific Island Network vital signs monitoring plan. Natural Resource Report NPS/PACN/NRR—2006/003. National Park Service, Fort Collins, Colorado.
- Jones, T., D. McKay, K. DeVerse, and K. Kozar. 2011c. Water quality vital signs monitoring protocol for the Pacific Island Network - Appendixes: Version 1.0. Natural Resource Report NPS/PACN/NRR—2011/419. National Park Service, Fort Collins, Colorado.

- Jones, T., D. McKay, K. DeVerse, K. Kozar, K.L. Kramer, A. Farahi, and G. Dicus. 2011b. Water quality vital signs monitoring protocol for the Pacific Island Network: Standard operating procedures; Version 1.0. Natural Resource Report NPS/PACN/NRR—2011/420. National Park Service, Fort Collins, Colorado.
- Jones, T., K. DeVerse, G. Dicus, D. McKay, A. Farahi, K. Kozar, and E. Brown. 2011a. Water quality vital signs monitoring protocol for the Pacific Island Network: Volume 1; Version 1.0. Natural Resource Report NPS/PACN/NRR—2011/418. National Park Service, Fort Collins, Colorado.
- Karydis, M., and D. Kitsiou. 2013. Marine water quality monitoring: a review. *Marine Pollution Bulletin* 77:23–36.
- Kuznetsova, A., P.B. Brockhoff, and R.H.B. Christensen. 2016. lmerTest: Tests in Linear Mixed Effects Models. R package version 2.0-33.
- Larsen, D.P., A.R. Olsen, and D.L. Stevens Jr. 2008. Using a master sample to integrate stream monitoring programs. *Journal of Agricultural, Biological, and Environmental Statistics*, 9:243–254.
- Lindenmayer, D.B., and G.E. Likens. 2010. The science and application of ecological monitoring. *Biological Conservation*, 143(6):1317–1328.
- Millard, S.P. 2013. Package “EnvStats”.
- Mitchell, B., A. Chung-MacCoubrey, J. Comiskey, L. Garrett, M. MacCluskie, B. Moore, T. Philippi, G. Sanders, and J.P. Schmit. 2018. Inventory and Monitoring Division protocol review guidance. Natural Resource Report NPS/NRSS/IMD/NRR—2018/1644. National Park Service, Fort Collins, Colorado.
- Montgomery, D.R., and L.H. MacDonald. 2002. Diagnostic approach to stream channel assessment and monitoring. *Journal of the American Water Resources Association* 38:1–16.
- Mueller, D.K., T.L. Schertz, J.D. Martin, and M.W. Sandstrom. 2015. Design, analysis, and interpretation of field quality-control data for water-sampling projects: U.S. Geological Survey Techniques and Methods, book 4, chap. C4, 54 p.
- National Park Service (NPS). 1916. The National Park Service Organic Act of 1916. 16 U.S.C. § 1 et seq.
- National Park Service (NPS). 1998. National Parks Omnibus Management Act of 1998. Pub. L. No. 105–39, 112 Stat. 3497.
- National Park Service (NPS). 1999. The natural resource challenge. U.S. Department of the Interior, National Park Service, Washington, D.C.

- National Park Service (NPS). 2001. Director's order 19: Records management. U.S. Department of the Interior, National Park Service, Washington, D.C.
- National Park Service (NPS). 2006. Management policies 2006. Department of the Interior, National Park Service, Washington, D.C.
- National Research Council (NRC). 1990. Managing troubled waters: The role of marine environmental monitoring. National Academy of Sciences, National Academy Press, Washington, D.C.
- Park, S.Y., J.H. Choi, S. Wang, and S.S. Park. 2006. Design of a water quality monitoring network in a large river system using the genetic algorithm. *Ecological Modelling*, 199:289–297.
- R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>
- Raikow, D.F., A.C. Farahi, A.L. McCutcheon, and K. Kozar. In review. Pacific Island Network Standing Water Quality Protocol, Version 2.0, Science Report NPS/PACN/SR—2025/XXXX, National Park Service, Fort Collins, Colorado.
- Raikow, D.F., and A.C. Farahi. 2014. Water quality in the Asan River, War in the Pacific National Historical Park: Summary report 2007–2012. Natural Resource Data Series NPS/PACN/NRDS—2014/662. National Park Service, Fort Collins, Colorado.
- Raikow, D.F., and A.C. Farahi. 2015. Water quality in streams of National Park of American Samoa: Summary report 2009–2011. Natural Resource Data Series NPS/NPSA/NRDS—2015/753. National Park Service, Fort Collins, Colorado.
- Raikow, D.F., and A.C. Farahi. 2016. Water quality in streams of Haleakala National Park: Summary report 2007–2011. Natural Resource Data Series NPS/PACN/NRDS—2016/1007. National Park Service, Fort Collins, Colorado.
- Raikow, D.F., and K. Kozar. 2023. Quality assurance plan for water quality monitoring in the Pacific Island Network. Natural Resource Report NPS/PACN/NRR—2023/2576. National Park Service, Fort Collins, Colorado.
- Raikow, D.F., K. Kozar, A.L. McCutcheon, and A.C. Farahi. 2023. Pacific Island Network marine water quality monitoring protocol: version 2.0. Natural Resource Report NPS/PACN/NRR—2023/2568. National Park Service, Fort Collins, Colorado.
- Raikow, D.F., M. Wasser, A.L. McCutcheon, and A.C. Farahi. 2024. Trends in water quality of Waikolu Stream, Kalaupapa National Historical Park, Moloka'i, Hawaii, 2007–2017. Natural Resource Report NPS/PACN/NRR—2024/2638. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2302153>

- Raikow, D.F., S. Kichman, A.L. McCutcheon, and A.C. Farahi. 2021. Marine water quality in Pacific Island national parks: Temporal, spatial, and chemical patterns 2008–2015. Natural Resource Report NPS/PACN/NRR—2021/2220. National Park Service, Fort Collins, Colorado.
- Starcevich, L.A.H. 2013. Power analysis for national park service lake chemistry data from 2008 to 2011, National Park Service, Natural Resource Stewardship and Science, Fort Collins, CO.
- State of Hawaii. 2004. Department of Health. Water quality standards. Department of Health. HAR Title 11, Ch. 54. 62 pp.
- Stevens, D.L., Jr., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99:262–278.
- VanLeeuwen, D.M., L.W. Murray, and N.S. Urquhart. 1996. A mixed model with both fixed and random trend components across time. *Journal of Agricultural, Biological, and Environmental Statistics* 1(4): 435–453.
- Weissinger, R., and D. Sharrow. 2018. Status and trends of water quality at Zion National Park: Water years 2006–2016. Natural Resource Report. NPS/NCPN/NRR—2018/1628. National Park Service. Fort Collins, Colorado

Appendix A. Power Analysis

See Appendix A in Raikow et al. (2023) for a discussion of power analysis rationale. Generally, the goal of resource management is to avoid change resulting in biological impairment, and monitoring is useful if change is detected before impairment occurs. Therefore, the amount of change to be detected (δ), should allow change to be detected before it reaches a level that might cause impairment. Further, the State of Hawaii has defined impairment for streams and these values also informed choice of deltas; e.g., State of Hawaii (2004) defines impairment for TP at 50.0 $\mu\text{g/L}$ in the wet season. In Waikolu Stream, as monitored by PACN, TDP remained near 40 $\mu\text{g/L}$ for most of the study period of 2007–2017, thus a relatively small change in absolute concentration would exceed state standards (Raikow and Farahi 2014).

