



Pacific Island Network

Marine Water Quality Monitoring Protocol

Version 2.0

Natural Resource Report NPS/PACN/NRR—2023/2568



ON THE COVER

The coast near Kalaupapa National Historical Park

Photograph: NPS/Anne Farahi

Pacific Island Network

Marine Water Quality Monitoring Protocol

Version 2.0

Natural Resource Report NPS/PACN/NRR—2023/2568

David Raikow¹, Kelly Kozar¹, Amanda L. McCutcheon¹, and Anne Farahi¹

¹National Park Service

Pacific Island Inventory and Monitoring Network

Hawaii Volcanoes National Park

PO Box 52

Hawaii National Park, Hawaii 96718

September 2023

U.S. Department of the Interior

National Park Service

Natural Resource Stewardship and Science

Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the [Pacific Island I&M Network website](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Raikow, D. F., K. Kozar, A. L. McCutcheon, and A. 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.
<https://doi.org/10.36967/2300648>

Contents

	Page
Figures.....	vi
Tables	xii
Acronyms	xv
Standard Operating Procedures	xvii
Executive Summary	xx
Acknowledgments.....	xxii
1 Background and Objectives	23
1.1 The Pacific Island Network	23
1.2 Synopsis of Trends Observed and Scientific Review Rationale.....	25
1.3 General Biogeochemistry	26
1.4 Land-Sea Interaction	29
1.5 El Niño Southern Oscillation.....	30
1.6 Climate Change	31
1.7 Marine Water Quality in PACN Parks.....	31
1.8 Considerations Affecting Overall Protocol Design	32
1.9 Objectives	32
2 Sampling Design	33
2.1 Summary of Methodological Changes	33
2.2 Sampling Regime	34
2.2.1 Sampling Frame and Stratification	34
2.2.2 Power	35
2.2.3 Sampling Frequency	37
2.2.4 Number of Sample Sites, Site locations, Site Dispersion.....	37
2.2.5 Sampling Depth	44
2.2.6 Water Quality Parameters	44
3 Field methods.....	46

Contents (continued)

	Page
3.1 Planning and Equipment.....	46
3.2 Sonde Operation	46
3.3 Collecting Water Samples	46
4 Data Analysis, Handling, and Reporting.....	47
4.1 Project Information Management Overview	47
4.2 Pre-season Preparations for Information Management	48
4.2.1 Set Up of Project Workspace.....	48
4.2.2 GPS Loading and Preparation	48
4.2.3 Implementation of Working Database Copy	48
4.3 Overview of Database Design.....	55
4.4 Data Entry and Processing.....	55
4.4.1 Regular Data Backups	56
4.4.2 Data Verification.....	56
4.4.3 Field Form Handling Procedures.....	56
4.4.4 Image Handling Procedures	56
4.4.5 GPS Data Procedures	57
4.5 Data Quality Review	57
4.5.1 Quality Review Tool.....	57
4.5.2 Geospatial Data	57
4.6 Metadata Procedures	57
4.7 Data Certification and Delivery.....	57
4.7.1 Data Edits after Certification.....	58
4.8 Data Analysis.....	58
4.9 Reporting and Product Development	61
4.10 Product Delivery, Posting, and Distribution.....	61
4.10.1 STORET	62

Contents (continued)

	Page
4.10.2 Special Procedures for Sensitive Information	62
4.11 Archival and Records Management.....	63
4.12 Season Close Out.....	63
4.13 Changing Laboratory Contracts	63
4.14 Modifying the Protocol.....	63
5 Operational Requirements	65
5.1 Facilities and Equipment	65
5.2 Start-up Costs	67
5.3 Annual Budget.....	67
5.4 Support Provided by Parks	67
6 Personnel Requirements and Training	68
7 Literature Cited	69
Appendix A: Power Analysis	77
Appendix B: Database Documentation.....	117

Figures

	Page
Figure 1. Park units of the Pacific Island Network.	24
Figure 2. Sample sites at Kaloko-Honokōhau National Historical Park.	39
Figure 3. Sample sites at Kalaupapa National Historical Park.	40
Figure 4. Sample sites in War in the Pacific National Historical Park.	41
Figure 5. Sample sites in National Park of American Samoa..	43
Figure 6. Idealized flow diagram of the cyclical stages of project information management, from pre-season preparation to season close-out.	47
Figure 7. Statistics used in water quality and hydrology “Trend Analyses.”	59
Figure 8. Data flow diagram for Pacific Island Network water quality data.	62
Figure A1. Plot of 10-year linear regression power for chlorophyll (delta = 250%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	81
Figure A2. Plot of 10-year linear regression power for nitrate + nitrite (delta = 150%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	82
Figure A3. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	82
Figure A4. Plot of 10-year linear regression power for salinity (delta = 2%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	83
Figure A5. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	83
Figure A6. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	84
Figure A7. Plot of 10-year linear regression power for turbidity (delta = 150%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	84

Figures (continued)

	Page
Figure A8. Plot of 10-year linear regression power for temperature ($\delta = 4\%$) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	85
Figure A9. Plot of 10-year linear regression power for pH ($\delta = 0.25$) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	85
Figure A10. Plot of 10-year linear regression power for chlorophyll ($\delta = 250\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	87
Figure A11. Plot of 10-year linear regression power for nitrate + nitrite ($\delta = 150\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	87
Figure A12. Plot of 10-year linear regression power for oxygen saturation ($\delta = 10\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	88
Figure A13. Plot of 10-year linear regression power for salinity ($\delta = 2\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	88
Figure A14. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; $\delta = 100\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	89
Figure A15. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; $\delta = 100\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	89
Figure A16. Plot of 10-year linear regression power for turbidity ($\delta = 150\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	90
Figure A17. Plot of 10-year linear regression power for temperature ($\delta = 4\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	90
Figure A18. Plot of 10-year linear regression power for pH ($\delta = 0.25$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	91
Figure A19. Plot of 10-year linear regression power for chlorophyll ($\delta = 250\%$) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).	92

Figures (continued)

	Page
Figure A20. Plot of 10-year linear regression power for nitrate + nitrite (delta = 150%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).	92
Figure A21. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).	93
Figure A22. Plot of 10-year linear regression power for salinity (delta = 2%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).	93
Figure A23. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).	94
Figure A24. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).	94
Figure A25. Plot of 10-year linear regression power for turbidity (delta = 150%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).	95
Figure A26. Plot of 10-year linear regression power for temperature (delta = 4%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).	95
Figure A27. Plot of 10-year linear regression power for pH (delta = 0.25) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).	96
Figure A28. Plot of 10-year linear regression power for chlorophyll (delta = 250%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).	97
Figure A29. Plot of 10-year linear regression power for nitrate + nitrite (delta = 150%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).	97
Figure A30. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).	98
Figure A31. Plot of 10-year linear regression power for salinity (delta = 2%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).	98
Figure A32. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).	99
Figure A33. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).	99

Figures (continued)

	Page
Figure A34. Plot of 10-year linear regression power for turbidity (delta = 150%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).	100
Figure A35. Plot of 10-year linear regression power for temperature (delta = 4%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).	100
Figure A36. Plot of 10-year linear regression power for pH (delta = 0.25) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).	101
Figure A37. Plot of 10-year linear regression power for chlorophyll (delta = 250%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	102
Figure A38. Plot of 10-year linear regression power for nitrate + nitrite (delta = 150%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	102
Figure A39. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	103
Figure A40. Plot of 10-year linear regression power for salinity (delta = 2%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	103
Figure A41. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	104
Figure A42. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	104
Figure A43. Plot of 10-year linear regression power for turbidity (delta = 150%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	105
Figure A44. Plot of 10-year linear regression power for temperature (delta = 4%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	105
Figure A45. Plot of 10-year linear regression power for pH (delta = 0.25) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	106
Figure A46. Plot of 10-year linear regression power for chlorophyll (delta = 250%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).	107
Figure A47. Plot of 10-year linear regression power for nitrate + nitrite (delta = 150%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).	107

Figures (continued)

	Page
Figure A48. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).....	108
Figure A49. Plot of 10-year linear regression power for salinity (delta = 2%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).....	108
Figure A50. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).....	109
Figure A51. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).....	109
Figure A52. Plot of 10-year linear regression power for turbidity (delta = 150%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).	110
Figure A53. Plot of 10-year linear regression power for temperature (delta = 4%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).	110
Figure A54. Plot of 10-year linear regression power for pH (delta = 0.25) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).	111
Figure A55. Plot of 10-year linear regression power for chlorophyll (delta = 250%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	112
Figure A56. Plot of 10-year linear regression power for nitrate + nitrite (delta = 150%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	112
Figure A57. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	113
Figure A58. Plot of 10-year linear regression power for salinity (delta = 2%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	113
Figure A59. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	114
Figure A60. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	114
Figure A61. Plot of 10-year linear regression power for turbidity (delta = 150%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	115

Figures (continued)

	Page
Figure A62. Plot of 10-year linear regression power for temperature ($\delta = 4\%$) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	115
Figure A63. Plot of 10-year linear regression power for pH ($\delta = 4\%$) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	116
Figure B1. Data table relationships for the Water Quality Database.	119

Tables

	Page
Table SOP-1. A list of the water quality standard operating procedures used in conjunction with this protocol.	xvii
Table 1. Phosphorus (P) and Nitrogen (N) nutrient species found in aquatic ecosystems.	26
Table 2. Summary of methodological changes made to the original 2011 water quality monitoring protocol for Pacific Island Network parks (Jones et al., “Protocol,” 2011).	33
Table 3. Number of marine water quality sample sites by Pacific Island Network parks.	37
Table 4. Annual information management tasks for Pacific Island Network marine water quality monitoring.	49
Table 5. Protocol staff expenses for Pacific Island Network marine water quality monitoring.	66
Table 6. Total protocol expenses for Pacific Island Network marine water quality monitoring.	67
Table A1. Deltas for power analysis of marine water quality parameters at Pacific Island Network parks.	79
Table A2. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	80
Table A3. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).	86
Table A4. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in National Park of American Samoa Ofu unit (80% power, Type I error = 0.05).	91
Table A5. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in National Park of American Samoa Tutuila unit (80% power, Type I error = 0.05).	96
Table A6. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).	101
Table A7. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).	106

Tables (continued)

	Page
Table A8. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).....	111
Table B1. "tbl_Activity"—User entered or imported water quality activities.	120
Table B2. "tbl_Analytical_Procedures"—User entered analytical procedures.	122
Table B3. "tbl_Db_Revisions"—Database revision history data.....	122
Table B4. "tbl_Event_Details"—Sampling event details.....	123
Table B5. "tbl_Event_Group"—Sampling trip metadata and calibration values.	123
Table B6. "tbl_Events"—Sampling events.....	125
Table B7. "tbl_Events_Pics"—User entered station visit picture links.....	127
Table B8. "tbl_Field_Procedures"—User entered field procedures.	128
Table B9. "tbl_Gear_Configuration"—User entered gear configurations.....	129
Table B10. "tbl_General_Standards"—General standards for water quality parameters.....	129
Table B11. "tbl_Lab_Calibration"—Quality assurance/quality check lab sample calibration data for a sampling event.	130
Table B12. "tbl_Lab_Calibration_Values"—Lab sample calibration values for a quality assurance/quality check lab sample.	131
Table B13. "tbl_Lab_QC"—Laboratory quality control values.	131
Table B14. "tbl_Lab_Sample_Prep"—User entered lab sample preparation procedures.	132
Table B15. "tbl_Labs"—User entered labs.....	133
Table B16. "tbl_Locations"—Sampling unit locations.	133
Table B17. "tbl_Locations_Pics"—User entered station picture links.....	137
Table B18. "tbl_PreserveTransportStore"—User entered preservation, transport, and storage procedures.	137
Table B19. "tbl_QA_Results"	138
Table B20. "tbl_QAQC"—Quality assurance and quality control methods.....	139
Table B21. "tbl_Results"—Water quality and sonde results.	140

Tables (continued)

	Page
Table B22. "tbl_Serial_Numbers"—Associated serial numbers for gear that is entered in tbl_Gear_Configurations.....	142
Table B23. "tbl_Sites"—Location aggregations.....	142
Table B24. "tlu_ActivityTypes"—List of Activity Types from WQX STORET including translation from Modern STORET.....	143
Table B25. "tlu_Addresses"—Look up table of addresses.....	143
Table B26. "tlu_Characteristics"—User entered characteristic definitions (parameters that are measured).	144
Table B27. "tlu_Contacts"—Look up table of contacts associated with the protocol.....	146
Table B28. "tlu_Geospatial"—Abbreviated geospatial table from STORET 10/10/2006 (Methods and Datums).....	147
Table B29. "tlu_Permitted_Values"—Non-STORET table containing permitted values for some of the STORET input fields in NPSTORET.	147
Table B30. "tlu_Primary_Type"—Look up table for water body types.	148
Table B31. "tlu_Sample_Type"—Look up table for sample type.	148
Table B32. "tlu_Unit_of_Measurement"—Look up table of units of measure from STORET 10/10/2006 (Units of Measure—Added and populated 'DISPLAY_NAME' field).....	148
Table B33. "tlu_Wind"—Look up table for the wind codes based on the Beaufort Scale.....	149
Table B34. "xref_Activity_QAQC"—Cross-reference table between activities and quality assurance and quality control.....	149
Table B35. "xref_Contact_Address"—Cross-reference table between contacts and addresses.	149
Table B36. "xref_Event_Contacts"—Cross-reference table between events and contacts.	150

Acronyms

ARMA:	Autoregressive moving average
ARIMA:	Autoregressive integrated moving average
CO₂:	Carbon dioxide
ENSO:	El Niño Southern Oscillation
EPA:	Environmental Protection Agency
FGDC:	Federal Geographic Data Committee
GIS:	Geographic information system
IMD:	Inventory and Monitoring Division
IRMA:	Integrated Resource Management Applications
KAHO:	Kaloko-Honokōhau National Historical Park
KALA:	Kalaupapa National Historical Park
NEPA:	National Environmental Protection Act
NH₄⁺:	Ammonium
NHP:	National Historical Park
NO₂⁻ :	Nitrite
NO₃⁻ :	Nitrate
NPS:	National Park Service
NPSA:	National Park of American Samoa
PACN:	Pacific Island Network
PO₄:	Phosphate
QA:	Quality assurance
QC:	Quality control
SGD:	Submarine groundwater discharge
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
WRD:	Water Resources Division

Standard Operating Procedures

Twenty-four standard operating procedures (SOPs) are associated with all Pacific Island Network water quality monitoring protocols, including this one (Table SOP-1). The SOPs for all water quality monitoring protocols are listed here. To accommodate frequent changes, each SOP is informally published online through the National Park Service Integrated Resources Management Applications (IRMA) portal (<https://irma.nps.gov/Portal>). The SOPs can be retrieved from IRMA using the citation or the hyperlinked reference code shown below. Versioning tools in IRMA will offer the most current version from these links.

Table SOP-1. A list of the water quality standard operating procedures used in conjunction with this protocol.

Title	Citation	IRMA Reference Code
SOP #1: Safety Protocol	Farahi A. (Lead Aquatic Biological Science Technician), McCutcheon A. (Biological Science Technician), Jones T. (Coastal Ecologist), Raikow D. (Aquatic Ecologist) 2021. SOP #1: Safety Protocol. Version 2.11. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293516
SOP #2: General Tasks Prior to Conducting Field Work	Farahi A., McCutcheon A., Jones T., Kudray G. (Program Manager), Raikow D. 2021. SOP #2: General Tasks Prior to Conducting Field Work. Version 2.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265519
SOP #3: Training Observers	Farahi A., McCutcheon A., Jones T., Kudray G., Raikow D. 2021. SOP #3: Training Observers. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293517
SOP #4a: Using Garmin® GPS Units	Wasser M. 2021. SOP #4a: Using Garmin® GPS Units. Version 2.01. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293725
SOP #4b: Downloading and Uploading Data from/to a Garmin® GPS	Wasser M. 2021. SOP #4b: Downloading and Uploading Data from/to a Garmin® GPS. Version 1.01. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293508
SOP #5: Selecting Water Quality Sampling Stations	Wasser M. 2021. SOP #5: Selecting Water Quality Sampling Stations. Version 3.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2294176

Table SOP-1 (continued). A list of the water quality standard operating procedures used in conjunction with this protocol.