The time period over which δ is to be detected was 10 years, with $\alpha = 0.05$, and $\beta = 0.20$ ($1 - \beta = \text{power} = 80\%$). A power level of 80% was chosen to be consistent with power analyses in the original protocol (Jones et al. 2011a; T. Jones personal communication). Wilcoxon tests were conducted to assess the number of sites needed to detect an anomalous individual outlying event, i.e., change from one quarter to the next quarter with the same α , β , and δ . Note that considerably less data were collected in Lafuti Stream and Calacag Stream, which may have affected the outcome of analyses compared to other streams.

Deltas were in part chosen for each parameter separately based on monitoring results as directed by the original protocol (Jones et al. 2011a). Deltas chosen for monitoring of stream water quality differed from deltas chosen for monitoring of marine water quality due to the presence of greater concentrations of nutrients in stream water compared to marine water (Table 6). Multiple deltas were evaluated to better understand the effect of sample size. Because a small absolute difference in nutrient concentration in streams could result in a change of biological significance, small deltas ($\delta = 25\%$, 50% , 100%) were chosen for nutrients; and these deltas were smaller than those used in the power analysis for marine areas ($\delta = 100\%$ for TDN and TDP, $\delta = 150\%$ for nitrate + nitrite, Raikow et al. 2023). Deltas also overlapped those used in some power analyses in the original protocol ($\delta = 10\%$, 25% , and 50% , Jones et al. 2011a). Results are presented as tables showing the minimum number of sites needed to detect a linear increase and single quarter change when sampled once, twice, or four times a year at various levels of change (δ).

For all streams, the number of sites required to detect change decreased with increasing sampling frequency and δ (see the tables in the sections below). Generally, nitrate + nitrite required more sites than TDN and TDP, reflecting greater variability of this parameter. Fewer sites were required to detect change in non-nutrient parameters compared to nutrients. Sufficient power to detect change, both as trends and anomalous events, can frequently be obtained by sampling fewer sites than prescribed by the original protocol (Jones et al. 2011a). Sampling two quarters a year was frequently sufficient to detect change at selected deltas over 10 years.

Table 6. Deltas for power analysis.

Parameter	Deltas Chosen for Power Analysis	Delta in Terms of Parameter Units	Justification
TDP	• 25% • 50% • 100%	• 10 µg/L • 20 µg/L • 40 µg/L	TDP exceeded the State of Hawaii criterion in the dry season. A 25% increase in TDP would result in exceedance for the state criterion in the wet season. Because a small absolute difference in nutrient concentration in streams could result in a change of biological significance, small deltas were chosen for nutrients.
TDN	• 25% • 50% • 100%	• 0.08 mg/L • 0.16 mg/L • 0.32 mg/L	A 25% increase in the TDN in either the dry or wet season would result in exceedance of the State of Hawaii criteria. Because a small absolute difference in nutrient concentration in streams could result in a change of biological significance, small deltas were chosen for nutrients.
NO ₂ ⁻ + NO ₃ ⁻	• 25% • 50% • 100%	• 25 µg/L • 50 µg/L • 100 µg/L	Small absolute differences in some water quality parameter values could result in a change of biological significance, and deltas overlapped those used in the power analysis for anchialine pools in the original protocol. Because a small absolute difference in nutrient concentration in streams could result in a change of biological significance, small deltas were chosen for nutrients.
Chlorophyll	• 400% • 800%	• 0.45 µg/L • 0.90 µg/L	Chlorophyll was generally low with a median of 0.3 µg/L. An increase of 400% would result in concentrations of 1.5 µg/L, which is one tenth of the highest outlying measurements observed.
O ₂ saturation	• 10% • 20%	• 10% • 20%	A significant reduction in O ₂ saturation would be dangerous, so 10% change was chosen.
SpC	• 400% • 800%	• 0.4 mS/cm • 0.8 mS/cm	Specific conductance is extremely low, and thus a large change would need to occur to raise concern.
Temperature	• 10% • 20%	• 1°C • 2°C	Temperature varied within a range of 6°C. A delta of 10% was chosen to be conservative.
Turbidity	• 400% • 800%	• 0.4 FNU • 0.8 FNU	Median turbidity was 0.10 FNU, and minimum State of Hawaii criterion is 2.0 FNU in the dry season. An increase of 400% would result in measured value of 0.5 FNU, or one quarter of the State of Hawaii criterion.
pH	• 0.5 • 1.0	• 0.5 • 1.0	pH remained primarily within a range of 7.0 – 8.5. A 1-point change out of this range might stress organisms, thus a delta of 0.5 was chosen to be conservative.

Waikolu Stream, Kalaupapa National Historical Park

Table 7 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Waikolu Stream, Kalaupapa National Historical Park.

Table 7. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in Waikolu Stream, Kalaupapa National Historical Park, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	3	3	2	1	3
Total dissolved phosphorus	50%	1	1	1	1	2
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	6	7	3	2	5
Total dissolved nitrogen	50%	2	2	1	1	3
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	6	6	4	2	6
Nitrate + Nitrite	50%	2	2	1	1	3
Nitrate + Nitrite	100%	1	1	1	1	2
Chlorophyll	400%	2	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	1	1	1	1	2
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	2	2	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	2	2	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	2	2	1	1	2
pH	1.0	1	1	1	1	2

Alelele Stream, Haleakalā National Park

Table 8 shows the number of sites required to detect change decreased with increasing sampling frequency and δ for Alelele Stream, Haleakalā National Park.

Table 8. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in Alelele Stream, Haleakalā National Park, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	4	4	2	1	5
Total dissolved phosphorus	50%	2	2	1	1	2
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	>10	10	5	3	9
Total dissolved nitrogen	50%	3	3	2	1	3
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	>10	>10	9	5	>10
Nitrate + Nitrite	50%	5	5	3	2	4
Nitrate + Nitrite	100%	2	2	1	1	2
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	9	9	5	3	9
Oxygen Saturation	20%	3	3	2	1	5
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	2	2	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	2	2	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	3	3	2	1	4
pH	1.0	1	1	1	1	2

Palikea Stream, Lower Reach, Haleakalā National Park

Table 9 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Palikea Stream, Lower Reach, Haleakalā National Park.

Table 9. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in Palikea Stream, lower reach, Haleakalā National Park, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	>10	>10	>10	6	8
Total dissolved phosphorus	50%	6	6	4	2	3
Total dissolved phosphorus	100%	2	2	1	1	2
Total dissolved nitrogen	25%	8	9	5	3	6
Total dissolved nitrogen	50%	3	3	2	1	3
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	>10	>10	10	5	>10
Nitrate + Nitrite	50%	5	5	3	2	5
Nitrate + Nitrite	100%	2	2	1	1	2
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	1	1	1	1	2
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	2	2	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	2	2	1	1	2
pH	1.0	1	1	1	1	2

Palikea Stream, Upper Reach, Haleakalā National Park

Table 10 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Palikea Stream, Upper Reach, Haleakalā National Park.