Title	Citation	IRMA Reference Code
SOP #6: YSI EXO Sonde Operation	Farahi A., McCutcheon A. 2021. SOP #6: YSI EXO Sonde Operation and Calibration. Version 1.1. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265523
SOP #7: Collecting Freshwater Samples: General Procedures	Farahi A., McCutcheon A., Jones T., Raikow D. 2021. SOP #7: Collecting Freshwater Samples: General Procedures. Version 2.11. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265526
SOP #8: Collecting Groundwater Samples at KAHO	Farahi A., McCutcheon A., Jones T., Raikow D. 2021. SOP #8: Collecting Groundwater Samples at Kaloko-Honokōhau National Historical Park (KAHO). Version 2.21. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265527
SOP #09: Collecting Marine Water Samples	Farahi A., McCutcheon A., Jones T., Raikow D. 2021. SOP #9: Collecting Marine Water Samples. Version 3.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265528
SOP #10: Quality Control When Changing Labs	Raikow D., Farahi A., McCutcheon A. 2021. SOP #10: Quality Control When Changing Labs. Version 1.0. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2284968
SOP #11: Post-field Work Procedures and Equipment Maintenance	Farahi A., McCutcheon A., Jones T., Raikow D. 2021. SOP #11: Post-field Work Procedures and Equipment Maintenance. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265531
SOP #12: Workspace Setup and Project Records Management	Kozar K., Weisenborn K. 2021. SOP #12: Workspace Setup and Project Records Management. Version 1.04. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293510
SOP #13: Datasheet Handling Procedures	Kozar K. 2021. SOP #13: Datasheet Handling Procedures. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293511
SOP #14: Managing Photographic Images	Kozar K. 2021. SOP #14: Managing Photographic Images. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293512

Table SOP-1 (continued). A list of the water quality standard operating procedures used in conjunction with this protocol.

Title	Citation	IRMA Reference Code
SOP #15: Preparing YSI Files for Importing into the Database	Kozar K., et. al. 2021. SOP #15: Preparing YSI Files for Importing into the Database. Version 2.0. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293513
SOP #16: Data Entry and Verification	Kozar K. 2021. SOP #16: Data Entry and Verification. Version 1.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293514
SOP #17: Post-season Data Quality Review Certification	Kozar K. 2021. SOP #17: Post-season Data Quality Review Certification. Version 1.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265538
SOP #18: Metadata Development	Kozar K. 2021. SOP #18: Metadata Development. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265539
SOP #19: Sensitive Information Procedures	Kozar K. 2021. SOP #19: Sensitive Information Procedures. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265549
SOP #20: Analysis and Reporting	Farahi A., McCutcheon A., Jones T., Raikow D. 2021. SOP #20: Data Analysis and Reporting. Version 1.01. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2265550
SOP #21: Product Delivery Specifications	Kozar K. 2021. SOP #21: Product Delivery Specifications. Version 1.03. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2293515
SOP #22: Product Posting and Distribution	Kozar K. 2021. SOP #22: 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, Hawaii National Park, Hawaii.	2265552
SOP #23: Revising the Protocol	Farahi A., McCutcheon A., Jones T., Raikow D. 2021. SOP #23: Revising the Protocol. Version 1.02. Pacific Island Network Water Quality Monitoring Protocol. Unpublished National Park Service Report, Pacific Island Inventory and Monitoring Network, Hawaii National Park, Hawaii.	2294156

Executive Summary

The National Park Service 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 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 the marine areas 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. These data inform natural resource management decisions made in the face of environmental threats, such as climate change, chemical and microbial contamination, ocean acidification, nutrient enrichment, invasive species, shoreline erosion, and sedimentation.

This protocol revision follows guidance set forth by IMD and evaluates recommendations put forth in prior marine water quality trend reporting (Raikow et al. 2021). It is a substantive change to the marine portion of the PACN water quality protocol version 1 (Jones et al., “Protocol,” 2011). Here we revise sampling design and field methods based on trend and power analyses of data collected from 2008 to 2015 and conduct a full scientific review of the marine portion of the original water quality protocol. Methods were modified to improve understanding of landscape-level influences on nearshore water quality, cull redundant sampling, and increase program efficiency, while still meeting or exceeding the original goals of the monitoring protocol. Specific changes include the following:

- The objectives have been modified by specifying the magnitude of change the sampling design must be able to detect within 10 years and removing the goal of establishing ranges for water quality parameter values
- Total dissolved nitrogen, total dissolved phosphorus, and nitrate + nitrite are clearly identified as primary analytes
- Sampling no longer occurs at “near-bottom” depths
- Sampling no longer occurs at temporary/random sites
- Sampling will occur twice a year instead of four times per year
- New fixed sites have been added to improve spatial coverage and monitor submarine groundwater discharge and river discharge
- Sampling will occur during ebb tide when possible
- Sampling high river discharge events will occur when possible
- Sampling at the actual sea floor will occur during annual benthic surveys

Sample sites are established within the marine areas of Kaloko-Honokōhau National Historical Park (KAHO), Kalaupapa National Historical Park (KALA), War in the Pacific National Historical Park (WAPA), and National Park of American Samoa (NPSA). Water quality parameters monitored at

each site include total dissolved phosphorus (TDP), total dissolved nitrogen (TDN), nitrate + nitrite, pH, temperature, dissolved oxygen, total algae (chlorophyll), turbidity, and specific conductance (salinity). Water sampling methods remain unchanged from the previous protocol; three replicate surface water samples consisting of independent grabs are collected at each 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.

Data will be 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 into the public domain and reported to parks via trend reports and briefing statements. Trend reports will be published approximately once every 10 years (or sooner if warranted) and peer-reviewed. These reports will generally consist of an introduction; methods; analyses, including linear mixed models, Mann-Kendall analyses, spatial analyses, results; and a discussion that will include interpretation of results, management implications, and suggested improvements to protocol methods, if applicable. Briefing reports are intended to provide annual updates of marine water quality data to parks but will not contain statistical analyses or interpretation of results as found in trend reports. Operational reviews and updates to SOPs will be conducted annually.

Acknowledgments

For their contributions to implementing and improving PACN water quality protocols, we thank Gary Rosenlieb, Pete Poyner, John Marra, Sallie Beavers, Sean Eagan, Eric Brown, Mike Gawel, Justin Mills, Visa Vaivai, Sylvester Lee, Sheila McKenna, Greg Kudray, Ryan Monello, Tazhay Jones, Mark Wasser, Kevin Brinck, Tara Holitzki, Tracy Weigner, and two anonymous reviewers.

1 Background and Objectives

The mission of the National Park Service (NPS) is to preserve natural and cultural resources unimpaired for future generations (Organic Act of 1916; Dilsaver 2016). The 1998 National Parks Omnibus Management Act instructed the Secretary of the Interior to monitor long-term trends in natural resources (Public Law 105–391). 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 (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

The PACN water quality protocol was implemented in 2008 across 10 national park units on islands in the Pacific Ocean (Figure 1). Four of these parks, including Kaloko-Honokōhau National Historical Park (KAHO), Kalaupapa National Historical Park (KALA), War in the Pacific National Historical Park (WAPA), and National Park of American Samoa (NPSA), encompass significant marine natural resources. Pearl Harbor National Memorial located on Oahu also contains marine waters but is monitored by the U.S Navy. Threats to marine natural resources in PACN parks include climate change, chemical and microbial contamination, ocean acidification, nutrient enrichment, invasive species, shoreline erosion, and sedimentation. Specific park management concerns related to marine water quality include endangered sea turtles and monk seals at KALA, non-point source pollution derived from human and animal wastes at NPSA, nutrient loading by terrestrial inputs to watersheds that drain into the sea, and the expansion of human activities, including harbors at KAHO and land use/development at WAPA.

Pacific Island Network (PACN)

National Park Service
Inventory and Monitoring Program

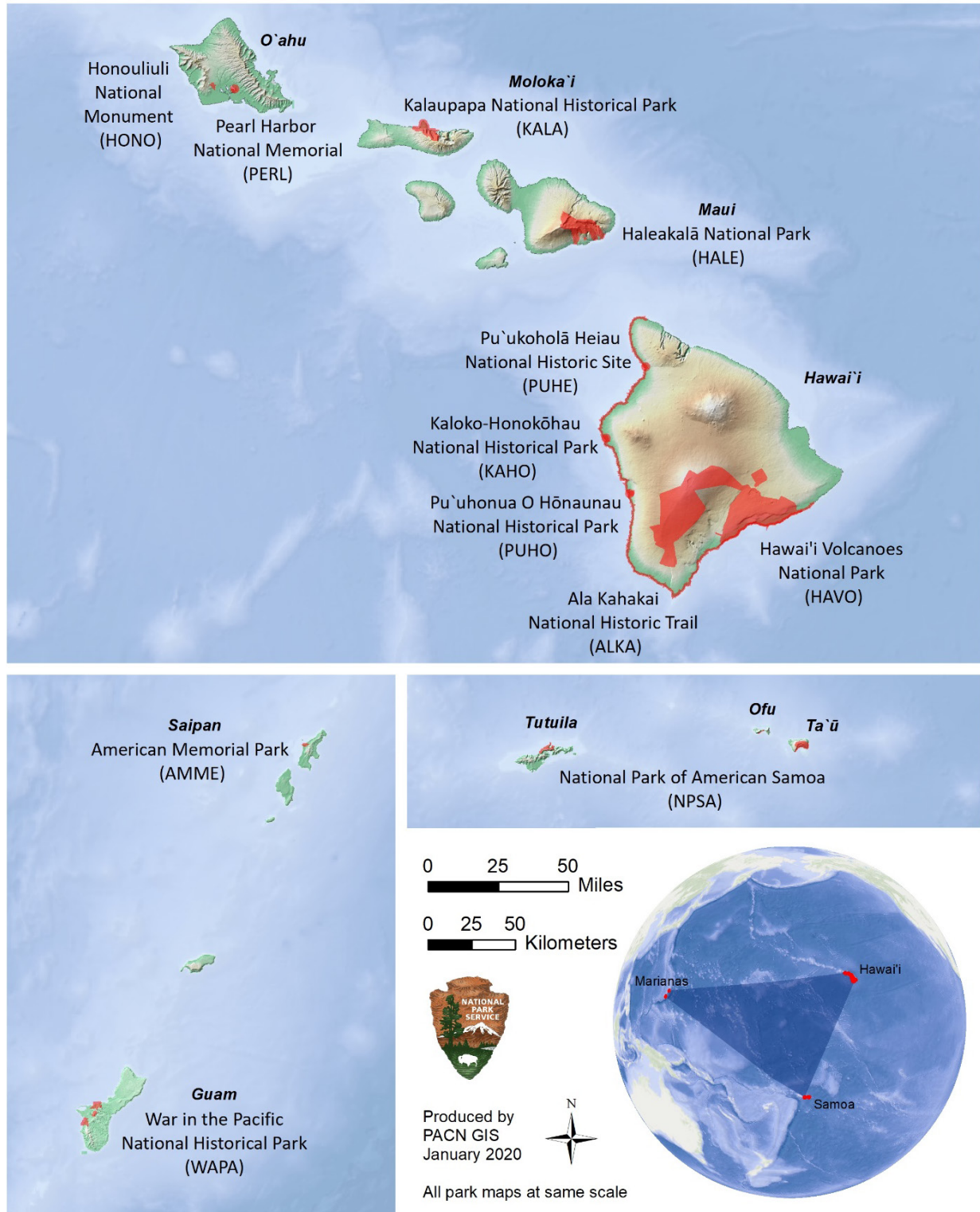


Figure 1. Park units of the Pacific Island Network. Pearl Harbor National Memorial and Honouliuli National Monument are not monitored by PACN.

1.2 Synopsis of Trends Observed and Scientific Review Rationale

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 data from 2008 to 2015 (Raikow et al. 2021). Waters were found to be low in total dissolved phosphorus (TDP), with concentrations generally at or below the 15.0 µg/L detection limit. Waters were low in total dissolved nitrogen (TDN) with concentrations centered close to the detection limit of 0.07 mg/L and with outliers up to 0.44 mg/L. Nitrate + nitrite ($\text{NO}_3^- + \text{NO}_2^-$) concentration ranges were centered at or below ~10 µg/L. Near-bottom waters had lower concentrations of nutrients than surface waters. Fixed and temporary sites did not differ substantially with regard to any parameter. Waters were high in dissolved oxygen, low in turbidity, and thus oligotrophic and consistent with previous studies.

Only results at KAHO merited concern with regard to water quality: 1) Honokohau Small Boat Harbor, the entrance to which is within the marine boundaries of KAHO, consistently released a plume of water that was colder, fresher, and higher in nutrients than ambient seawater (Raikow et al. 2021), 2) a possible algal bloom was observed in KAHO in 2010 that did not appear to be caused by the harbor plume (Raikow et al. 2021), and 3) monitoring results for open waters north of the harbor plume corroborated state determinations of impaired waters for $\text{NO}_3^- + \text{NO}_2^-$, total phosphorous (TP), and turbidity (at Honokohau Beach HI315174 and Pine Trees-Honokohau HIW00146, from 2006 to present; Raikow et al. 2021; State of Hawaii 2008, 2018). However, it should be noted that state field methods, analytical methods, and analytes differ from PACN methods (Raikow et al. 2021; State of Hawaii 2004).

Very few temporal changes were observed over the study period at any park. A ~25% decrease in TDN was observed at KALA from 2013 to 2015. Decreasing salinity of 1–2 parts-per-thousand (ppt) was detected over the study period 2008–2015 in KAHO, KALA, WAPA Asan unit, and NPSA Ofu unit. Increasing temperatures of up to 2 °C were detected at KAHO and up to 1 °C at KALA during the latter portion of the study period 2008–2015, but this may have been an artifact of relatively low values at the beginning and high values at the end of the observation period. Nutrients existed almost completely in dissolved forms. Seasonality was suggested for temperature and chlorophyll. Spatial patterns were only detected at KAHO with respect to the previously known plume emanating from Honokohau Small Boat Harbor. Surface and near-bottom measurements were highly correlated with each other.

Based on these results, Raikow et al. (2021) recommended several major methodological changes. Briefly, the report indicated a need to clarify nutrient sampling techniques and metrics, adjust the sample design to ensure that landscape-level influences present in the study areas are captured, and discontinue sampling at uncertain depths below the surface collected from a boat in favor of less frequent, true-bottom samples collected by divers. The previous site selection method did not capture spatial heterogeneity present in near-shore habitats despite protocol objectives explicitly stating that spatial variance was to be measured. Addition of fixed sample sites optimized to capture spatial patterns and removal of randomly selected temporary sites were recommended. The timing of sampling did not account for tidal stage or recent rainfall events. Sampling during ebb tides and after river discharge events have subsided was recommended. Multiple depths were sampled at high

monetary cost with limited scientific insight. Surface and selected true-bottom sampling were recommended as surface and “near-bottom” samples were similar and correlated. Recommended improvements will reduce monetary costs and field and travel time, improve understanding of terrestrial inputs, and maintain the comparability and ability to detect change (i.e., statistical power) of data over time.

Version 1 of the PACN water quality protocol addressed freshwater, brackish, and marine ecosystems and consisted of several published documents, including a narrative (Jones et al., “Protocol,” 2011), Standard Operating Procedures (SOPs; Jones et al., “Standard operating procedures,” 2011), and Reference Materials (Jones et al., “Appendixes,” 2011). The revision of the PACN water quality protocol will be split into three documents covering marine areas, streams, and lentic ecosystems. While the original protocol contains useful information, such as conceptual models, this revision replaces the original protocol with respect to marine habitats. In addition, a Quality Assurance Plan (QAP) applicable to all PACN water quality protocols will be published, and SOPs have been published on the Integrated Resource Management Applications (IRMA) Portal (Raikow and Kozar 2023). There will no longer be a published “Reference Material” document.

1.3 General Biogeochemistry

Measuring and monitoring water quality consists of assessing the chemistry of water that affects living organisms. How water will be used affects what chemical components are of interest; for example, assessing the quality of drinking water is different than assessing the quality of water in ecosystems. In natural habitats the assessment of water quality can focus on the presence of contaminants and/or the concentration of nutrients and elements essential for life. Attention is typically focused on nitrogen (N), phosphorus (P), and oxygen (O) because nitrogen and phosphorus in water are used directly by plants and algae, and oxygen in water is used directly by animals. A short review of biogeochemistry, the study of nutrient cycling in ecosystems, is presented here to clarify differences between the forms of elements found in water (Table 1). For example, the distinction between particulate and dissolved forms is important.

Table 1. Phosphorus (P) and Nitrogen (N) nutrient species found in aquatic ecosystems.

Nutrient Species	Symbol	Components
Total Phosphorus	TP	PP + TDP
Particulate Phosphorus	PP	Algae, zooplankton, detritus, P in or on inorganic particles
Total Dissolved Phosphorus	TDP	SRP + DOP
Soluble Reactive Phosphorus	SRP	PO ₄ , phosphate, orthophosphate, or inorganic phosphorus
Dissolved Organic Phosphorus	DOP	P bound in organic molecules derived from organisms
Total Nitrogen	TN	PN + TDN
Particulate Nitrogen	PN	Algae, zooplankton, detritus, N in or on inorganic particles
Total Dissolved Nitrogen	TDN	DIN + DON

Table 1 (continued). Phosphorus (P) and Nitrogen (N) nutrient species found in aquatic ecosystems.

Nutrient Species	Symbol	Components
Dissolved Inorganic Nitrogen	DIN	$\text{NH}_4^+ + \text{NO}_2^- + \text{NO}_3^-$
Dissolved Organic Nitrogen	DON	N bound in organic molecules derived from organisms
Ammonium	NH_4^+	In solution ammonium exists in equilibrium with dissolved ammonia, and can be reported as “total ammonia”
Nitrate	NO_3^-	Often reported as $\text{NO}_3^- + \text{NO}_2^-$
Nitrite	NO_2^-	Often reported as $\text{NO}_3^- + \text{NO}_2^-$

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 TDP and TDN. Particulate nutrients can be measured directly by collecting material on filters, and particulate loads deduced by subtracting dissolved concentration from total concentration. This protocol focuses on TDN and TDP (see also Section 2 – Sampling Design).

Although nitrogen makes up 78% of the atmosphere, that nitrogen is not directly usable by most organisms. Under natural conditions atmospheric elemental nitrogen (N_2) is “fixed” by bacteria into ammonia (NH_3 ; reviewed by Wetzel 2001; Camargo and Alonso 2006). Although a gas, ammonia is highly soluble, equilibrates as the ion ammonium (NH_4^+) in aqueous solution, and predominates in this aqueous form in aquatic ecosystems. Equilibrium between NH_3 and NH_4^+ is temperature and pH-dependent, with NH_3 increasing with increasing temperature and pH. NH_4^+ is oxidized into nitrite (NO_2^-) then quickly oxidized into nitrate (NO_3^-), with both reactions falling under the term “nitrification.” In aqueous solution NO_2^- equilibrates with nitrous acid (HNO_2), but NO_3^- does not have a unionized aqueous species. Equilibrium between NO_2^- and HNO_2 is dependent on pH, with NO_2^- concentration increasing with pH. Nitrate naturally occurs at much higher concentrations than NO_2^- in aquatic ecosystems because NO_2^- is quickly oxidized into NO_3^- , which is why the two are typically reported as a single concentration ($\text{NO}_3^- + \text{NO}_2^-$). Nitrate can be “denitrified” back into N_2 . Decaying organic matter is generally converted from organic molecules into NH_3 , a process called “ammonification” or “mineralization.” Nitrogen is generally considered to be limiting in marine ecosystems, meaning that natural processes, like cellular growth, that require multiple nutrients cannot proceed without adding more nitrogen. Nitrate is of particular concern, and thus a focus of monitoring, because increasing $\text{NO}_3^- + \text{NO}_2^-$ can lead to eutrophication in aquatic ecosystems. Increasing $\text{NO}_3^- + \text{NO}_2^-$ may indicate fecal pollution derived from agriculture, raw sewage, or water treatment plants.

Phosphorus (P) cycling is simpler than N cycling due to the absence of a natural gaseous phosphorus species (reviewed by Correll 1998; Wetzel 2001). Under natural conditions the amount of biologically available P is limited by the release of phosphate (PO_4) bound to minerals, predominately apatite ($\text{Ca}_5(\text{PO}_4)_3\text{OH}$) through geologic erosion. Bound PO_4 is released by

“carbonization” and directly assimilated by bacteria and autotrophs (plants and algae). Although other chemical forms of P can exist in nature (e.g., pyrophosphates) such forms are rapidly hydrolyzed into PO_4 . Phosphorus is also considered to be limiting in marine ecosystems and is in such high demand by living aquatic organisms such as phytoplankton that concentrations of phosphorus are typically non-detectable. Hence detection of high or increasing phosphorus may indicate pollution from agricultural runoff, fertilizer from urban areas, or sewage.

Both the nitrogen and phosphorus cycles have been altered at the global scale by humans (reviewed by Vitousek et al. 1997; Smil 2000). The amount of biologically available N and P has greatly increased due to fertilizer production and use, fossil fuel combustion, the growing of N-fixing crops, and mobilization of nutrients previously unavailable to organisms. At the local scale, agricultural runoff and sewage effluent supply deliver large loads of nutrients to coastal environments. Alteration of nutrient cycles by humans is a primary motivation for monitoring nutrients in aquatic ecosystems, as are the release of organisms from previous nutrient availability limitation, the effect of ratios of C:N:P and relative abundances of nutrient species on planktonic community and food-web structure, and toxicity of some nutrient species to aquatic animals at high concentrations (Camargo and Alonso 2006; Sardans et al. 2012; Gilbert 2012).

Other water quality parameters, including temperature, specific conductance, dissolved oxygen, total algae (chlorophyll), turbidity, and pH, can be monitored using electronic probes. Oxygen is required by fish and other animals, and thus oxygen concentration is an essential parameter to measure in water quality monitoring. Atypically low oxygen levels can quickly kill aquatic animals, even in ecosystems where they previously thrived. Oxygen can be expressed in absolute units such as mg/L, but since the capacity of water to hold oxygen in solution is affected by temperature, a relative unit such as % saturation can be more useful for comparison across time and between ecosystems. Water can become supersaturated with oxygen when oxygen production by autotrophs exceeds the rate at which the waterbody can equilibrate with the atmosphere. Specific conductance directly measures the capacity of water to conduct electricity as affected by ion concentrations, and as such can be used to calculate salinity. Most aquatic animals are adapted to specific salinity ranges, so radical changes in salinity can render a previously hospitable ecosystem uninhabitable to the current community of animals. Turbidity is a measure of light attenuation or cloudiness, but there are many units and detection methods, with no industry standard. Turbidity by itself is not necessarily harmful, but increased turbidity could mean less light is penetrating the water, which could result in alteration of the benthic algal community that depends on light, and thus alteration of the base of the food web for the current community of animals.

Other constituents of water are governed by large scale processes. Salts dissolving globally over geologic time result in seawater normally having a pH of 8.1 (Lau and Mink 2006). Atmospheric carbon dioxide (CO_2) exists in equilibrium with dissolved CO_2 by forming carbonic acid in water and lowering pH in all aquatic ecosystems. Consumption of CO_2 by autotrophs including algae reduces dissolved CO_2 concentrations, reducing carbonic acid and raising pH. Hence changes in pH can be used as an indicator of algal blooms. Marine surface waters are generally clear (have low turbidity), except when wave action suspends sediments, when sediments are delivered to coastal areas by

terrestrial runoff, and during algal blooms. Temperature and salinity in near-shore marine waters can vary seasonally and regionally. Hawaiian coastal waters have been described as moderately warm and saline ($\sim 25^{\circ}\text{C} \pm 1^{\circ}\text{C}$ and $\sim 35\text{‰} \pm 0.2\text{‰}$ respectively; Lau and Mink 2006).

1.4 Land-Sea Interaction

The biogeochemistry of oceanic island nearshore environments is influenced by the interaction between terrestrial meteoric precipitation, porous landforms, and surface runoff to coastlines. Wind mixes marine surface water through wave action, maintaining high oxygen saturations. While open marine waters far from shore can be stratified into a surface layer mixed by wind and extending up to 100 m deep over colder and more nutrient-enriched water (Lau and Mink 2006), stratification of nearshore marine water can include a 1–2 m thick layer at the surface that is cooler and less saline than deeper water (Garrison et al. 2003; Johnson et al. 2008). Windward coasts of Pacific oceanic islands typically have high annual rainfalls, high rates of aquifer recharge, high erosion rates, and well-developed stream networks that drain directly into the ocean (Lau and Mink 2006). Conversely, precipitation falling on leeward sides of Pacific islands can immediately penetrate the ground rather than flowing overland (Oki 1999; Moore 1999), and this precipitation mixes with groundwater and seawater infiltrating terrestrial aquifers, creating brackish groundwater lenses (Moore 1999). Complex underlying geology, including lava tubes and karst caves, can transmit water quickly, while lava dikes can impede groundwater flow resulting in perched aquifers (Oki 1999; Knee and Paytan 2011; Taboroši et al. 2004). Hence, the shorelines of Pacific islands can interact with nearshore marine habitats in complex ways. For example, one such complex interaction is the expulsion of brackish water in a process called submarine groundwater discharge (SGD; reviewed by Taniguchi et al. 2002; Burnett et al. 2003).

Submarine groundwater discharge is an example of ecological subsidy, whereby nutrients and energy are derived from one area or ecosystem, and then supplied to another ecosystem and used (Polis and Power 2004). While ecosystems can mutually exchange resources through different mechanisms, shorelines discharging groundwater can experience a unique, continual, rapid, and reciprocal exchange mediated by tides moving water between offshore water and the subterranean terrestrial aquifer (Moore 1999; Li et al. 1999; Robinson et al. 2007). Larger pulses of SGD to the nearshore environment also occur immediately after terrestrial rainfall events (Taniguchi 2002). Additionally, geothermal heating can induce large-scale circulation patterns of groundwater through shoreline aquifers, which may have significance on the Island of Hawai‘i due to the presence of active volcanoes, wave action, seabed topography, and sediment porosity (Moore 1999; Taniguchi et al. 2002; Burnett et al. 2003).

The evaluation of nearshore marine water quality is also pertinent to terrestrial coastal aquatic ecosystems due to the reciprocal aquifer-open water exchange nature of SGD. Consideration of marine influence on terrestrial coastal aquatic ecosystems is of particular importance to KAHŌ due to a large and dense population of anchialine pools, a globally rare waterbody type that provides important habitat for endemic invertebrates. The historically dominant interest of researchers and resource managers, however, has been the effect of SGD-supplied materials, including pollutants, to anchialine pools, fishponds, and nearshore marine ecosystems such as corals reefs.

Generally, SGD is known to supply materials derived from land to nearshore environments, including nutrients (Li et al. 1999; Slomp et al. 2004; Fabricius 2005; Paytan et al. 2006; Knee et al. 2016), fecal indicator bacteria (Knee et al. 2008; Abaya et al. 2018), and pollutants, including metals, pesticides, and emerging contaminants (Knee and Paytan 2011). Nutrient loads supplied to marine nearshore environments by SGD can equal or exceed inputs supplied by surface runoff (Moore 1999; Garrison et al. 2003; Knee et al. 2008). Discharge of groundwater into near-shore marine environments can be constant, if variable in magnitude over time (Holliday et al. 2007; Dulai et al. 2016). While SGD may be dominated by recirculated seawater volumetrically, accounting for over 90% of the total volume of water moving into the ocean at any one time, terrestrially derived groundwater drives net nutrient subsidies to nearshore marine environments (Li et al. 1999). Land-use and landscape features, including harbors (Bienfang 1980), golf courses (Dollar and Atkinson 1992; Wong et al. 1998; Knee et al. 2010), terrestrial agriculture (Amato et al. 2016), and water treatment plants (Amato et al. 2016), are known to directly affect the nutrient composition of SGD (Knee et al. 2010). Increased nutrient concentrations derived from anthropogenic disturbance found in nearshore marine environments have been generally linked to changes to benthic community structure (McCook 1999), eutrophication (Gonzalez et al. 2008), and harmful algal blooms (Paerl et al. 2018).

Rivers and streams deliver freshwater, sediments, nutrients, debris, pathogens, and contaminants to coasts (Milliman and Farnsworth 2013; Bartley et al. 2014). Terrestrial runoff to coastlines is known to deliver nutrients that negatively impact corals and promote macroalgae, supply particulate organic matter consumable by corals and other filter feeders, and deposit sediment that reduce light penetration and settles on corals (Fabricius 2005; Wiegner et al. 2016). Although no large rivers exist on the relatively small Pacific islands monitored by PACN, the marine areas receive surface water inputs. For example, the Asan River discharges into the Asan marine unit of WAPA, Namo Stream and the Agat/Santa Rita wastewater treatment plant discharge into the Agat unit of WAPA, Waikolu Stream and Wai'le'ia Stream discharge into the marine area of KALA, and many streams discharge into the marine areas of NPSA. These rivers and streams should deliver low nutrient and sediment loads. However, coral reefs in areas with relatively low human impacts are still subject to sedimentation, for example, on the island of Molokai (Ogston et al. 2004), and therefore such processes are still important elements of benthic marine ecology. When comparing PACN monitoring results to other Pacific islands, it should be kept in mind that most studies of surface water discharge from these areas have focused on human-dominated areas. For example, Hilo Bay on Island of Hawai'i, into which the Wailoa and Wailuku Rivers flow, receives high N, C, P, and fecal indicator bacteria loads in pulses following rainfall events (Wiegner et al. 2016).

1.5 El Niño Southern Oscillation

The Pacific Ocean undergoes large-scale multi-year shifts in ocean surface temperatures. A multi-year cycle of ocean surface warming and cooling occurs in the tropical Pacific Ocean called the Southern Oscillation (reviewed by Wang et al. 2016). The warming phase of the Southern Oscillation is called an “El Niño” event, the cooling phase is called a “La Niña” event, and the entire cycle is also called the El Niño Southern Oscillation (ENSO). The El Niño, La Niña, and intervening “normal” or “neutral” cycles of the Southern Oscillation can each last for multiple years. During

neutral conditions, trade winds blowing westerly push warm surface water to the western Pacific, with subsequent upwelling of cool water in the eastern Pacific. This temperature differential creates an atmospheric cycling of warm moisture-laden air rising in the west and cool dry air sinking in the east called the Walker circulation. Generally, during the La Niña phase, trade winds increase, causing cool eastern Pacific water to extend across the Pacific and intensify the temperature differential, resulting in more rain in the western Pacific. During the El Niño phase, trade winds weaken, allowing warm surface water to extend east across the Pacific. As a result, the Walker circulation is disrupted, and more rain occurs in the eastern and central Pacific with drier conditions in the west. This cycle can have a direct impact on water quality monitoring activities by PACN and it is important to consider it when interpreting results.

1.6 Climate Change

Climate change affects the pH, temperature, and salinity of marine waters. Varying in extent globally, marine pH has fallen by ~0.5 since 1990 (pH is a unitless measure) as a direct result of increased atmospheric CO₂ concentration and carbonic acid equilibrium (EPA 2016). Note that because pH is a log scale, small numerical changes reflect large ecological changes. Marine surface water temperature has risen ~0.5 °C since 1980 (EPA 2016). Climate change effects on salinity are indirect and influenced by a variety of local and non-local factors such that some areas may become more saline and others less saline. Marine salinity in an area, or the “salinity field,” is driven by evaporation, precipitation, river discharge, and the effect of wind on water, all of which are integral and interacting components of climatological processes (Yu 2011; Pierce et al. 2012; Durack et al. 2012). The relative importance of salinity field drivers varies globally, with rainfall dominated regions displaying lower salinities (Yu 2011; Durack et al. 2012). Salinity is directly coupled with temperature in marine systems as both parameters interact as part of global hydrologic and climatological cycles. Evaporation rate, for example, increases with temperature and leads to greater precipitation. As such and because patterns in the salinity field are relatively easy to measure and more consistent when compared to quantifying broad temporal and spatial changes in local water cycles (Durack et al. 2012), spatial and temporal patterns in marine salinity and temperature have been proposed as sentinel indicators of climate change (Pierce et al. 2012).

1.7 Marine Water Quality in PACN Parks

Marine water quality in PACN parks from 2008 to 2015 was examined by Raikow et al. (2021). PACN nearshore waters were considered to be in good to excellent condition and oligotrophic with very low concentrations of TDP, TDN and NO₃⁻ + NO₂⁻. Little to no particulate fractions were detected at any park. Conditions measured at the surface were highly correlated with conditions near the bottom, although some small absolute differences were observed. Surface waters at KAHO, for example, were frequently cooler and less saline than water near the bottom, an effect of SGD. Seasonality was generally detected for temperature and chlorophyll. Spatial patterns of increased nutrient concentrations were only detected at KAHO with respect to the Honokohau Small Boat Harbor. Decreasing trends were detected for salinity at KAHO, KALA, WAPA Asan unit, and NPSA Ofu unit. An increasing trend in temperature was detected at KAHO and KALA. These temporal patterns in salinity and temperature were considered to most likely be driven by ENSO effects that were present from 2008 to 2015.

1.8 Considerations Affecting Overall Protocol Design

Many components are necessary for the 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.) Sampling in the interest of meeting data collection goals that would require putting personnel at unacceptable risk is prohibited. For example, marine work using a boat is not considered safe to do in KALA during winter months, so no water samples are collected in the last or first quarters of a calendar year. Further factors affecting this revision included logistical constraints, cost limitations, marine benthic and fish protocols, consultation with the NPS Water Resources Division, and analysis of data collected to date.