Table 10. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in Palikea Stream, upper reach, Haleakalā National Park, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	8	8	4	2	3
Total dissolved phosphorus	50%	3	3	2	1	2
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	4	4	2	1	3
Total dissolved nitrogen	50%	2	2	1	1	2
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	>10	>10	>10	8	>10
Nitrate + Nitrite	50%	8	8	5	2	6
Nitrate + Nitrite	100%	3	3	2	1	3
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	2	2	1	1	3
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	3	3	2	1	3
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	1	1	1	1	2
pH	1.0	1	1	1	1	2

Pīpīwai Stream, Haleakalā National Park

Table 11 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Pīpīwai Stream, Haleakalā National Park.

Table 11. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in Pīpīwai Stream, Haleakalā National Park, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	10	10	5	3	6
Total dissolved phosphorus	50%	2	2	1	1	2
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	4	4	2	1	4
Total dissolved nitrogen	50%	2	1	1	1	2
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	>10	>10	>10	6	>10
Nitrate + Nitrite	50%	6	6	3	2	6
Nitrate + Nitrite	100%	3	3	2	1	3
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	1	1	1	1	2
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	1	1	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	1	1	1	1	2
pH	1.0	1	1	1	1	2

Amalau Stream, Forest Sites, National Park of American Samoa

Table 12 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Amalau Stream, Forest Sites, National Park of American Samoa.

Table 12. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in upstream forested sites of Amalau Stream, National Park of American Samoa, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	1	1	1	1	2
Total dissolved phosphorus	50%	1	1	1	1	2
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	1	1	1	1	2
Total dissolved nitrogen	50%	1	1	1	1	2
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	1	1	1	1	2
Nitrate + Nitrite	50%	1	1	1	1	2
Nitrate + Nitrite	100%	1	1	1	1	2
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	1	1	1	1	2
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	1	1	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	1	1	1	1	2
pH	1.0	1	1	1	1	2

Amalau Stream, Village Sites, National Park of American Samoa

Table 13 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Amalau Stream, Village Sites, National Park of American Samoa.

Table 13. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in downstream village sites of Amalau Stream, National Park of American Samoa, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	1	1	1	1	2
Total dissolved phosphorus	50%	1	1	1	1	2
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	1	1	1	1	2
Total dissolved nitrogen	50%	1	1	1	1	2
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	1	1	1	1	2
Nitrate + Nitrite	50%	1	1	1	1	2
Nitrate + Nitrite	100%	1	1	1	1	2
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	1	1	1	1	2
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	1	1	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	1	1	1	1	2
pH	1.0	1	1	1	1	2

Leafu Stream, Forest Sites, National Park of American Samoa

Table 14 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Leafu Stream, Forest Sites, National Park of American Samoa.

Table 14. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in upstream forest sites of Leafu Stream, National Park of American Samoa, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	2	2	1	1	2
Total dissolved phosphorus	50%	1	1	1	1	2
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	4	4	2	1	5
Total dissolved nitrogen	50%	2	2	1	1	2
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	8	8	4	2	9
Nitrate + Nitrite	50%	2	2	1	1	4
Nitrate + Nitrite	100%	1	1	1	1	2
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	1	1	1	1	2
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	1	1	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	1	1	1	1	2
pH	1.0	1	1	1	1	2

Leafu Stream, Village Sites, National Park of American Samoa

Table 15 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Leafu Stream, Village Sites, National Park of American Samoa.

Table 15. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in downstream village sites of Leafu Stream, National Park of American Samoa, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	1	1	1	1	2
Total dissolved phosphorus	50%	1	1	1	1	2
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	1	1	1	1	2
Total dissolved nitrogen	50%	1	1	1	1	2
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	1	1	1	1	2
Nitrate + Nitrite	50%	1	1	1	1	2
Nitrate + Nitrite	100%	1	1	1	1	2
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	1	1	1	1	2
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	1	1	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	1	1	1	1	2
pH	1.0	1	1	1	1	2

Fagatuitui Stream, National Park of American Samoa

Table 16 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Fagatuitui Stream, National Park of American Samoa.

Table 16. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in Fagatuitui Stream, National Park of American Samoa, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	8	7	4	2	6
Total dissolved phosphorus	50%	2	2	1	1	3
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	>10	>10	9	4	>10
Total dissolved nitrogen	50%	5	5	3	2	5
Total dissolved nitrogen	100%	2	2	1	1	2
Nitrate + Nitrite	25%	>10	>10	>10	>10	>10
Nitrate + Nitrite	50%	>10	>10	7	4	8
Nitrate + Nitrite	100%	4	4	2	1	5
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	2	2	1	1	2
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	1	1	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	3	3	2	1	3
pH	1.0	1	1	1	1	2

Lafuti Stream, Lower Reach, National Park of American Samoa

Table 17 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Lafuti Stream, Lower Reach, National Park of American Samoa.

Table 17. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in Lafuti Stream, lower reach, National Park of American Samoa, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	>10	>10	6	3	>10
Total dissolved phosphorus	50%	4	4	2	1	5
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	>10	>10	10	5	>10
Total dissolved nitrogen	50%	5	5	3	2	6
Total dissolved nitrogen	100%	2	2	1	1	3
Nitrate + Nitrite	25%	>10	>10	7	4	>10
Nitrate + Nitrite	50%	4	4	5	1	5
Nitrate + Nitrite	100%	1	2	1	1	2
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	4	4	2	1	5
Oxygen Saturation	20%	1	2	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	1	1	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	2	2	1	1	3
pH	1.0	1	1	1	1	2

Laufuti Stream, Upper Reach Pools, National Park of American Samoa

Table 18 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Laufuti Stream, Upper Reach Pools, National Park of American Samoa.

Table 18. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in Laufuti Stream, upper reach pools, National Park of American Samoa, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	>10	>10	8	4	>10
Total dissolved phosphorus	50%	5	4	2	1	5
Total dissolved phosphorus	100%	2	2	1	1	2
Total dissolved nitrogen	25%	>10	>10	6	3	>10
Total dissolved nitrogen	50%	3	3	2	1	4
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	>10	>10	>10	>10	>10
Nitrate + Nitrite	50%	>10	>10	>10	9	>10
Nitrate + Nitrite	100%	9	9	5	3	>10
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	>10	>10	8	4	>10
Oxygen Saturation	20%	4	5	3	1	8
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	1	1	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	3	3	2	1	5
pH	1.0	1	1	1	1	2

Asan River, War in the Pacific National Historical Park

Table 19 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Asan River, War in the Pacific National Historical Park.

Table 19. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in the Asan River, War in the Pacific National Historical Park, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	7	7	4	2	6
Total dissolved phosphorus	50%	2	2	1	1	3
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	>10	10	5	3	7
Total dissolved nitrogen	50%	3	3	2	1	3
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	>10	>10	>10	>10	>10
Nitrate + Nitrite	50%	>10	>10	>10	>10	>10
Nitrate + Nitrite	100%	>10	>10	6	3	6
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	7	7	4	2	8
Oxygen Saturation	20%	2	2	1	1	4
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	2	2	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	2	2	1	1	2
pH	1.0	1	1	1	1	2

Calacag Stream, War in the Pacific National Historical Park

Table 20 shows that the number of sites required to detect change decreased with increasing sampling frequency and δ for Calacag Stream, War in the Pacific National Historical Park.

Table 20. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test, 10 baseline years) when sampled once (Q1 or Q3), twice (Q1 and Q3), or four times (All quarters) a year, in Calacag Stream, War in the Pacific National Historical Park, at 80% power, 0.05 Type I error, and various levels of change (delta, δ).

Parameter	δ	Q1	Q3	Q1 and Q3	All Quarters	Wilcoxon Test
Total dissolved phosphorus	25%	1	1	1	1	2
Total dissolved phosphorus	50%	1	1	1	1	2
Total dissolved phosphorus	100%	1	1	1	1	2
Total dissolved nitrogen	25%	1	1	1	1	2
Total dissolved nitrogen	50%	1	1	1	1	2
Total dissolved nitrogen	100%	1	1	1	1	2
Nitrate + Nitrite	25%	1	1	1	1	2
Nitrate + Nitrite	50%	1	1	1	1	2
Nitrate + Nitrite	100%	1	1	1	1	2
Chlorophyll	400%	1	1	1	1	2
Chlorophyll	800%	1	1	1	1	2
Oxygen Saturation	10%	1	1	1	1	2
Oxygen Saturation	20%	1	1	1	1	2
Specific conductance	400%	1	1	1	1	2
Specific conductance	800%	1	1	1	1	2
Temperature	10%	1	1	1	1	2
Temperature	20%	1	1	1	1	2
Turbidity	400%	1	1	1	1	2
Turbidity	800%	1	1	1	1	2
pH	0.5	1	1	1	1	2
pH	1.0	1	1	1	1	2

Appendix B. Dissolved Nutrient Fractions

In order to empirically justify the focus on dissolved nutrients in the monitoring of PACN waters, an analysis of dissolved and particulate nutrient fractions was conducted. Unfiltered water samples were collected alongside field-filtered samples at PACN water quality monitoring sites from 2013–2014. The proportion of the dissolved nitrogen (N) and phosphorus (P) fractions were calculated as the ratio of dissolved to total nutrient concentrations. Values used for dissolved and total nutrient concentrations were means of three replicate subsamples. Results are presented as the distribution of the proportions of the dissolved fraction of N or P (Table 21). Histograms show the count of proportions (Figures 8–15). In the histograms, 1.0 means 100% dissolved N or P.

Many locations contained calculated proportions of dissolved nutrients greater than 1.0, which is physically impossible. Interpretation of this counter-intuitive result is informed by the density curve. Because many of the distributions were largely normal, with some left skewness explained below, the presence of values greater than 1.0 can be explained by variance in the accuracy of the laboratory analysis for nutrient concentration. Because most of the results show proportions of the dissolved fractions very close to 1.0, the presence of values greater than 1.0 is to be expected and does not invalidate the results.

The proportion of dissolved N and P was very high at all locations, frequently over 90%, as indicated by medians (Table 21). Mean values were affected by left-skewed data, or instances of lower dissolved fractions, indicating the presence of more abundant particulates. The otherwise highly normal distributions of results centered around high dissolved proportions coupled with clustered left-skewed data indicates bi-modality. This can be explained by the grouping of samples collected at low-particulate sites or sampling events during times of low particulates with sites or instances of high particulate content. Phosphorus was more sensitive to this effect, displaying more instances of greater particulate content, seen as low values in histograms.

Streams at HALE displayed high proportions of dissolved N with more frequent instances of particulate P (Figures 8 and 9). Waikolu Stream at KALA displayed high proportions of dissolved N and P fractions (Figures 10 and 11). The Asan River at WAPA displayed high proportions of dissolved N and P fractions, with more extreme instances of higher particulates (Figures 12 and 13). NPSA streams displayed high proportions of dissolved N and P fractions, but the distributions of this data are less robust than other sites due to fewer unfiltered samples (Figures 14 and 15). These results lead to clear recommendations for PACN stream water quality monitoring, namely, due to the high proportion of dissolved fractions the focus should be dissolved fractions, and high-water conditions, particularly at HALE, must be separated from low-water conditions during analysis.

Table 21. Summary statistics for proportion of dissolved nitrogen and phosphorus in streams.

Statistic	Haleakalā National Park Nitrogen	Kalaupapa National Historical Park Nitrogen	War in the Pacific National Historical Park Nitrogen	National Park of American Samoa Nitrogen	Haleakalā National Park Phosphorus	Kalaupapa National Historical Park Phosphorus	War in the Pacific National Historical Park Phosphorus	National Park of American Samoa Phosphorus
Minimum	0.54	0.64	0.56	0.72	0.17	0.68	0.05	0.73
1 st Quartile	0.81	0.80	0.76	0.94	0.36	0.86	0.57	0.93
Median	0.92	0.90	1.00	0.98	0.71	0.90	1.00	1.01
Mean	0.95	0.89	1.00	1.03	0.70	0.90	0.75	0.96
3 rd Quartile	1.06	0.98	1.37	1.09	1.00	0.94	1.00	1.03
Maximum	1.42	1.24	1.48	1.36	1.56	1.06	1.00	1.12