1.9 Objectives

The purpose of ecosystem monitoring is to understand patterns over time and space, natural or otherwise, 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 2012). Here, monitoring serves the NPS mission by improving understanding of specific ecosystems under management. Change over time, or trends, may 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 most importantly, relevant information on marine water quality to park managers and the public. The objectives of this revised protocol remain the same as the first version (Jones et al., “Protocol,” 2011), with the exception that determining the ranges of parameter values has been removed because a baseline report that describes these values has been published (Raikow et al. 2021). 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 include the following:

- To collect high-quality time-series data on TDP, TDN, $\text{NO}_3^- + \text{NO}_2^-$, temperature, pH, dissolved oxygen, salinity, chlorophyll, and turbidity in the marine areas 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 100% change in TDP, 100% change in TDN, 150% change in $\text{NO}_2^- + \text{NO}_3^-$, 4% change in temperature, 0.25 value change in pH, 10% change in oxygen saturation, 2% change in salinity, 250% change in chlorophyll, and 150% change in turbidity over 10 years with at least 80% power, using alpha of 0.05.

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 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 chief of science, 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 above protocol objectives. 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; see 2.2.2 Power below) the methodology should be able to detect. As part of this revised protocol, a new power analysis was conducted using 2008–2015 data reported in Raikow et al. (2021), and deltas were chosen for each parameter based on results of past monitoring and set to no more than half of a level of change considered to be potentially harmful, as a conservative threshold.

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

Topic	Change	Justification
Objectives	Determination of the range of water quality parameters was removed.	Ranges of baseline water quality parameters have been determined (Raikow et al. 2021).
	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, 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 all parks was 100% in all parks except one at 98% (Raikow et al. 2021).
	The amount of change to be detected (delta) was specified for each parameter, rather than 50% as previously applied to each parameter, and added to the objectives.	Deltas were determined for each parameter based on results obtained from 2008 to 2015 (Raikow et al. 2021) and set to no more than half of a level of change potentially harmful, as a conservative threshold.

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

Topic	Change	Justification
Sampling Depth	Sampling at a depth approximately 2 to 3 m above the sea floor, termed “near bottom,” was removed.	Parameters measured at the surface and near-bottom were highly correlated. Near-bottom sampling did not increase general ecological understanding of park ecosystems, was redundant to surface sampling, added monetary cost, and varied in depth and did not actually occur at the benthic level (Raikow et al. 2021).
	Water sampling collected by divers during annual benthic surveys at the true sea floor was added.	Samples collected at the seafloor are expected to reflect conditions experienced by benthic organisms and may capture submarine groundwater discharge.
Sample Site Selection	Sampling at temporary sites was removed.	Temporary sites did not differ from fixed sites and can be randomly placed within demonstrably different plumes, creating artificial bias (Raikow et al. 2021).
Sampling Frequency	Sampling frequency was changed from four times a year to two times a year.	A new power analysis using field data obtained from 2008 to 2015 showed sampling twice a year is sufficient to detect change (see Appendix A).
Fixed Sample Site Count and Dispersion	New fixed sites were added.	Sites were added to improve spatial coverage and monitor submarine groundwater discharge and river discharge.
Sample Timing	Sampling will occur during ebb tide when possible, and sampling river discharge events will occur when possible.	Ebb tide sampling will maximize capture of submarine groundwater discharge, and river discharge sampling will better characterize important factors influencing near-shore conditions.

2.2 Sampling Regime

2.2.1 Sampling Frame and Stratification

Using the terminology reviewed in Albert et al. (2010), the marine area 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). For example, if sampling in a nearshore marine system with significant SGD only during flood tide, SGD could be minimized, and thus results may not be applicable during ebb tide, when SGD could alter conditions. There are three major considerations which would limit the sampling frame to a portion of the target population: safety, accessibility, and ecological stratification.

Here, the entire marine area of a park is the target population, and all safely accessible marine waters within KAHŌ, KALA, the Agat and Asan marine units of WAPA, and the marine areas of the Tutuila and Ofu units of NSPA are the sampling frames, as defined by the original protocol (Jones et

al., “Protocol,” 2011). In the original protocol, the sampling frame was further limited to sites above specific bathymetric isobars in order to correspond to benthic marine monitoring (Jones et al., “Protocol,” 2011). Results from the first decade of monitoring showed spatial heterogeneity at some parks, suggesting that sampling should be spatially stratified in some areas (Raikow et al. 2021). At the discretion of the Aquatic Ecologist and approval of the Program Manager, sampling may also occur outside the park boundary for specific scientific purposes.

Limiting the sampling frame to specific hydrographic isobars in the original protocol limited the representativeness of obtained data. Specifically, inference could not be extended much beyond the area of the isobar, which is why Raikow et al. (2021) limited interpolation of data in spatial analyses. In practice dispersion of sample sites did not limit the sampling frame to a fixed distance offshore. At KAHO, for example, the isobar was much closer to the shoreline in the northern section of the study area than in southern areas (Raikow et al. 2021). It was unclear if an influence of SGD could be measured at those locations. Thus, data obtained from sampling under the original protocol were primarily relevant to well-mixed open waters.

This revision is designed to maintain the long-term data set for well-mixed open waters and extend the sampling frame to areas within park boundaries not previously sampled. The extended areas include open waters farther out to sea that are expected to behave the same as previously sampled open waters, nearshore areas where SGD is expected to influence conditions, and the outflows of rivers and streams where riverine inputs are expected to have limited influence at low flow and pulses of greater influence at high flows.

Sites selected for expansion of the sampling frame will be treated differently than previously established sites in statistical analyses. For expansion of the sampling frame into previously unsampled open waters, a stratified-random approach will be employed placing new sites in open water within an established zone and to choose coordinates randomly within the zone for each sampling effort. This approach will help to balance spatial representation of the entire sampling frame and statistical inference to open waters, and are included in power analyses, see below. Additional sites close to shore and at river mouths are not placed randomly but sited specifically to investigate SGD and river outflow; as such, these sites are not included in power analyses nor included in the data set for long-term trend analysis. See below for park-specific discussion of site dispersion. Note that the original protocol included studies not related to trends, including long-term sonde deployment and study of river outflow, which were never implemented (Jones et al., “Protocol,” 2011). These sections have been removed for clarity.

2.2.2 Power

The original protocol used a power analysis based on sampling four fixed sites to estimate the chance of detecting a 10%, 25%, and 50% change in water quality parameter values. The analysis used data collected along the coast of the Island of Hawai‘i by a non-NPS entity as a basis for estimating variance (Jones et al., “Protocol,” 2011). Results of that analysis showed low power for several parameters, especially those with high variance. The power analysis was limited in applicability to the design of the original protocol, as noted by the authors, by a lack of data from park areas. Note also that levels of change to be detected (δ , delta) used in the original power analysis were arbitrary.

Hence 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 monitoring data from 2008 to 2015 (Appendix A), using $\alpha = 0.05$ and $\beta = 0.20$. These levels were used in order to be consistent with power analyses in the original protocol (Jones et al., “Protocol,” 2011; Tazhay 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.

Delta values were chosen for each water quality parameter separately based on monitoring results of the PACN water quality monitoring program obtained from 2008 to 2015 (Raikow et al. 2021) as directed by the original protocol (Jones et al., “Protocol,” 2011). 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 no more than half of a level of change deemed potentially harmful, as a conservative threshold: delta = 100% for TDP, 100% for TDN, 150% for $\text{NO}_2^- + \text{NO}_3^-$, 4% for temperature, 0.25 for pH, 10% for oxygen saturation, 2% for salinity, 250% for chlorophyll, and 150% for turbidity. The new power analysis separated plume and non-plume areas and included data from both fixed and temporary sites. The purpose of the analysis was to assess the implications of surface sampling one to four times per year at two to ten total sites. Results of the new power analysis (Appendix A) generally showed that sufficient power to detect change, both as trends and anomalous events, was obtained by sampling fewer sites than the eight sites sampled under the original protocol at most parks. Results also showed that sampling two quarters was sufficient to detect change at selected deltas (see objectives) over 10 years at all parks.

Some parks were not directly comparable with the previous protocol with respect to power, as site specific data did not previously exist. For example, in the current power analysis, KAHO sampling was split between areas known to be consistently within a nutrient-rich plume emanating from Honokohau Small Boat Harbor and areas not in the plume; WAPA sites were divided into Asan and Agat; NPSA was divided into Ofu and Tutuila. Hence the number of sites required to sufficiently detect change in KAHO marine waters is summarized below in terms of plume and non-plume areas. When the number of sites needed to detect change varied by parameter, the largest number of sites needed to detect change in any single parameter was chosen (Table 3). For example, while two sites were generally sufficient to detect change for most measures in non-plume KAHO areas, $\text{NO}_3^- + \text{NO}_2^-$ required nine sites to be sampled in non-plume areas to detect change, and this latter value was selected for all measures.

Oxygen saturation in Ofu (NPSA) initially required eight sites to meet power analysis goals, whereas all other parameters only required two sites. After review of the data, it was observed that high variability of Ofu oxygen was the product of tidal action, whereby low tides produced isolated pools where oxygen was depleted over time. The power analysis was re-calculated to account for this pattern, which reduced the number of sites needed to detect change. Future analyses will separate data into pool and non-pool categories and this revised protocol requires sampling to be conducted at specific tides when possible (see section 2.2.3 below).

Table 3. Number of marine water quality sample sites by Pacific Island Network parks.

Park	Area	Minimum Number of Sites for Open Waters ¹	Number of Open Water Sites Established ²	Other Additional Sites ³
Kaloko-Honokōhau National Historical Park (KAHO)	Non-plume	9	10	5
	Plume	2	4	–
National Park of American Samoa (NPSA)	Tutuila	5	9	1
	Ofu	3	5	–
War in the Pacific National Historical Park (WAPA)	Asan	2	2	1
	Agat	4	4	2
Kalaupapa National Historical Park (KALA)	–	7	10	1

¹Number of sites required by power analysis (open water) to detect change in open waters with a Type II error rate of 0.20 when sampling two times per year.

²Number of sites chosen to satisfy power requirements (open water).

³Number of additional sites chosen to evaluate other landscape features and that do not count against power requirements.

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. In the interest of lowering costs, and with no reduction in power, sites will be sampled twice per year. Analysis of data collected 2008–2015 suggested ebb tides (flowing away from shore) may display conditions reflecting the expulsion of SGD. Therefore, sampling should target ebb tide whenever possible to maximize potential capture of SGD and control for tidal condition. At this time there may not be sufficient data to conclude that a difference in water quality exists between tides at a magnitude sufficient to influence detection of long-term trends. Thus, this phenomenon should be examined further, and adjustments made to future methods to account for variation between tides. In addition, discharge events at streams and rivers should be sampled opportunistically if it is possible to do so safely, in order to examine influence on near shore environments.

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 but permanently established sites (fixed sites), and a panel of four sites randomly generated for each sampling event (temporary sites, referred to in the original protocol as “random sites”). Use of this type of split-panel design balances consistency, (i.e., the reduction of potentially confounding factors caused by changing site location), with probabilistic sampling, (i.e., random site location). Although the dispersion of sample sites under the original protocol was intended to “to make inferences to the entire target population within the sampling frame” (Jones et al., “Protocol,” 2011), analysis of data collected 2008–2015 (Raikow et al. 2021) showed that temporary sites did not differ from fixed sites when important spatial phenomena such as plumes were accounted for. Thus, for marine areas of

PACN parks, there was no benefit to using temporary sites, whereas there were costs, namely inconsistent placement within spatial phenomena that require data to be split into different groups, plume and non-plume areas, and lack of coverage of other landscape-level features. Therefore, this protocol revision ceases the use of temporary sites.

The four randomly generated fixed sites established in the original protocol at each park and sampled during each event since 2008 are retained and will continue to be sampled at each event under this protocol revision. New open-water sites will be chosen at random from designated areas in order to improve spatial coverage, maintain statistical inference within the sampling frame, and contribute to power requirements (Jones et al., “Protocol,” 2011). Further additional sites are established to evaluate the potential influence of landscape features including SGD, plumes, and river outlets. Thus, new sites are placed non-randomly in order to explicitly improve evaluation of known and potential spatial variability, and do not contribute to power requirements (Table 3).

Fixed sites that do not contribute to meeting power needs for evaluation of open-water conditions are established near stream mouths to assess potential plumes from these sources, which is a standard method for assessing stream inputs to near-shore environments (e.g., Weigner et al. 2013; Weigner et al. 2016). Some new sites will be accessed from shore, which is a new procedure under this protocol revision. Direct examination of spatial variation is consistent with both the original and modified program objectives. The retention of sampling at previously sampled fixed sites allows consistency across years for the purpose of detecting long-term trends in open waters.

Site selection at KAHO is split between open-water plume, open-water non-plume, and near-shore areas (Figure 2). While in the open-water non-plume area nine sites are required to meet minimum power requirements, 10 sites are placed in open-water areas and spaced to improve spatial coverage. These 10 sites include three fixed sites sampled since 2008 (i.e., sites retained from the previous protocol: FKAHO02_mr, FKAHO05_mr, FKAHO06_mr), four previously-established fixed sites that were not sampled regularly under the previous protocol (FKAHO01_mr, FKAHO08_mr, FKAHO09_mr, FKAHO10_mr), and three new fixed sites placed farther away from shore that will be randomly selected for each sampling event within designated areas.

While in the plume area two sites are required to meet minimum power requirements, four sites have been chosen to assess the plume longitudinally: Honokohau Harbor (FKAHO17_mr, the plume origin site), a new site, FKAHO12_mr (previously sampled regularly), and FKAHO14_mr (not previously sampled regularly). Five new shoreline sites are also added to assess SGD, specifically targeting major landscape features (Aiopio Fish Trap, off-shore of Aimakapa Fishpond, shoreline between Aimakapa and Kaloko fishponds, off-shore of Kaloko Fishpond, and the shoreline north of Kaloko Fishpond), and are thus not randomly placed. These near-shore sites do not count toward power needs and will be analyzed as a separate population.



Figure 2. Sample sites at Kaloko-Honokōhau National Historical Park. A, B, and C represent bounded areas in which sites will be randomly chosen.

At KALA seven sites are required to meet power requirements. Ten sites have been chosen, including the four fixed sites previously sampled on a regular basis (FKALA03_mr, FKALA07_mr, FKALA11_mr, and FKALA14_mr), three fixed sites not previously regularly sampled (FKALA01_mr, FKALA09_mr, FKALA10_mr), and three new fixed sites that will be randomly selected for each sampling event within designated areas. In addition, one site is added near the mouth of Waikolu Stream in order to evaluate the spatial extent of freshwater discharge (Figure 3).

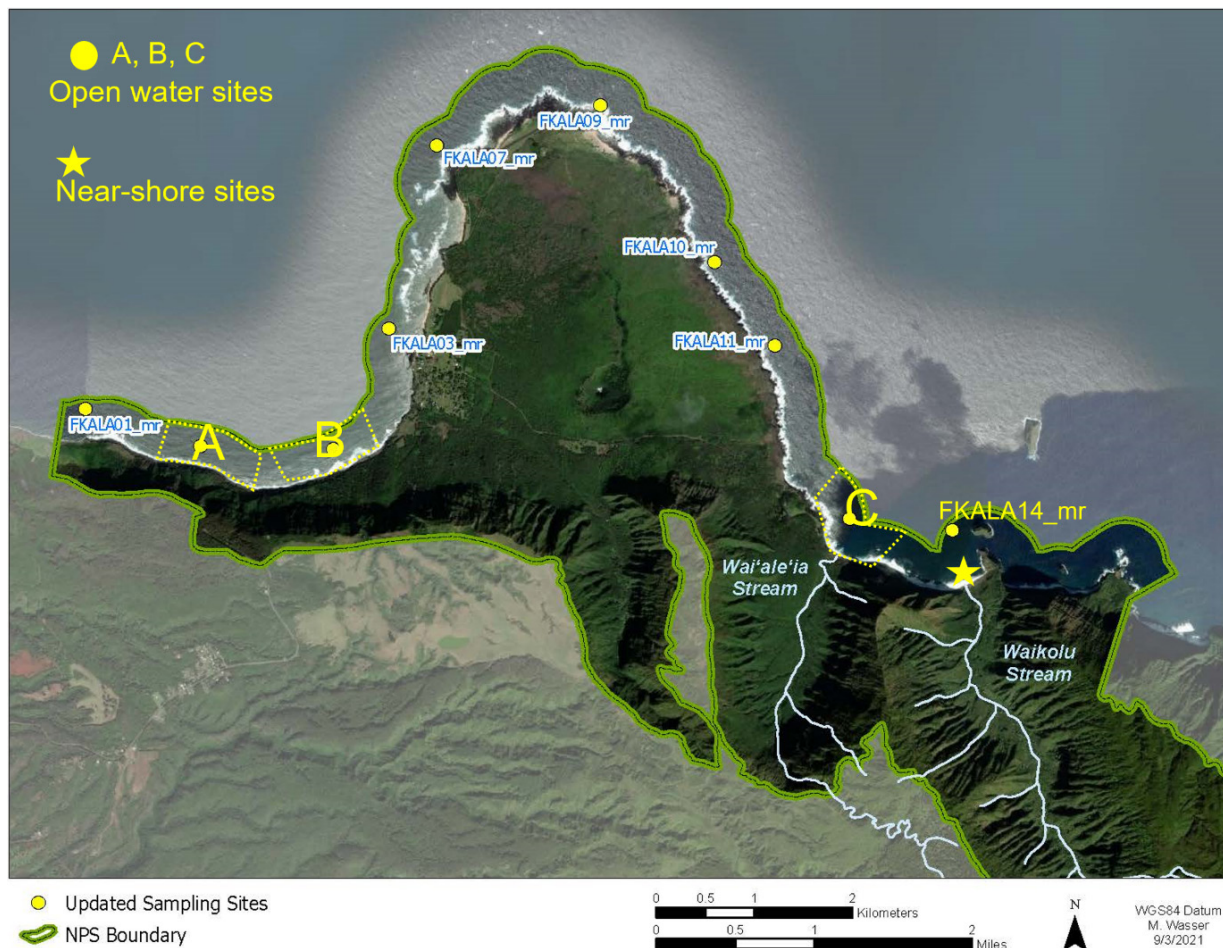


Figure 3. Sample sites at Kalaupapa National Historical Park. A, B, and C represent bounded areas in which sites will be randomly chosen.