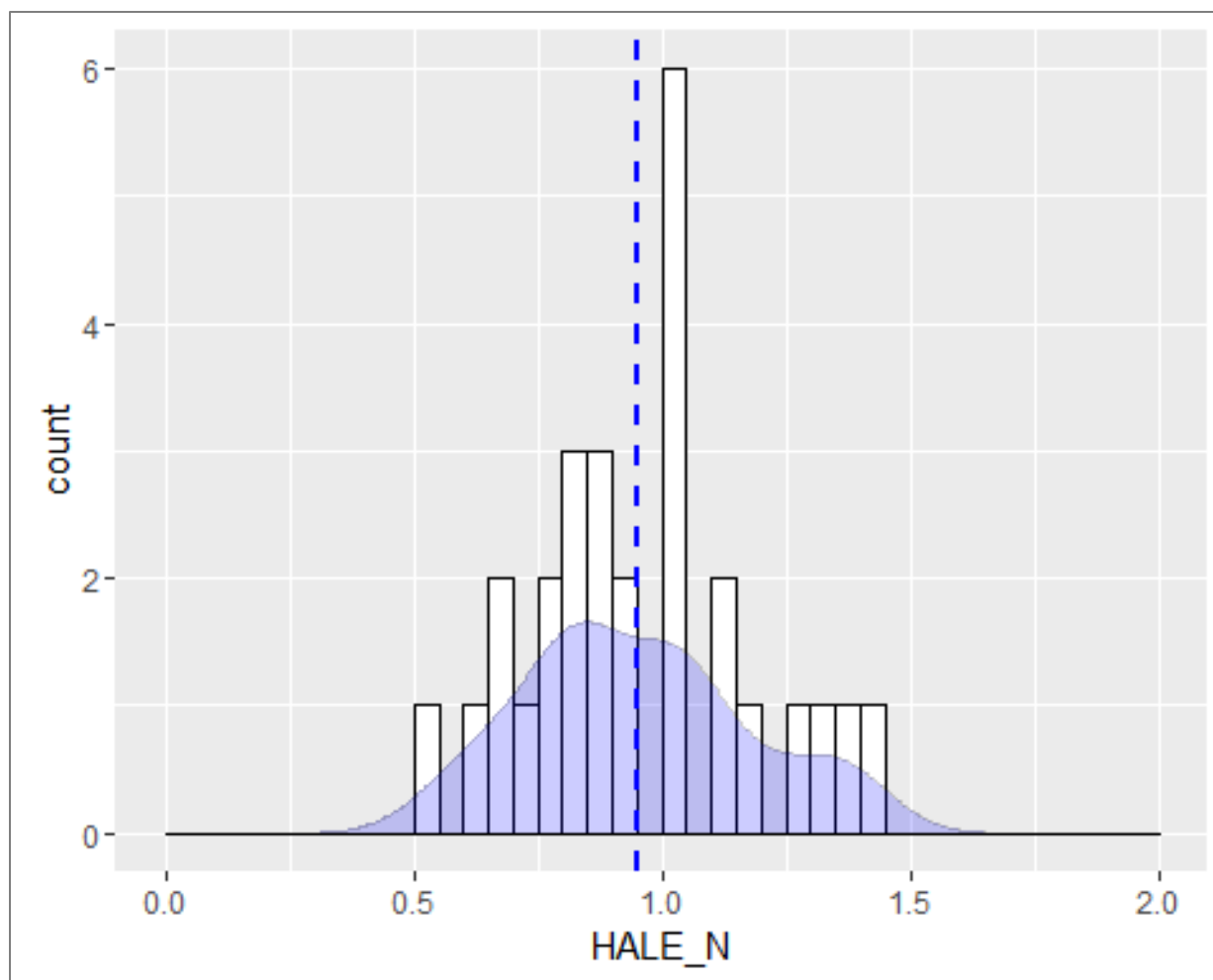


Figure 8. Proportions of dissolved nitrogen in HALE streams. Distribution density is presented as the blue curve and mean as the blue dotted line.

NPS

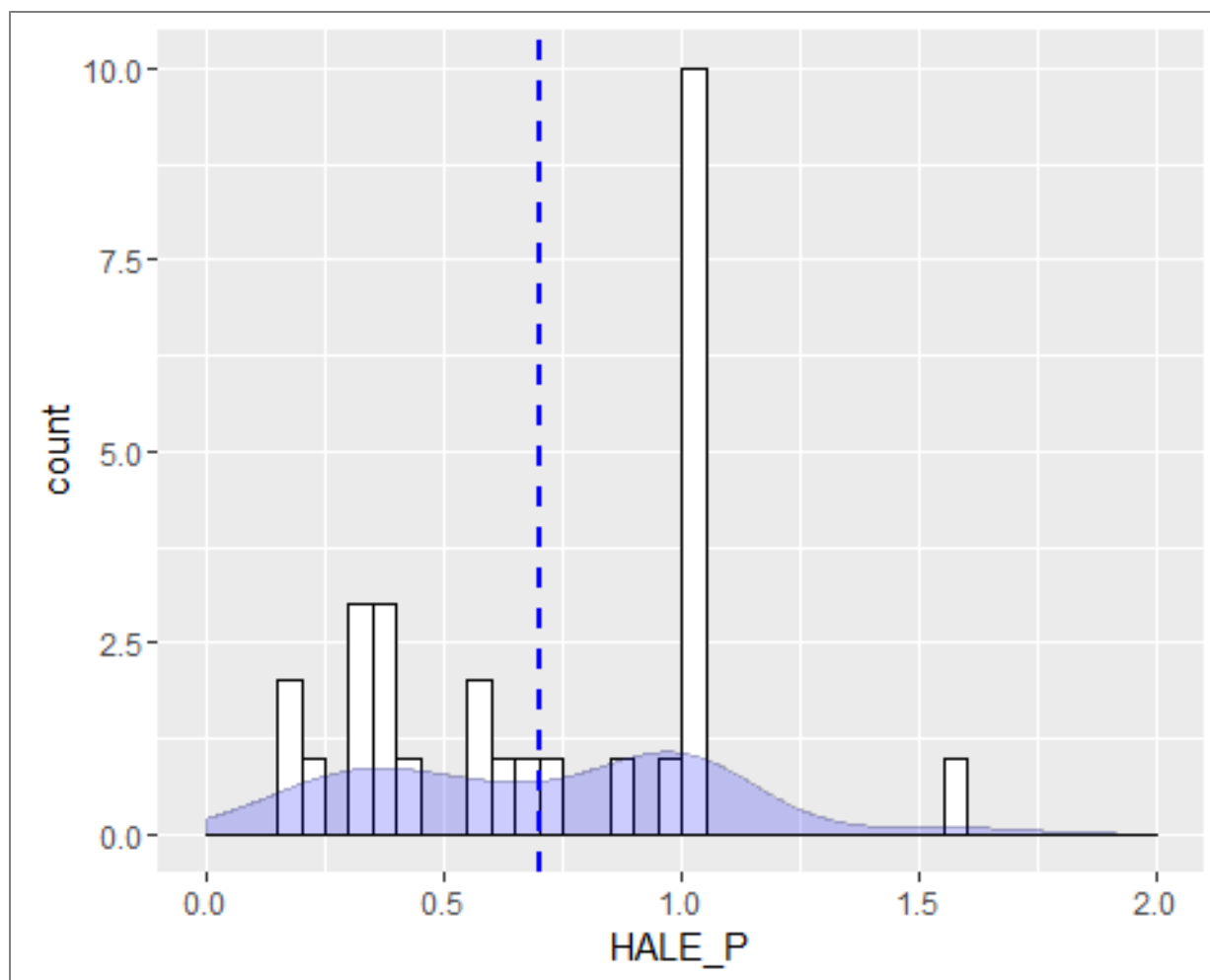


Figure 9. Proportions of dissolved phosphorus in HALE streams. Distribution density is presented as the blue curve and mean as the blue dotted line.

NPS

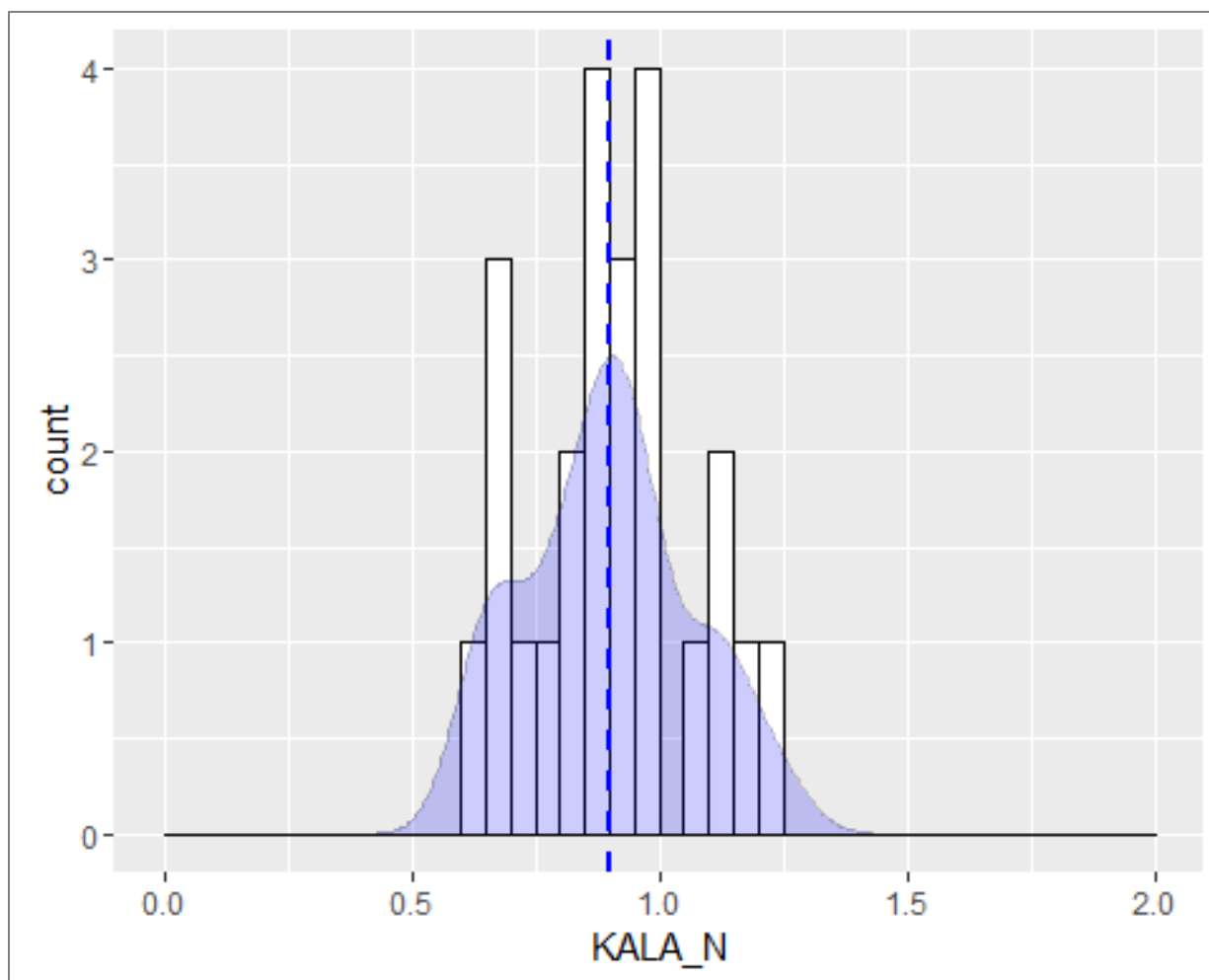


Figure 10. Proportions of dissolved nitrogen in Waikolu Stream, KALA. Distribution density is presented as the blue curve and mean as the blue dotted line.

NPS

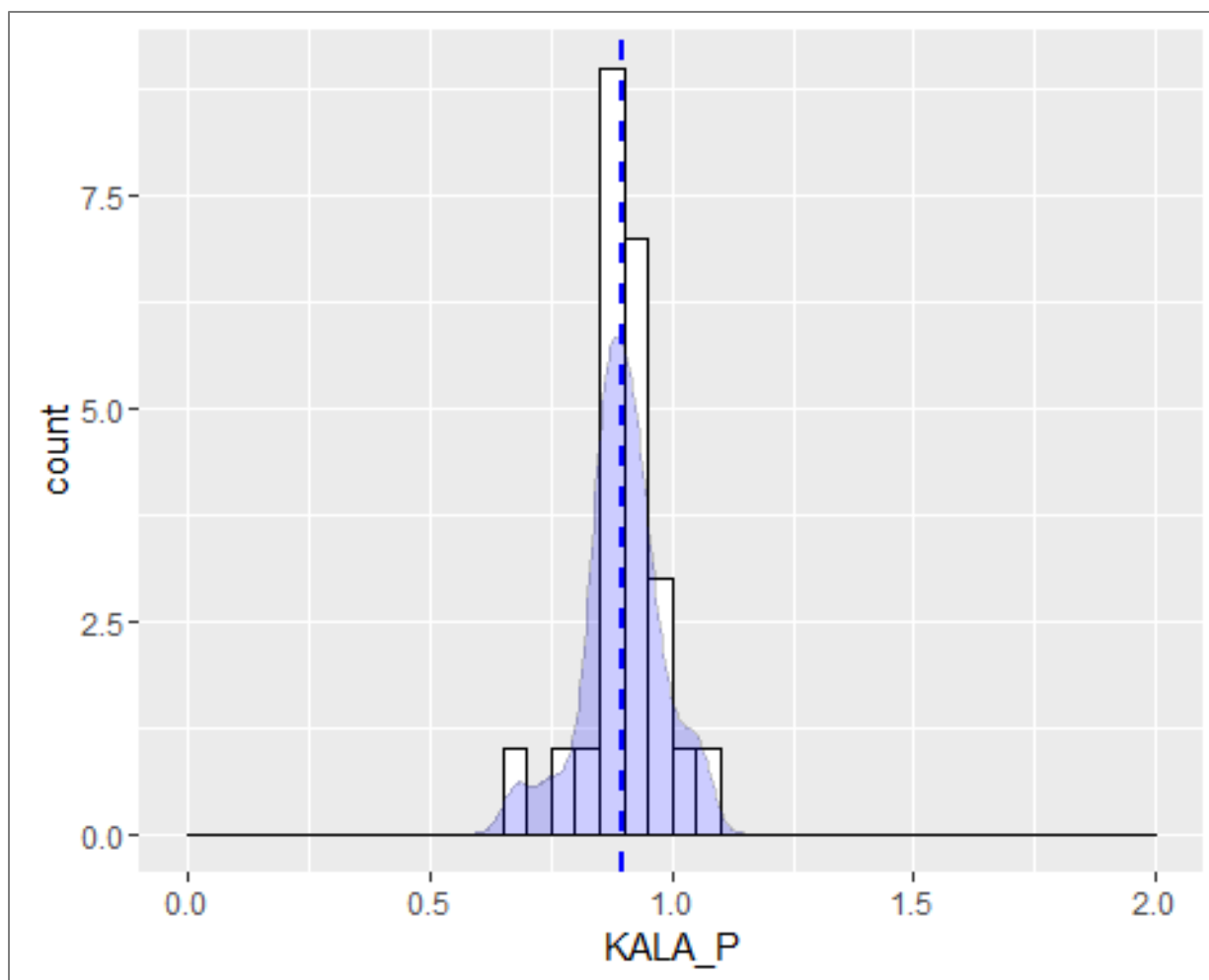


Figure 11. Proportions of dissolved phosphorus in Waikolu Stream, KALA. Distribution density is presented as the blue curve and mean as the blue dotted line.