Site selection at WAPA is split between the Asan and Agat areas with regard to power. Two sites are required to meet power requirements at Asan and this requirement will be met by sampling the two fixed sites regularly under the previous protocol (FWAPA02_mr and FWAPA05_mr; Figure 4). Four sites are required to meet power requirements at Agat and this requirement will be met by sampling two fixed sites regularly under the previous protocol (FWAPA10_mr and FWAPA15_mr) and two new fixed sites that will be randomly selected for each sampling event within designated areas. One additional site is added at Asan to evaluate the influence of discharge from the Asan River, and two sites at Agat are added to evaluate the influence of Namo stream and wastewater discharge.

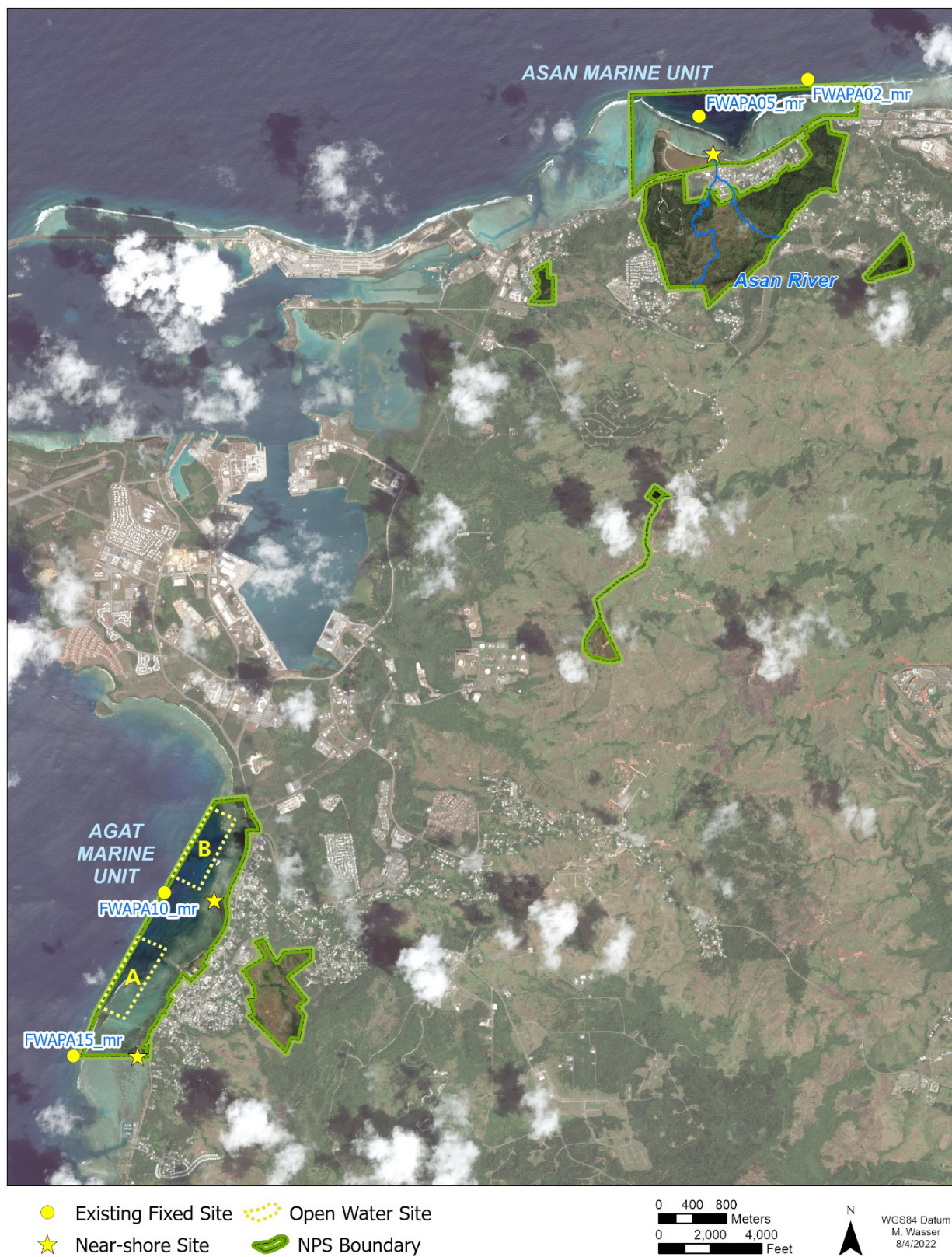


Figure 4. Sample sites in War in the Pacific National Historical Park. A and B represent bounded areas in which sites will be randomly chosen.

Site selection at NPSA is now split between Tutuila and Ofu with regard to power. Five sites are required to meet power requirements at Tutuila and this requirement will be met by sampling seven fixed sites (FNPSA02_mr, FNPSA04_mr, FNPSA05_mr, FNPSA08_mr, FNPSA11_mr, FNPSA12_mr, and FNPSA14_mr) and two new fixed sites that will be randomly selected for each sampling event within designated areas (Figure 5). One additional site is added at Tutuila to evaluate the influence of stream discharge. Three sites are required at Ofu, and five will be sampled, including fixed sites at each area sampled regularly under the previous protocol (FOFU01_mr, FOFU08_mr, and FOFU02-mr).

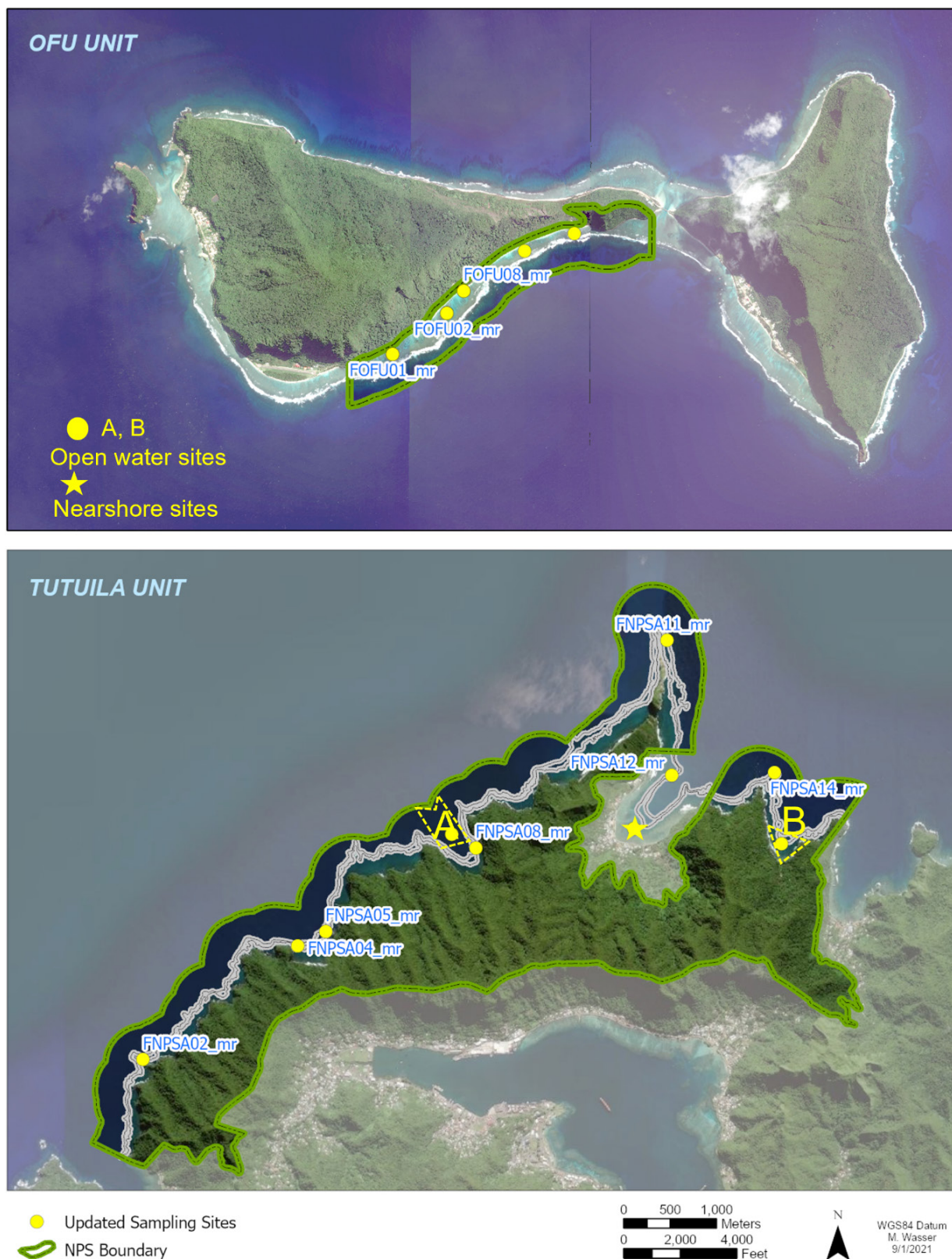


Figure 5. Sample sites in National Park of American Samoa. A and B represent bounded areas in which sites will be randomly chosen. Top: OFU Unit. Bottom: Tutuila Unit.

2.2.5 Sampling Depth

The original protocol sampled within 1 m of the surface, at depths 2–3 m from the bottom, and on occasion at mid-column depths. The depth of 2–3 m above the bottom was chosen to prevent equipment from becoming entangled in coral reefs and causing damage to both equipment and coral reef habitat (Anne Farahi, pers. comm.). These non-surface samples, despite being labeled as “bottom” or “near-bottom” samples in the database, were taken at intermediate depths where water originating at the bottom becomes well-mixed with ambient water, and therefore were not representative of conditions experienced by benthic organisms.

Analysis of data collected from 2008 to 2015 showed that surface samples were highly correlated with these intermediate depth samples (i.e., labeled “near bottom” in the database; Raikow et al. 2021). Due to the lack of differences between surface and non-surface samples and because non-surface samples were not actually sampled at the bottom, this protocol revision no longer includes the non-surface samples previously sampled. This protocol revision adds new sampling at the true sea floor. True-bottom samples will be collected by divers during annual benthic animal surveys. Samples will be taken within reef complexes if present, or the sea floor if coral is not present at a site. Samples taken by divers will be examined to explore the efficacy and value of sampling at the sea floor, and if capturing SGD is possible. Should diver-obtained samples taken at the true bottom prove insightful, such sampling could be expanded in the future with additional diving work. These true-bottom samples will not be grouped with surface samples for purposes of evaluating overall trends but will be evaluated as a separate data set.

2.2.6 Water Quality Parameters

The original protocol was not clear with respect to analyzing TN/TP or TDN/TDP. For example, the executive summary lists TDP and TDN (Jones et al., “Protocol,” 2011; 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 (Anne 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 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. The purposes of the study were to ensure that analysis of TDP and TDN would capture the majority of P and N present in samples, justify continued monitoring of dissolved nutrients, and maintain the long-term data set. Results showed that median proportions of dissolved N and P constituted 100% of nutrients present in marine areas of all parks except WAPA, where the median was 98% (Raikow et al. 2021). Such results should not be surprising because sampling is mandated to occur when field conditions are safe. In the case of marine sampling, safe conditions include a lack of wave action, which is the physical mechanism that suspends particulates. Thus, the original protocol, as well as this revision, specifically target field

sampling when particulates are not expected to be present. Based on the results of the nutrient fraction study, chemical water quality parameters in this protocol revision are unchanged from analytes previously monitored.

Water quality parameters previously monitored at each site remain unchanged, and include: TDP, TDN, $\text{NO}_3^- + \text{NO}_2^-$, pH, temperature, oxygen (reported by the sonde as both dissolved concentration and saturation), turbidity, and salinity. Note that salinity is calculated from the measurement of specific conductance and temperature. Note that the YSI EXO sonde currently in use by PACN employs a total-algae probe rather than a chlorophyll-a probe used in the previous YSI 6600 sonde model. Chlorophyll 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 and Program Manager. In particular, should a discharge event be sampled at a river or stream mouth, both filtered and unfiltered samples should be taken to allow evaluation of particulate loads in addition to dissolved nutrients.

3 Field methods

3.1 Planning and Equipment.

Industry-standard devices, such as Niskin or Kemmerer samplers, will be used to collect water from the water column. Multi-parameter sondes will be used for non-nutrient parameters. These are currently YSI EXO Sondes, but YSI 6600 Sondes may be used if necessary (see 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 prior to every sampling trip. Briefly, specific conductance, dissolved oxygen, total algae, turbidity, and pH will be calibrated, and calibration results tabulated in a notebook. See SOP #6: YSI EXO Sonde Basic Operation and Calibration for general procedures.

3.3 Collecting Water Samples

Three replicate samples will be collected at each site within 1 m below the surface. Each replicate will consist of an independent grab. Standard water samples will be filtered for analysis of dissolved nutrients as quickly and safely as possible following collection using filter towers, currently “Thermo Scientific Nalgene Reusable Filter Holders with Receiver.” Filtration can occur in the field, but samples may be filtered on shore immediately following boat operations if necessary. Water will be filtered using industry-standard 0.47 μ m Glass microfiber GF/F filters that have been muffled. 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 returned to offices and then immediately frozen at -20 °C. 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 and with approval of the Program Manager. Marine water collection procedures are described in detail in SOP #9: Collecting Marine Water Samples and SOP #7: Collecting Freshwater Samples for general filtering and sample handling procedures.

Other procedures of note include recording GPS locations, navigation directions, site descriptions, and taking images of sites. No permanent markers will be established by PACN without permission from the park. Consult SOP #4a: Using Garmin® GPS Units for guidance on Global Positioning System (GPS) receivers and GPS transfer software. Consult SOP #4b: 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 data set, including but not limited to comparison of filtering methods, field filtering vs. lab-filtering, marine depth profiles for physical parameters, 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 *Data Management Plan for the Pacific Island Network* (Dicus 2006), which describes the overall information management strategy for the network, and SOPs #12–22.

4.1 Project Information Management Overview

Project information management may be best understood as an ongoing or cyclic process, as shown in Figure 6. Specific annual information management tasks for this project and their timing are described in section 4.2.3. Readers may also refer to each respective chapter section below for additional guidance and instructions.

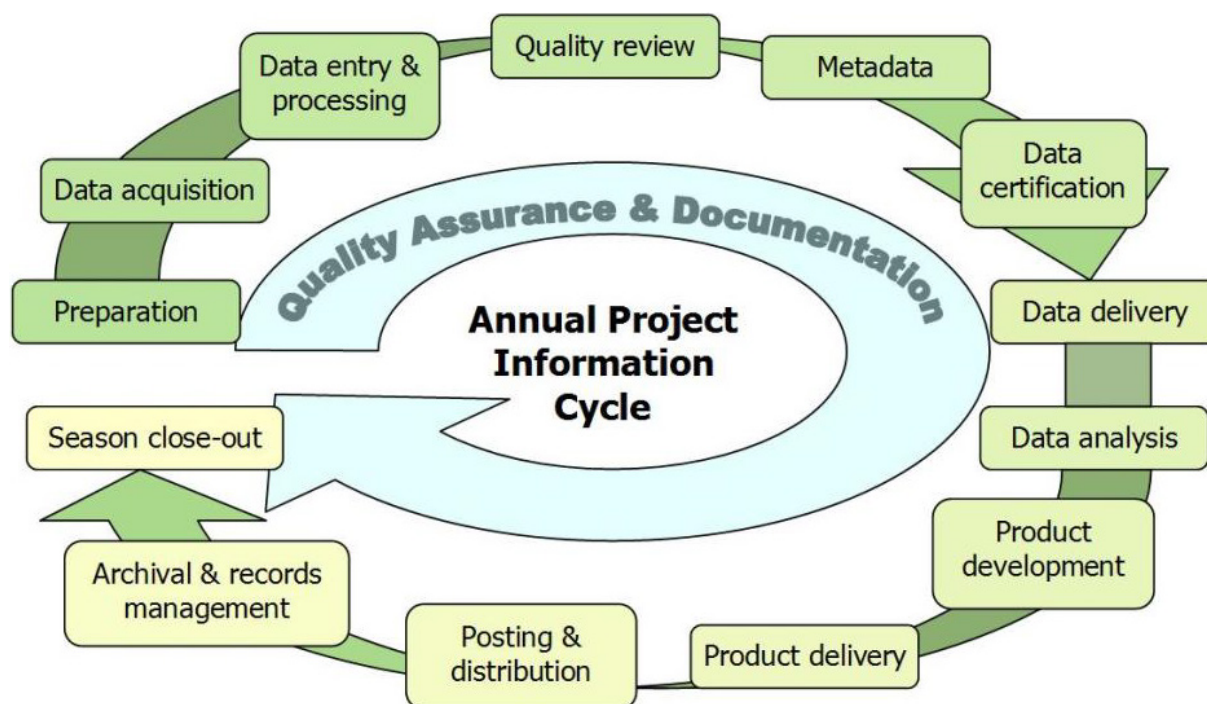


Figure 6. Idealized flow diagram of the cyclical stages of project information management, from pre-season preparation to season close-out. Note that quality assurance and documentation are thematic and not limited to any particular stage of the information life cycle.

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 and processing: Data entry and uploads into the working copy of the database, YSI data processing, etc.

- Quality review: Data are reviewed for quality and logical consistency. Data in the database are checked to ensure they match original datasheets.
- Metadata: Documentation of the year's data collection and results of the quality review.
- Data certification: Data are certified as complete for the period of record.
- Data delivery: Certified data and metadata are delivered for archival and uploaded to the master project database.
- Data analysis: Data are summarized, explored, and statistically analyzed.
- Product development: Reports, maps, and other products.
- Product delivery: Draft reports and other products are provided to parks for comment, and revisions made, as necessary.
- Posting and distribution: Products are submitted to NPS for publication.
- Archival and 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.

4.2 Pre-season Preparations for Information Management

4.2.1 Set Up of Project Workspace

A section of the networked PACN server 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. If network connections are too slow for efficient data entry and processing, individual staff members may set up a workspace on their own workstation, with periodic data transfer to the PACN server. Daily backups of the workstation to an external hard drive will ensure that no data are lost. Additional details may be found in SOP #12: 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 #4a: Using Garmin® GPS Units and SOP #4b: Downloading and Uploading Data from/to a Garmin® GPS.

4.2.3 Implementation of Working Database Copy

The Data Manager will issue a working copy of the database and ensure proper access on the part of the project staff (Table 4). Refer to section 4.3, Overview of Database Design, for additional information about the database design and implementation strategy.

Table 4. Annual information management tasks for Pacific Island Network marine water quality monitoring.

Project Stage	Task Description	Responsibility	Timing
Preparation	Meet (or conference call) to recap past field season, discuss the upcoming field season, and document any needed changes to field sampling protocols or the working database	• PACN Aquatic Ecologist • PACN Lead Aquatic Biological Science Technician • PACN Data Manager • PACN GIS Specialist	Oct
	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
	Generate temporary sample site coordinates for all parks for the following year	• PACN GIS Specialist	By Jan 1
	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 #4b Downloading and Uploading Data from/to a Garmin® GPS)	• PACN GIS Specialist • PACN Lead Aquatic Biological Science Technician • Technicians	Before each tour

¹The PACN Digital Library is a hierarchical digital filing system stored on the PACN file server. Network users have read-only access to these files, except where information sensitivity may preclude general access.

²The NPS Data Store is the online repository of documents and data sets about natural and cultural resources in the parks. Only non-sensitive information is posted publicly in NPS Data Store

Table 4 (continued). Annual information management tasks for Pacific Island Network marine water quality monitoring.

Project Stage	Task Description	Responsibility	Timing
Preparation (continued)	Ensure that project workspace for the upcoming year is ready for use (SOP #12 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 and Processing	Download GPS data and upload to project workspace on the server (SOP #4b Downloading and Uploading Data from/to a Garmin® GPS)	• Technicians	After each tour
	Scan datasheets and upload to project workspace on the server (SOP #13 Datasheet Handling Procedures)	• Technicians	After each tour

¹The PACN Digital Library is a hierarchical digital filing system stored on the PACN file server. Network users have read-only access to these files, except where information sensitivity may preclude general access.

²The NPS Data Store is the online repository of documents and data sets about natural and cultural resources in the parks. Only non-sensitive information is posted publicly in NPS Data Store

Table 4 (continued). Annual information management tasks for Pacific Island Network marine water quality monitoring.

Project Stage	Task Description	Responsibility	Timing
Data Entry and Processing (continued)	Download and process digital images, store in project workspace on the server (SOP #14 Managing Photographic Images)	Technicians	After each tour
Data Entry and Processing	Download and process YSI files, store in project workspace on the server (SOP #15 Preparing YSI Files for Importing into the Database)	Technicians	After each tour
	Enter data into working copy of the database (SOP #16 Data Entry and Verification)	Technicians	After each tour
	Verification of accurate transcription as data are entered (SOP #16 Data Entry and Verification)	Technicians	After each tour
Quality Review	Quality review and data validation using database tools for verified data (SOP #17 Post-season Data Quality Review Certification)	PACN Lead Aquatic Biological Science Technician	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 #19 Sensitive Information Procedures)	- PACN Aquatic Ecologist - Technicians	Jan–Mar
	Update project metadata records (SOP #18 Metadata Development)	PACN Data Manager	Jan–Mar

¹The PACN Digital Library is a hierarchical digital filing system stored on the PACN file server. Network users have read-only access to these files, except where information sensitivity may preclude general access.

²The NPS Data Store is the online repository of documents and data sets about natural and cultural resources in the parks. Only non-sensitive information is posted publicly in NPS Data Store

Table 4 (continued). Annual information management tasks for Pacific Island Network marine water quality monitoring.

Project Stage	Task Description	Responsibility	Timing
Data Certification and Delivery	Certify the season's data and complete the certification report, send certification report to PACN Data Manager (SOP #21 Product Delivery Specifications)	• PACN Aquatic Ecologist	April–May
	Upload certified data into master project database, store data files in PACN Digital Library (SOP #22 Product Posting and Distribution)	• PACN Data Manager	May–June
	Finalize and parse metadata records, store in PACN Digital Library ¹	• PACN Data Manager	May–June
	Update project GIS data sets and associated metadata records, store in PACN Digital Library ¹	• PACN GIS Specialist	May–June
	Upload data set to local NPSTORET database and send to WRD	• PACN Data Manager	July–August
Data Analysis and Reporting	Plotting data for analysis of data following delivery from lab, plotting data for certification, preparing figures for reports	• Technicians	As needed
	Examine data for spatial and temporal status and trends (SOP #20 Data Analysis and Reporting)	• PACN Aquatic Ecologist	Continuous
	Generate report-quality map output for reports	• PACN GIS Specialist	As needed

¹The PACN Digital Library is a hierarchical digital filing system stored on the PACN file server. Network users have read-only access to these files, except where information sensitivity may preclude general access.

²The NPS Data Store is the online repository of documents and data sets about natural and cultural resources in the parks. Only non-sensitive information is posted publicly in NPS Data Store

Table 4 (continued). Annual information management tasks for Pacific Island Network marine water quality monitoring.

Project Stage	Task Description	Responsibility	Timing
Data Analysis and Reporting (continued)	Screen all reports and data products for sensitive information (SOP #19 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 Coordinator for review	PACN Aquatic Ecologist	As available
	Upload completed report to PACN Digital Library ¹ (SOP #21 Product Delivery Specifications)	PACN Aquatic Ecologist or PACN Data Manager	Upon approval
	Deliver other products according to the delivery schedule and instructions (SOP #21 Product Delivery Specifications)	PACN Aquatic Ecologist	Upon completion
Posting and Distribution	Upload certified data set, metadata, and reports to the NPS Data Store ² (SOP #22 Product Posting and Distribution)	PACN Data Manager	Upon completion
Archival and Records Management	Store finalized products in PACN Digital Library ¹	PACN Data Manager	Upon receipt
Season Close-out	Inventory equipment and supplies	- PACN Aquatic Ecologist - Technicians	Oct
	Conference call to discuss previous fiscal year (close out), discuss plans for next fiscal year	- PACN Aquatic Ecologist - Technicians	Oct

¹The PACN Digital Library is a hierarchical digital filing system stored on the PACN file server. Network users have read-only access to these files, except where information sensitivity may preclude general access.

²The NPS Data Store is the online repository of documents and data sets about natural and cultural resources in the parks. Only non-sensitive information is posted publicly in NPS Data Store

Table 4 (continued). Annual information management tasks for Pacific Island Network marine water quality monitoring.

Project Stage	Task Description	Responsibility	Timing
Season Close-out (continued)	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

¹The PACN Digital Library is a hierarchical digital filing system stored on the PACN file server. Network users have read-only access to these files, except where information sensitivity may preclude general access.

²The NPS Data Store is the online repository of documents and data sets about natural and cultural resources in the parks. Only non-sensitive information is posted publicly in NPS Data Store.

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 (tables, fields, and relationships, as documented in Appendix B). The working database is implemented in Microsoft Access to permit greater flexibility when implementing on computers with limited or unreliable network 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 #16: 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. These periodic backup files should be compressed to save drive space, and may be deleted once enough subsequent backups are made. 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 this process 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:

- 1) defining and enforcing standards for electronic formats, locally defined codes, measurement units, and 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.
- 2) checking for unusual or unreasonable patterns in data
- 3) checking for comparability of values between data sets
- 4) 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 #17: Post-season Data Quality Review 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: Datasheet 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 #14: 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 #12: 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, comparability of values between data sets, and assess overall data quality. The Field Lead should run this tool and can 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 PACN Aquatic Ecologist 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, and this involves the development of metadata. 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 Federal Geographic Data Committee (FGDC) guidelines and will contain all components of supporting information such that the data may be confidently manipulated, analyzed, and synthesized. The PACN Aquatic Ecologist will be responsible for providing a completed, up-to-date metadata interview form, available in Appendix 18a in SOP #18: Metadata Development, to the Data Manager. The Data Manager and GIS Specialist will facilitate metadata development by consulting on the use of the metadata interview form, by creating and parsing metadata records from the information in the interview form, and by posting such records to national clearinghouses. For specific instructions, refer to SOP #18: 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 the following: 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 distributing 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# 21: 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 Digital Library.

4.8 Data Analysis

Many reviews have been written describing the analysis of water quality data collected over time (e.g., Robson et al. 2000; Helsel and Hirsch 2002; USDA 2003; Meals et al. 2011; Mozejko 2012). Many different statistical methods have been applied to the analysis of water quality data collected over time, and labeled as detection of trends, with linear regression and Mann-Kendall Tau being most common method of “trend” detection (Figure 7). The data produced under this protocol are time-series data sets, meaning measurements taken at one place (e.g., site, ecosystem, or park) over multiple points in time (e.g., quarterly, annually). Although we produce time-series and are analyzing them, the term “Time Series Analysis” frequently refers to a specific set of statistical tests and approaches, including curve decomposition; autoregressive moving average (ARMA) and autoregressive integrated moving average (ARIMA) models; wave-function analysis, including spectral, Fourier, and wavelet analyses; change-point analysis; and forecasting. Generally, at least 40 data points are recommended for robust Time Series Analysis, but useful results may be possible from some tests with less data. Most techniques of Time Series Analyses cannot yet be robustly applied to PACN water quality data. For example, the marine water quality trend report, Raikow et al. (2021) analyzes data from 2008 to 2015 with up to 17 data points per parameter). Longitudinal Analysis is a general term for analysis of data collected over time and overlaps with Time Series Analysis.

Study	Step-change					Correlation				Regression				Time-series			
	Rank-sum	Hodges-Lehmann	Mann-Whitney	ANCOVA	T-test	Lettenmaier	Thiel-Sen Slope	Spearman Rho	Mann-Kendall Tau	Max-Likelihood	Multiple Linear	LOESS	Linear	Decomposition	Forecasting	Change-point	ARMA, ARIMA
Yake (1979)																	
Hirsch et al. (1982)																	
Lettenmaier (1988)																	
Berryman et al. (1988)																	
Hirsch (1988)																	
Loftis et al. (1989)																	
Uri (1991)																	
Walker (1991)																	
Hirsch et al. (1991)																	
Stow et al. (1998)																	
Urquhart et al. (1998)																	
Robson et al. (1998)																	
Robson et al. (2000)																	
Smith and McCann (2000)																	
Grubb and Robson (2000)																	
Antonopoulos et al. (2001)																	
Helsel and Hirsch (2002)																	
Onoz and Bayazit (2003)																	
USDA (2003)																	
Hrynkiw et al. (2003)																	
Räike et al. (2003)																	
Trench (2004)																	
Xiong and Guo (2004)																	
Ragavan and Fernandez (2006)																	
Meals et al. (2011)																	
Mozejko (2012)																	
Parmar and Bhardwaj (2014)																	
Tizro et al. (2014)																	
Hydrosolutions (2014)																	
Kisi and Ay (2014)																	
Vuorenmaa et al. (2014)																	
Saplioglu and Yavuz (2014)																	
Isles et al. (2015)																	
Count	2	4	4	5	6	2	7	8	19	1	2	6	14	1	1	1	5

Figure 7. Statistics used in water quality and hydrology “Trend Analyses.”

Trend Analysis is another broad term referring to analysis of time-series data, with emphasis on detecting and describing temporal patterns. “Trend,” however, has a specific meaning with respect to statistical analysis. Temporal patterns can be explained by three distinct sources of variation: Trend, Cyclicity, and Error. The trend of a temporal pattern represents the overall long-term change,

typically referring to change in the mean. Sources of variation affecting the mean that cause repeating cycles, such as seasonality as well as stochasticity, can obscure the overall trend. Mean structure may change independently from variance structure. A long-term trend will demonstrate a significant linear component, indicating a directional change in the size of the population-level mean regardless of cyclical effects and annual variability (Urquhart and Kincaid 1999). The primary objective of most environmental monitoring programs, including this one, is the detection and description of trends of the spatial mean value for each parameter measured. For example, from 2009 to 2015, salinity decreased by 1–2 ppt in all areas except the Tutuila (NPSA) and Agat units (WAPA), and at KAHO temperature in marine waters increased (Raikow et al. 2021).

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 so as to allow the assessment and use of new methods as they emerge and to allow expansion of methods as data sets increase in size. Specific statistical procedures are described in detail, and updated as necessary, in the SOPs (e.g., SOP #20: Data 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 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 (e.g., the long-term pattern of TDP in the nearshore environment of KALA measured during ebb tide). 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 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 data sets to be non-normal by truncating the distribution. For example, TDP, chlorophyll, and turbidity were regularly censored in PACN waters from 2009 to 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 data set is censored (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 #20: Data Analysis and Reporting.

4.9 Reporting and Product Development

Reports are to follow standard NPS formats. A short internal NPS communicate 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 (e.g., Raikow 2021). 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. Trend reports will be issued approximately every 10 years or sooner if warranted (e.g., due to concerning data). Trend reports are externally reviewed NPS Natural Resource Reports (NRR); see SOP #20: Data Analysis and Reporting.

4.10 Product Delivery, Posting, and Distribution

Refer to SOP #21: 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 #22: 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.

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 data set has occurred. PACN's NPSTORET contents will be transferred annually to NPS Water Resource Division for uploads to the STORET National Data Warehouse (Figure 8). Although WRD's data dissemination needs to 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.