NPS

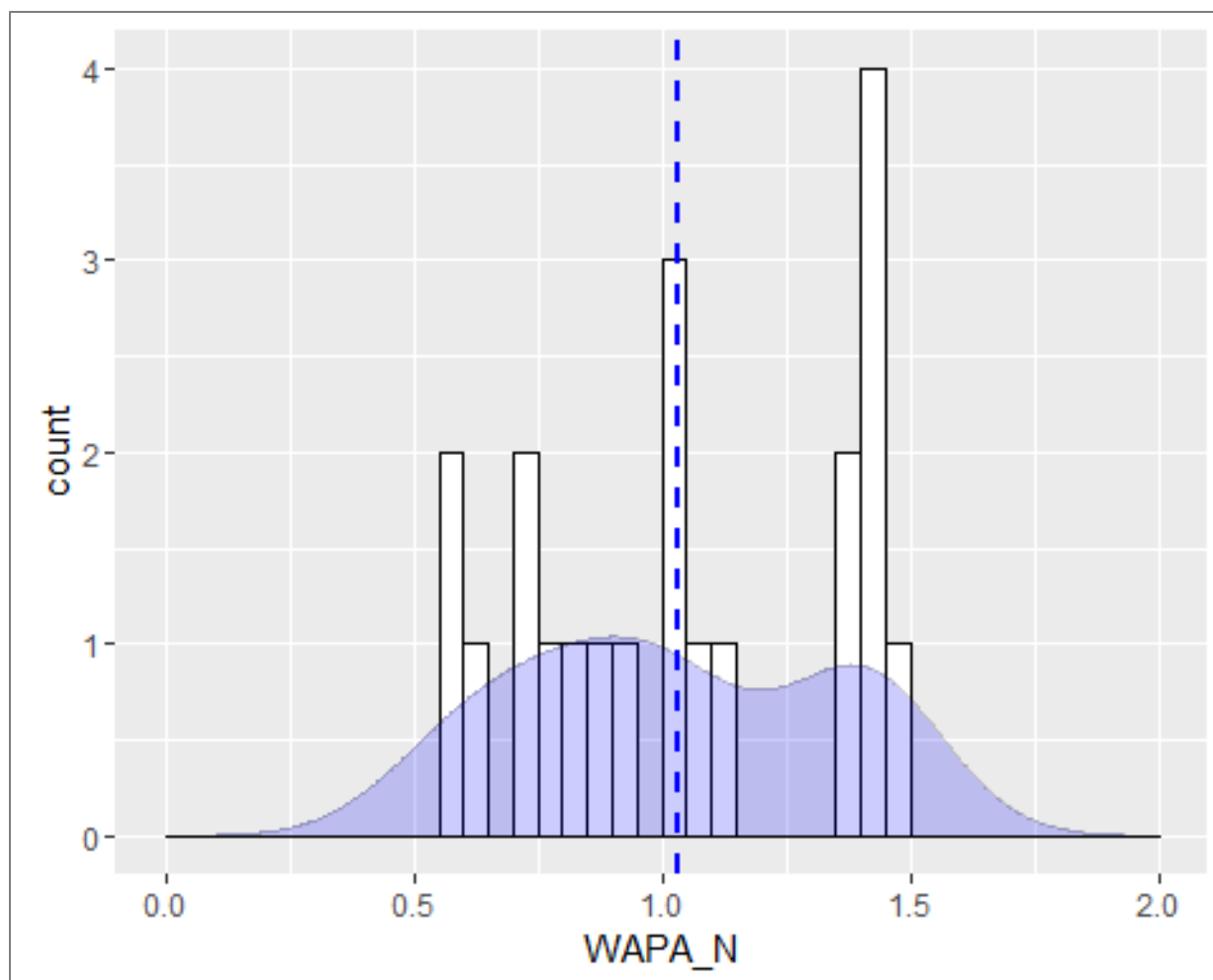


Figure 12. Proportion of dissolved nitrogen in the Asan River, WAPA. Distribution density is presented as the blue curve and mean as the blue dotted line.

NPS

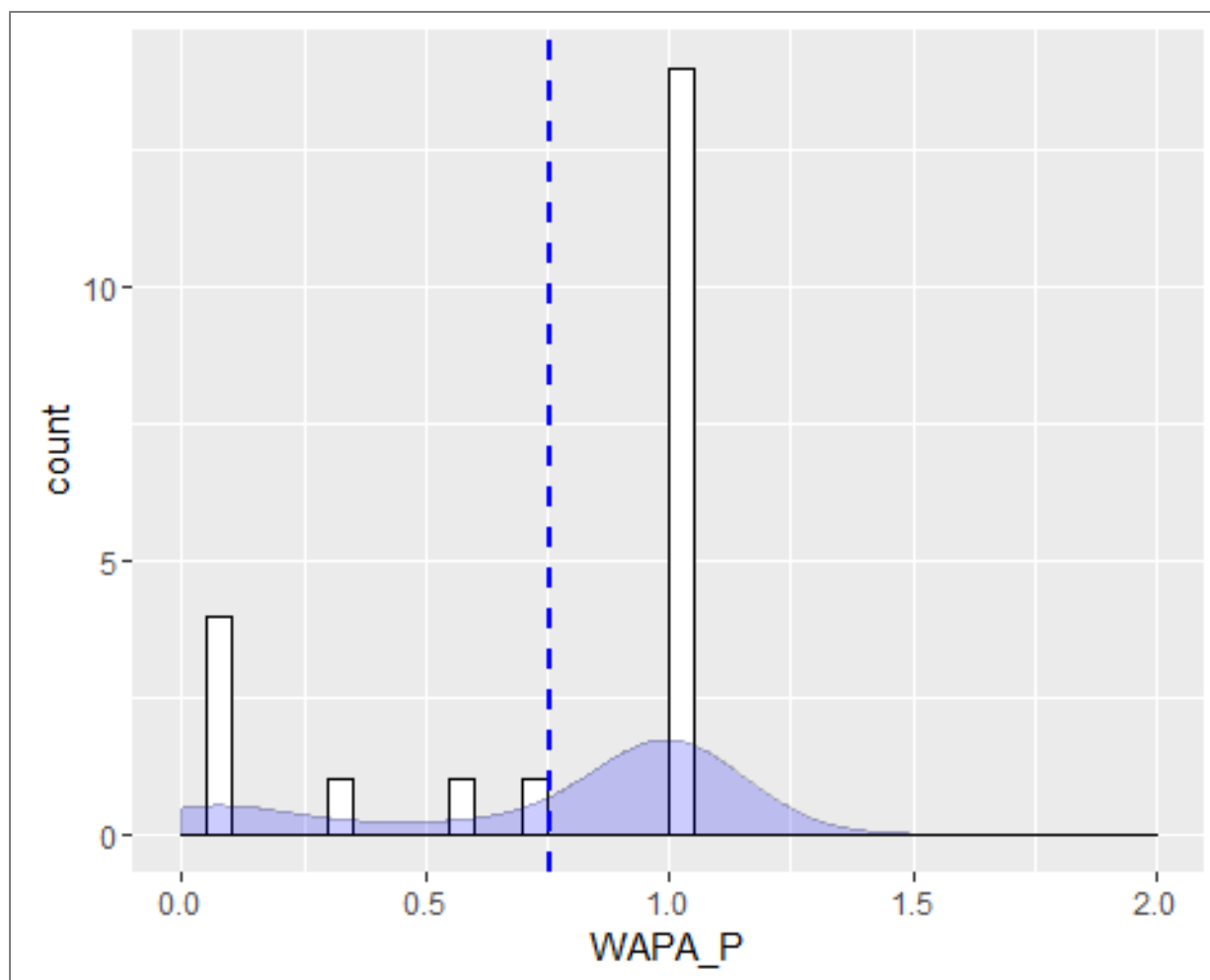


Figure 13. Proportions of dissolved phosphorus in the Asan River, WAPA. Distribution density is presented as the blue curve and mean as the blue dotted line.