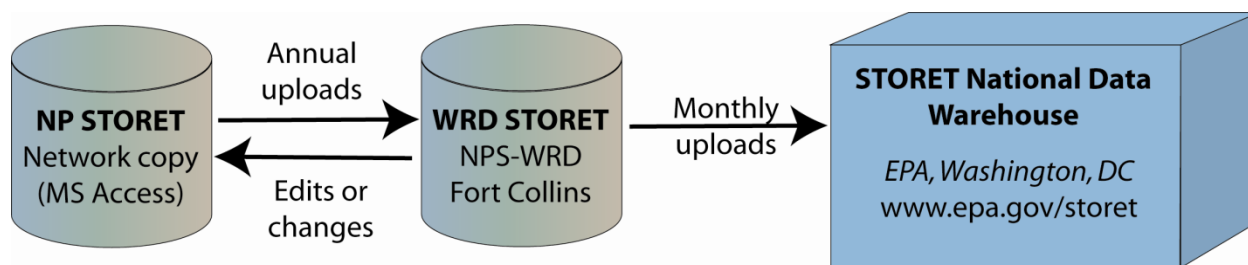


Figure 8. Data flow diagram for Pacific Island Network water quality data.

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 data from 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 #19: 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 park 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 #12: Workspace Setup and Project Records Management). Operational reviews and SOP updates will be conducted annually and uploaded to IRMA.

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, to the working database application, or to any of the SOPs associated with the protocol. Refer to section 4.4 Data Entry and Processing 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 with 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 standard operating procedures, 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).

5 Operational Requirements

5.1 Facilities and Equipment

Facility support, office space, data management, GIS services, and supply requirements (Tables 5 and 6) 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 below 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 staff expenses for Pacific Island Network marine water quality monitoring.

Staff	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 (\$) ^{1,2}	M&IE in Transit (\$) ^{1,3}	Lodging (\$) ^{1,4}	Total Travel (\$)	Total Costs (\$)
Program Manager	537	–	–	–	7	–	7	3,759	–	–	–	–	3,759
Aquatic Ecologist	389	–	–	–	7	–	7	2,723	–	–	–	–	2,723
Data Manager	394	–	–	–	3	–	3	1,182	–	–	–	–	1,182
Lead Biotech	278	1	5	4	8	–	18	5,004	590	354	945	1,889	6,893
PACN Biotech	265	2	–	–	8	4	14	3,710	–	–	–	–	3,710
WAPA Biotech	265	2	–	–	4	4	10	2,650	–	–	–	–	2,650
KALA Biotech	265	2	–	–	4	4	10	2,650	–	–	–	–	2,650
NPSA Biotech	265	2	–	–	4	4	10	2,650	–	–	–	–	2,650
Total Staff Costs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	26,217

¹“Isle of Hawaii: other”.

²Meals and Incidental Expenses (M&IE) full rate is \$118/day.

³75% of full M&IE rate.

⁴Lodging rate is \$189/night.

Table 6. Total protocol expenses for Pacific Island Network marine water quality monitoring.

Expenses	Total Costs (\$)
Total Staff Costs ¹	26,217
Analytical Costs ²	24,336
Supplies	3,000
Sonde Repairs	1,000
Sonde Replacement ³	17,000
WAPA Boat Contract	2,000
Grand Total	56,553

¹Total staff costs are detailed in Table 5.

²52 sites x 3 replicates x 2 surface sample events x 1 bottom sample event x \$52 cost per replicate set of analytes.

³Ten-year mean annual sonde replacement cost.

5.2 Start-up Costs

Startup 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 full-time PACN technician stationed at KAHO, and technicians partially funded by PACN and stationed at KALA, NPSA, and WAPA (Table 5). Travel costs are based on the “Isle of Hawaii: other” per-diem category. As this protocol, sample design, field visit schedule, safety, and other considerations evolve, this budget will also evolve. Estimates are based on 2021 expenses and pay schedules. 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. A contracted boat operator is required at WAPA until such time as boat operations are resumed. KAHO, NPSA, and KALA maintain boat operations under their respective park budgets and provide support in the form of ongoing boat maintenance, fuel, and staff time funded by park coral reef initiative budgets.

6 Personnel Requirements and Training

Responsibilities of the PACN Aquatic Ecologist include the following:

- 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.
- Reporting project status to the Program Manager.
- PACN biological technicians and park staff will shoulder most day-to-day tasks. Responsibilities of technicians include the following:
 - 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.

7 Literature Cited

- Abaya, L. M., T. N. Wiegner, S. L. Colbert, J. P. Beets, M. C. Kaile'a, K. L. Kramer, R. Most, and C. S. Couch. 2018. A multi-indicator approach for identifying shoreline sewage pollution hotspots adjacent to coral reefs. *Marine Pollution Bulletin* 129(1):70–80.
- 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.
- Amato, D. W., J. M. Bishop, C. R. Glenn, H. Dulai, and C. M. Smith. 2016. Impact of submarine groundwater discharge on marine water quality and reef biota of Maui. *PloS one* 11(11): e0165825.
- Antonopoulos, V. Z., D. M. Papamichail, and K. A. Mitsiou. 2001. Statistical and trend analysis of water quality and quantity data for the Strymon River in Greece. *Hydrol. Earth Syst. Sci.* 5:679–692.
- Bartley R., Z. T. Bainbridge, S. E. Lewis, F. J. Kroon, S. N. Wilkinson, J. E. Brodie, and D. M. Silburn. 2014. Relating sediment impacts on coral reefs to watershed sources, processes and management: a review. *Sci Total Environ.* 468–469:1138–1153.
- Berryman, D., B. Bobée, D. Cluis, and J. Haemmerli, 1988. Nonparametric tests for trend detection in water quality time series. *Journal of the American Water Resources Association* 24:545–556.
- Bienfang, P. 1980. Water quality characteristics of Honokohau Harbor: A subtropical embayment affected by groundwater intrusion. *Pacific Science* 34(3):279–291.
- Bolker, B. M. 2008. *Ecological models and data in R*. Princeton University Press, Princeton, New Jersey.
- Burnett, W. C., H. Bokuniewicz, M. Huettel, W. S. Moore, and M. Taniguchi. 2003. Groundwater and pore water inputs to the coastal zone. *Biogeochemistry* 66(1–2):3–33.
- Camargo, J. A. and A. Alonso. 2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. *Environment International* 32(6):831–849.
- Correll, D. L. 1998. The role of phosphorus in the eutrophication of receiving waters: A review, *Journal of Environmental Quality* 27(2):261–266.
- 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.

- Dollar, S., and M. J. Atkinson. 1992. Effects of nutrient subsidies from groundwater to nearshore marine ecosystems off the island of Hawaii. *Estuarine Coastal and Shelf Science* 35(4):409–424.
- Dulai, H., J. Kamenik, C. A. Waters, J. Kennedy, J. Babinec, J. Jolly, and M. Williamson. 2016. Autonomous long-term gamma-spectrometric monitoring of submarine groundwater discharge trends in Hawaii. *Journal of Radioanalytical and Nuclear Chemistry* 307(3):1865–1870.
- Durack, P. J., S. E. Wijffels, and R. J. Matear, 2012. Ocean salinities reveal strong global water cycle intensification during 1950 to 2000. *Science* 336:445–458.
- Environmental Protection Agency (EPA). 2016. Climate change indicators in the United States, Fourth Edition, EPA 430-R-16-004. Environmental Protection Agency, Washington, D.C.
- Fabricius, K. E. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin* 50:125–146.
- 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.
- Garrison, G. H., C. R. Glenn, and G. M. McMurtry. 2003. Measurement of submarine groundwater discharge in Kahana Bay, O'ahu, Hawai'i. *Limnology and Oceanography* 48(2):920–928.
- Gilbert, P. M. 2012. Ecological stoichiometry and its implications for aquatic ecosystem sustainability. *Current Opinion in Environmental Sustainability* 4(3):272–277.
- Gonzalez, F. U. T., J. A. Herrera-Silveira, and M. L. Aguirre-Macedo. 2008. Water quality variability and eutrophic trends in karstic tropical coastal lagoons of the Yucatán Peninsula. *Estuarine, Coastal and Shelf Science* 76:418–430.
- Grubb, H., and A. Robson. 2000. Exploratory visual analysis. *In* Z. Kundzewicz and A. Robson, editors. Detecting trend and other changes in hydrological data. WMO/TD-No. 1013. World Climate Programme – Data and Monitoring, Geneva.
- 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.
- Helsel D. R., and R. M. Hirsch. 2002. Statistical methods in water resources. Pages 65–95 *in* Techniques of water-resources investigations of the United States Geological Survey. Book 4, Hydrologic analysis and interpretation. U.S. Geological Survey, Washington, D.C.
- Hirsch, R. M. 1988. Statistical methods and sampling design for estimating step trends in surface-water quality. *Journal of the American Water Resources Association* 24:493–503.
- Hirsch, R. M., R. B. Alexander, and R. A. Smith. 1991. Selection of methods for the detection and estimation of trends in water quality. *Water Resources Research* 27:803–813.

- Hirsch, R. M., J. R. Slack, and R. A. Smith. 1982. Techniques of trend analysis for monthly water quality data. *Water Resources Research* 18:107–121.
- Holliday, D. T., C. Stieglitz, P. V. Ridd, and W. W. Read. 2007. Geological controls and tidal forcing of submarine groundwater discharge from a confined aquifer in a coastal sand dune system. *Journal of Geophysical Research* 112:C04015.
- Hrynkiw, T., T. Viraraghavan, and G. Fuller. 2003. Analysis of trends in water quality of Buffalo Pound Lake. *Canadian Water Resources Journal / Revue Canadienne des Ressources Hydriques* 28:337–357.
- Hydrosolutions. 2014. Clark Fork River nutrient water quality status and trends report 1998–2012. Montana Department of Environmental Quality, Helena.
- Isles, P. D. F., C. D. Giles, T. A. Gearhart, Y. Xu, G. K. Druschel, and A. W. Schroth. 2015. Dynamic internal drivers of a historically severe cyanobacteria bloom in Lake Champlain revealed through comprehensive monitoring. *Journal of Great Lakes Research* 41:818–829.
- Johnson, A. G., C. R. Glenn, W. C. Burnett, R. N. Peterson, P. G. Lucey. 2008. Aerial infrared imaging reveals large nutrient-rich groundwater inputs to the ocean, *Geophysical Research Letters* 35 L15606.
- Jones, T., K. DeVerse, G. Dicus, D. McKay, A. Farahi, K. Kozar, and E. Brown. 2011. 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.
- Jones, T., D. McKay, K. DeVerse, K. Kozar, K. L. Kramer, A. Farahi, and G. Dicus. 2011. 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., D. McKay, K. DeVerse, and K. Kozar. 2011. 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.
- Knee, K. L., B. A. Layton, J. H. Street, A. B. Boehm, and A. Paytan. 2008. Sources of nutrients and fecal indicator bacteria to nearshore waters on the north shore of Kauai (Hawaii, USA). *Estuaries and Coast* 31(4):607–622.
- Knee, K.L., J. H. Street, E. E. Grossman, A. B. Boehm, and A. Paytan. 2010. Nutrient inputs to the coastal ocean from submarine groundwater discharge in a groundwater-dominated system: Relation to land use (Kona coast, Hawaii, USA). *Limnology and Oceanography* 55: 1105-1122.
- Knee, K. L., and A. Paytan. 2011. Submarine groundwater discharge: A source of nutrients, metals, and pollutants to the coastal ocean. Pages 205–234 in E. Wolanski and D. S. McLusky, editors. *Treatise on Estuarine and Coastal Science* 4. Academic Press, Waltham.

- Knee, K. L., E. D. Crook, J. L. Hench, J. J. Leichter, and A. Paytan. 2016. Assessment of submarine groundwater discharge (SGD) as a source of dissolved radium and nutrients to Moorea (French Polynesia) coastal waters. *Estuaries and Coasts* 39(6):1651–1668.
- Karydis, M., and D. Kitsiou. 2013. Marine water quality monitoring: a review. *Marine Pollution Bulletin* 77:23–36.
- Kisi, O., and M. Ay. 2014. Comparison of Mann–Kendall and innovative trend method for water quality parameters of the Kizilirmak River, Turkey. *Journal of Hydrology* 513:362–375.
- Kuznetsova, A., P. B. Brockhoff, R. H. B. Christensen. 2016. lmerTest: Tests in linear mixed effects models. R package version 2.0-33.
- Lau, L. S., and J. K. Mink. 2006. *Hydrology of the Hawaiian Islands*. University of Hawai‘i Press, Honolulu.
- Lettenmaier, D. P. 1988. Multivariate nonparametric tests for trend in water quality. *Journal of the American Water Resources Association* 24:505–512.
- Li, L., D. A. Barry, F. Stagnitti, and J. Y. Parlange, 1999. Submarine groundwater discharge and associated chemical input to a coastal sea. *Water Resources Research* 35(11):3253–3259.
- Lindenmayer, D. B. and G. E. Likens. 2010. The science and application of ecological monitoring. *Biological Conservation*, 143(6):1317–1328.
- Loftis, J. C., R. C. Ward, R. D. Phillips, and C. H. Taylor. 1989. An evaluation of trend detection techniques for use in water quality monitoring programs. Environmental Protection Agency, Washington, D.C.
- McCook, L. 1999. Macroalgae, nutrients and phase shifts on coral reefs: scientific issues and management consequences for the Great Barrier Reef. *Coral Reefs* 18:357–367.
- Meals, D. W., J. Spooner. S. A. Dressing, and J. B. Harcum. 2011. Statistical analysis for monotonic trends. Tech Notes 6. Terta Tech, Fairfax, Virginia.
- Millard, S. P. 2013. EnvStats: An R package for environmental statistics. Springer, New York. <https://link.springer.com/book/10.1007/978-1-4614-8456-1>.
- Milliman, J. D., and K. L. Farnsworth. 2013. *River discharge to the coastal ocean: A global synthesis*. Cambridge University Press, Cambridge.
- 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.

- Moore, W. S. 1999. The subterranean estuary: A reaction zone of ground water and sea water. *Chemistry* 65(1–2):111–125.
- Mozejko, J. 2012. Detecting and estimating trends of water quality parameters. *In* K. Voudouris and D. Voutsas, editors. *Water Quality Monitoring and Assessment*. April. Intech. Doi:10.5772/2411.
- 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. U.S. Geological Survey, Reston, Virginia.
- 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, 2001. Department of 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.
- Ogston, A. S., C. D. Storlazzi, M. E. Field, and M. K. Presto. 2004. Sediment resuspension and transport patterns on a fringing reef flat, Molokai, Hawaii. *Coral Reefs* 23:559–569.
- Oki, D. S. 1999. Geohydrology and numerical simulation of the ground-water flow system of Kona, Island of Hawaii (Vol. 99, No. 4073). US Department of the Interior, US Geological Survey, Washington, D.C.
- Onoz, B., and M. Bayazit. 2003. The power of statistical tests for trend detection. *Turkish Journal of Engineering and Environmental Science* 27:247–251.
- National Park Service Organic Act, 16 U.S.C. § 1 et seq. (1916).
- Paerl, H. W., T. G. Otten, and R. Kudela. 2018. Mitigating the expansion of harmful algal blooms across the freshwater-to-marine continuum. *Environmental Science and Technology* 52(10):5519–5529.
- Parmar, K., and R. Bhardwaj. 2014. Water quality management using statistical analysis and time-series prediction model. *Applied Water Science* 4:425–434.
- Paytan, A., G. G. Shellenbarger, J. H. Street, K. Davis, M. B. Young, W. S. Moore. 2006. Submarine groundwater discharge: An important source of new inorganic nitrogen to coral reef ecosystems. *Limnology and Oceanography* 51:343–358.

- Pierce, D. W., P. J. Barnett, B. D. Santer, and P. J. Durack, 2012. The fingerprint of human-induced changes in the ocean's salinity and temperature fields. *Geophysical Research Letters* 39:L21704.
- Polis, A., and M. E. Power, Eds. 2004. Food webs at the landscape level. University of Chicago Press, Chicago.
- National Parks Omnibus Management Act of 1998, Pub. L. No. 105–39, 112 Stat. 3497 (1998).
- R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
- Ragavan, A. J., and G. C. Fernandez. 2006. Modeling water quality trend in long term time series. In *Proceedings of SAS Users Group Meeting (SUGI 31)*, paper 205–31. <http://www2.sas.com/proceedings/sugi31/205-31.pdf>.
- Räike, A., O. P. Pietiläinen, S. Rekolainen, P. Kauppila, H. Pitkänen, J. Niemi, A. Raateland, and J. Vuorenmaa. 2003. Trends of phosphorus, nitrogen and chlorophyll a concentrations in Finnish rivers and lakes in 1975–2000. *Science of the Total Environment* 310:47–59.
- Raikow, D. F., S. Kichman, A. L. McCutcheon, and A. 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.
- 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/XXX. National Park Service, Fort Collins, Colorado.
- Robinson, C., L. Li, and H. Prommer. 2007. Tide-induced recirculation across the aquifer-ocean interface. *Water Resources Research* 43:W07428.
- Robson, A., A. Bardossy, D. Jones, and Z. Kundzewicz. 2000. Statistical methods for testing for change. In Z. Kundzewicz and A. Robson, editors. *Detecting trend and other changes in hydrological data*. WMO/TD-No. 1013. World Climate Programme—Water, Geneva.
- Robson, A., T. K. Jones, D.W. Reed, and A. C. Bayliss. 1998. A study of national trend and variation in UK floods. *International Journal of Climatology* 18:165–182.
- Saplioglu, K. and B. R. Yavuz. 2014. Trend analysis of streams in the Western Mediterranean Basin of Turkey. *Fresenius Environmental Bulletin* 23:1–12.
- Sardans, J., A. Rivas-Ubach, and J. Penuelas. 2012. The elemental stoichiometry of aquatic and terrestrial ecosystems and its relationships with organismic lifestyle and ecosystem structure and function: a review and perspectives. *Biogeochemistry* 111(1–3):1–39.
- Slomp, C. P., and P. Van Cappellen. 2004. Nutrient inputs to the coastal ocean through submarine groundwater discharge: controls and potential impact. *Journal of Hydrology* 295(1–4):64–86.