NPS

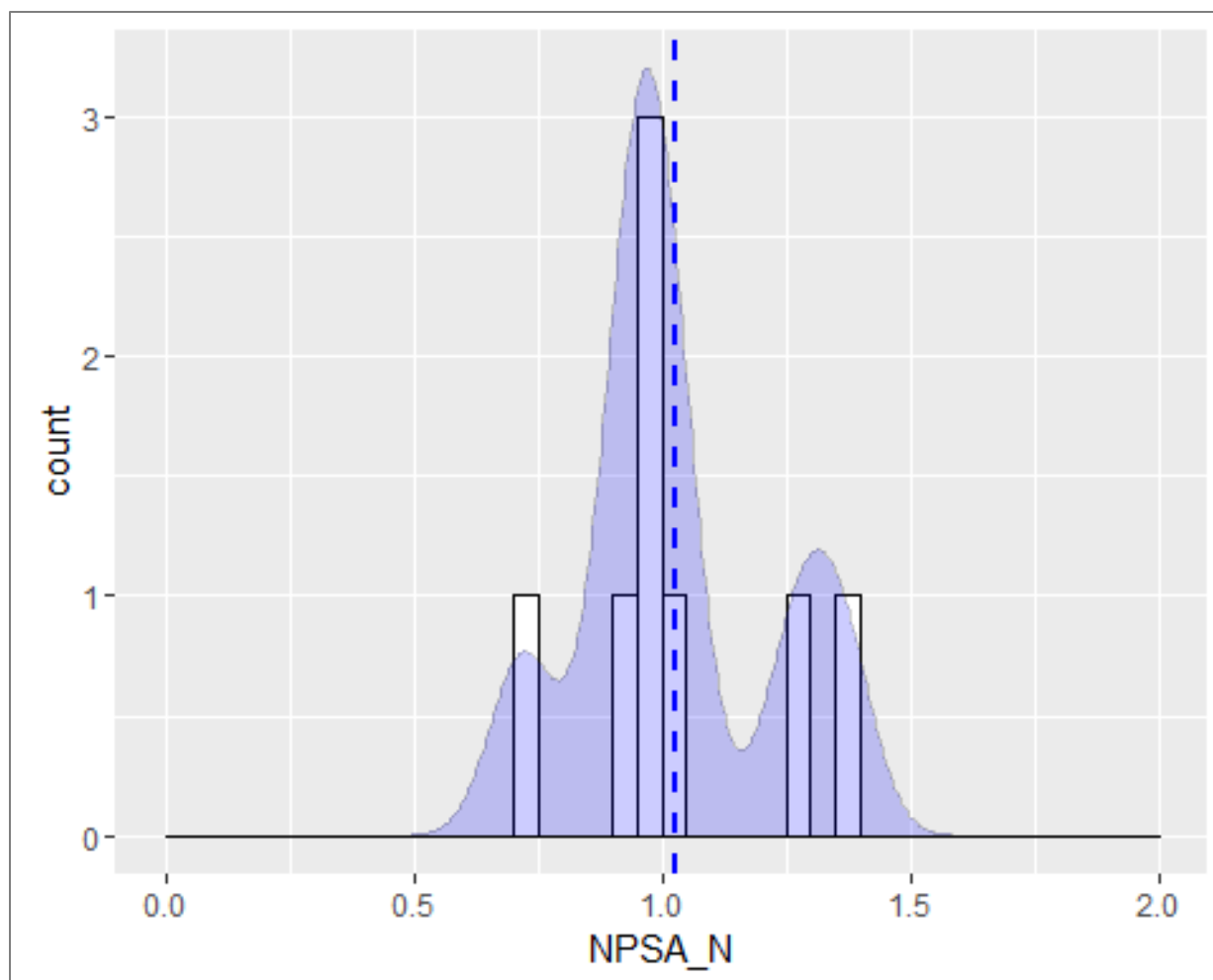


Figure 14. Proportions of dissolved nitrogen in streams of NPSA. Distribution density is presented as the blue curve and mean as the blue dotted line.

NPS

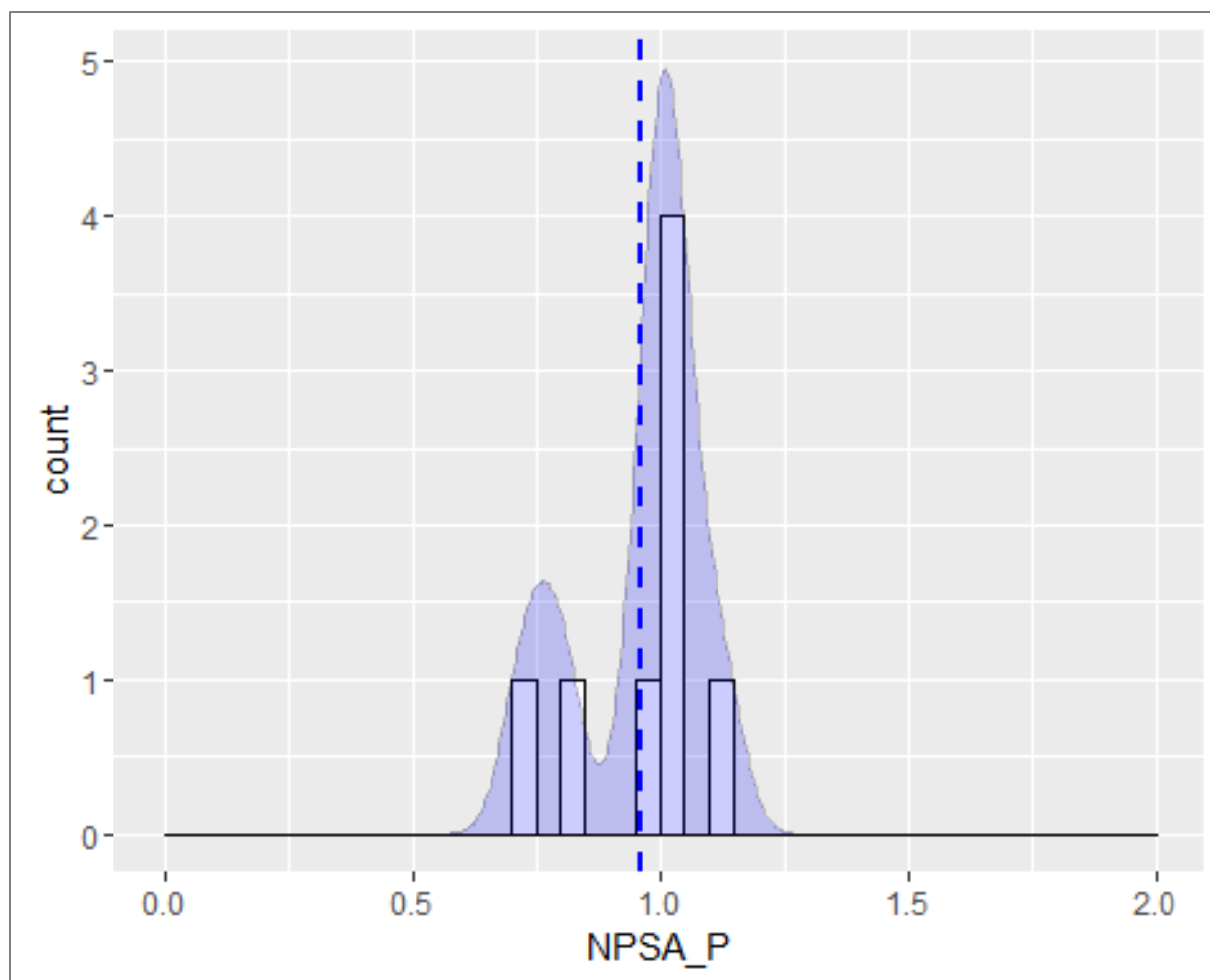


Figure 15. Proportions of dissolved phosphorus in streams of NPSA. Distribution density is presented as the blue curve and mean as the blue dotted line.

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