- Smil, V. 2000. Phosphorus in the environment: natural flows and human interferences. *Annual review of energy and the environment* 25:53–88.
- Smith, D. G., and P. B. Mccann. 2000. Water quality trend detection in the presence of changes in analytical laboratory protocols. Monitoring for the Millennium, National Water Quality Monitoring Council Conference, Austin, Texas.
- State of Hawaii, Department of Health. 2004. Water quality standards. HAR Title 11, Ch. 54. The Hawaii State Department of Health, Honolulu.
- State of Hawaii. 2008. State of Hawaii water quality monitoring and assessment report: integrated report to the U.S. Environmental Protection Agency and the U.S. Congress pursuant to sections §303(D) and §305(B), Clean Water Act (P.L. 97–117). The Hawaii State Department of Health, Honolulu.
- State of Hawaii. 2018. 2018 State of Hawaii water quality monitoring and assessment report. Hawaii Department of Health, Clean Water Branch, Honolulu.
- Stow, C. A., S. R. Carpenter, K. E. Webster, and T. M. Frost. 1998. Long-term environmental monitoring: Some perspectives from lakes. *Ecological Applications* 8:269–276.
- Taboroši, D., J. W. Jenson, and J. E. Mylororie, 2004. Karst features of Guam Mariana Islands. Technical Report No. 104. Water and Environmental Research Institute of the Western Pacific, University of Guam, Mangilao.
- Taniguchi, W. C., Burnett, J. E. Cable, and J. V. Turner. 2002. Investigation of submarine groundwater discharge. *Hydrological Processes* 16:2115–2129.
- Tizro, A. T., M. Ghashghaie, P. Georgiou, and K. Voudouris. 2014. Time series analysis of water quality parameters. *Journal of Applied Research in Water and Wastewater* 1:43–52.
- Trench, E. C. T. 2004. Analysis of phosphorus trends and evaluation of sampling designs in the Quinebaug River Basin, Connecticut. United States Geological Survey, Washington, D.C.
- Uri, N. D. 1991. Detecting a trend in water quality. *Research Journal of the Water Pollution Control Federation* 63:868–872.
- Urquhart, N. S., and T. M. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. *Journal of Agricultural, Biological, and Environmental Statistics* 4(4):404–414.
- Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. *Ecological Applications* 8:246–257.
- US Department of Agriculture (USDA). 2003. National water quality handbook. Natural Resources Conservation Service, Washington, D.C.

- 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.
- Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. *Science* 277(5325):494–499.
- Vuorenmaa, J., K. Salonen, L. Arvola, J. Mannio, M. Rask, P. and Horppila. 2014. Water quality of a small headwater lake reflects long-term variations in deposition, climate and in-lake processes. *Boreal Environmental Research* 19.
- Walker, W. W. 1991. Water quality trends at inflows to Everglades National Park. *Journal of the American Water Resources Association* 27:59–72.
- Wang, C., C. Deser, J. Y. Yu, P. DiNezio, and A. Clement. 2016. El Niño-Southern Oscillation (ENSO): A review. Pages 85–106 in P. Glynn, D. Manzello, and I. Enochs, editors. *Coral reefs of the Eastern Tropical Pacific*. Springer Science Publisher, Dordrecht, Netherlands.
- Weigner, Tracy, C. J. Edens, L. M. Abaya, K. M. Carlson, A. Lyon-Colbert, and S. L. Molloy. 2016. Spatial and temporal microbial pollution patterns in a tropical estuary during high and low river flow conditions. *Marine pollution bulletin* 114.
- Weigner, T., M. Lucas, and M. Stephanie. 2013. A comparison of water quality between low- and high-flow river conditions in a tropical estuary, Hilo Bay, Hawaii. *Estuaries and Coasts* 36.
- 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.
- Wetzel, R. G. 2001. *Limnology: Lake and river ecosystems*, Academic Press, New York.
- Wong, J. W. C., C. W. Y. Chan, and K. C. Cheung. 1998. Nitrogen and phosphorus leaching from fertilizer applied on golf course: Lysimeter study. *Water, Air, and Soil Pollution* 107(1):335–345.
- Xiong, L., and S. Guo. 2004. Trend test and change-point detection for the annual discharge series of the Yangtze River at the Yichang hydrological station / Test de tendance et détection de rupture appliqués aux séries de débit annuel du fleuve Yangtze à la station hydrologique de Yichang. *Hydrological Sciences Journal* 49:99–112.
- Yake, W. E. 1979. Water quality trend analysis – The Spokane River Basin [Online]. Washington State Department of Ecology, Lacey.
<https://apps.ecology.wa.gov/publications/documents/79e32.pdf>
- Yu, L. 2011. A global relationship between the ocean water cycle and near-surface salinity. *Journal of Geophysical Research* 116:1–17.

Appendix A: Power Analysis

This appendix describes the approach, specific methods, and results for assessing power to detect change in marine water quality metrics at Pacific Island Network parks. Changes to sampling frequency for water quality metrics in this revised protocol are based on these power analyses.

Methods and Approach

In frequentist statistical analysis there are two types of possible error: false positives and false negatives. A false positive means you are mistakenly concluding that the difference you see (e.g., between the mean in the control group and the mean in the experiment group) is most likely not caused by unseen, underlying, or stochastic variation naturally present in the groups, but caused by the thing you are testing. In other words, if the chance of getting the result you did being caused by the natural variation in the system is low, then the chance that the result is caused by the subject of the experiment is high. We express this chance in terms of alpha (α). Setting $\alpha = 0.05$ means that we will consider the difference between the control and experimental groups statistically significant if the probability (p) of getting that result by the natural underlying variation present in the system is 0.05 or lower. Alpha is the level we set a-priori, and p is the value we get in the analysis of the results. A p -value of $p < 0.0001$ means there was a 0.01% (one one-hundredth of a percent, not one percent) chance of getting the observed results caused by the underlying distribution of the system and not due to the treatment. Therefore, because the chance of falsely concluding that the null hypothesis (that the distributions of the control and experimental group are the same and there was no effect of the subject of the test) is one in ten thousand, we can have high confidence we are not seeing a false-positive, but a true-positive. False-positive error is called Type I error.

A false negative, or Type II error, means there is a true difference, but we are mistakenly concluding that there is no difference between groups or a treatment and accepting the null hypothesis. Making a false negative conclusion could cause resource managers to miss the opportunity to affect change needed to maintain resources. The chance of making this mistake is expressed in terms of beta (β). The “power” of a test is $1 - \beta$. In other words, if the chance of missing a true difference is 25%, then the probability of concluding there is a true-positive result is having a power of 75%.

Here, while we are concerned with detecting change over time, the concepts of α , β , and power are the same. For the analysis we must choose a time period over which the change is to be detected (time period), the amount of change we want to be able to detect (delta, δ), and the power we want to achieve. Ideally, all of this is based on empirical measurements of variation present in the system. In this case the power analysis for each parameter is based on that parameter’s variation measured by PACN over a 10-year period using the same methods by which they will be measured in the future. We assessed the implications of surface sampling one to four times per year at two to ten total sites, both in terms of detecting change over time and detecting discrete anomalous events. Surface water quality data from fixed and temporary sites in the non-plume area in KAHO marine waters was examined to set parameters for the analysis.

Deltas were chosen for each parameter separately based on monitoring results (Raikow et al. 2021) as directed by the original protocol (Jones et al., “Protocol,” 2011). Generally, the goal of resource

management is to avoid change that results in biological impairment, and monitoring is useful if change is detected before impairment occurs. Therefore, the amount of change to be detected, or delta, should allow change to be detected before it reaches a level that might cause impairment. In general, deltas were set to not more than half of a level of change deemed potentially harmful and set lower if achievable with a reasonable sampling effort (Table A1). For example, chlorophyll concentration was very low during normal conditions (median 0.18 $\mu\text{g/L}$, Raikow et al. 2021). During the 2011 apparent algal bloom at KAHO, chlorophyll rose to as high as 3.0 $\mu\text{g/L}$, or a 1500% increase. A 250% increase was used as a delta for chlorophyll, representing a change from the median during normal conditions during 2008-2015 to a value of 0.63 $\mu\text{g/L}$. The time period over which stated change (delta) is to be detected is 10 years, $\alpha = 0.05$, 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., “Protocol,” 2011; Tazhay Jones pers. comm.). 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, also with $\alpha = 0.05$, and $\beta = 0.20$, and the same deltas.

Table A1. Deltas for power analysis of marine water quality parameters at Pacific Island Network parks.

Parameter	Delta Chosen for Power Analysis	Delta in Terms of Parameter Units	Justification
Total Dissolved Phosphorus (TDP)	100%	15 µg/L	TDP was not typically found above the detection limit, thus substantial changes in concentrations would indicate exceedance of state standards.
Total Dissolved Nitrogen (TDN)	100%	0.10 mg/L	TDN was close to the detection limit with mean values just at the state impairment threshold. A 100% increase would indicate exceedance of state standards.
NO ₂ ⁻ + NO ₃ ⁻	150%	20 µg/L	Median nitrite + nitrate was observed at ~8 ug/L, with outliers measured as high as 40 ug/L, or a 400% increase. A 150% delta was chosen to be conservative.
Chlorophyll	250%	0.45 µg/L	During the 2011 apparent algal bloom at KAHŌ, chlorophyll rose from 0.18 to 3.0, a 1500% increase. A delta 250% was chosen to be conservative.
O ₂ saturation	10%	10%	Even a relatively small change in O ₂ saturation would be dangerous, so 10% change was chosen.
Salinity	2%	0.01 ppt	A negative trend was observed for salinity with a change of 4%, so a 2% delta was chosen.
Turbidity	150%	0.25 FNU	Median turbidity was 0.10 FNU, and the apparent bloom peaked at 3.0 NTU, a 2900% change. A delta of 150% was chosen to be conservative.
Temperature	4%	1 °C	A trend of increasing temperature was observed at KAHŌ, with a 3–4 °C change observed. A delta of 1 °C was chosen to be conservative.
pH	0.25	0.25	Median pH was 8.1 but spiked to almost 9 during the 2011 apparent algal bloom. A delta of 0.25 was chosen to be conservative.

Results

The approach used here is applied to regression models and referred to as power analysis using simulation (Bolker 2008). This is a three-step process in which many data sets are simulated using the observed independent parameter means and variances, a linear regression model is fit to each simulated data set, and the proportion of null hypotheses that were rejected is calculated. The proportion is the estimate of power. Using this approach, we evaluated the effect of different sampling designs by varying the number of sites and quarters included. Seasonality could not be effectively incorporated because of the extent of unsampled periods in the time series to date.

Results are presented as power curves for sampling in one quarter of the year (Q4), two quarters (Q2 and Q4), and all four quarters. Tables present the number of sites needed to detect a single quarter change by the established threshold with 80% power and a Type I error rate of 0.05. Results of the power analysis generally showed that sufficient power to detect change, both as trends and anomalous events, was obtained by sampling fewer sites than the eight sites sampled under the original protocol at most parks. An exception was nitrate + nitrite in KAHO non-plume areas, which can serve as an example for interpreting results. Minimum desired power can be achieved by trading-off number of sites and sampling frequency. For example, $\alpha = 0.05$, $\beta = 0.80$, and $\delta = 150\%$, for nitrate + nitrite in KAHO non-plume areas over ten years can be achieved sampling four times a year (blue line) with five sites, or two times a year (green line) with nine sites (see section A.1 below). Sampling one time a year does not achieve power goals with sampling 10 sites. If nine offshore sites are sampled twice a year in non-plume areas of KAHO, higher power levels will be achieved for all other parameters, e.g., 99% for chlorophyll (green line; see section A.1 below). The greater number of sites needed to achieve power goals for nitrate + nitrite in KAHO non-plume areas was caused by greater variation in measured values relative to other parameters. Results also showed that sampling two quarters was sufficient to detect change at selected deltas (see above and protocol objectives) over 10 years at all parks. Note that new sites close to the shore added to parks are not counted in the number of sites needed to achieve desired power.

A.1 Kaloko-Honokōhau National Historical Park—Non-plume Area

Table A2 lists the number of sites required to detect targeted levels of change in water quality metrics in Kaloko-Honokōhau National Historical Park. Figures A1 through A9 plot the 10-year linear regression of power to detect changes in different water quality metrics in non-plume areas of the park.

Table A2. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

Parameter	Delta	Q4	Q2 and Q4	All Quarters	Wilcoxon test
Chlorophyll	250%	6	3	2	3
Nitrate + Nitrite	150%	> 10	9	5	7

Table A2 (continued). Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

Parameter	Delta	Q4	Q2 and Q4	All Quarters	Wilcoxon test
Oxygen saturation	10%	2	2	2	3
Salinity	2%	6	3	2	4
Total Dissolved Nitrogen	100%	3	2	2	3
Total Dissolved Phosphorus	100%	4	2	2	5
Turbidity	150%	2	2	2	3
Temperature	4%	2	2	2	2
pH	0.25	2	2	2	2

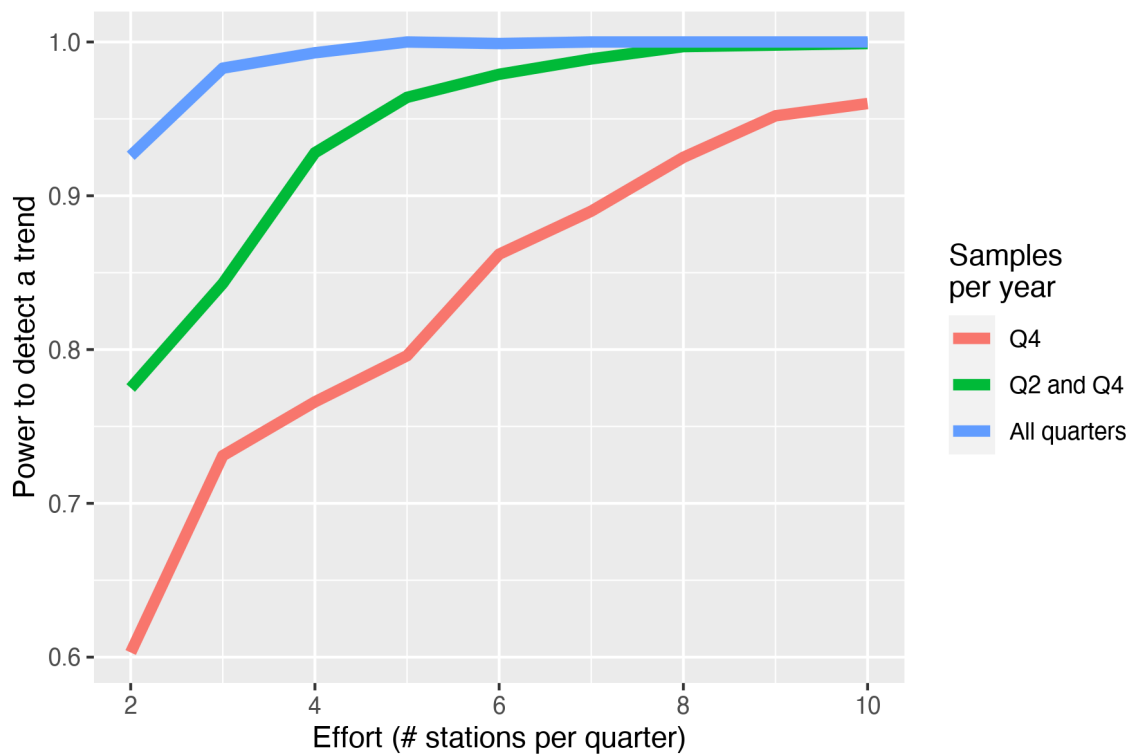


Figure A1. Plot of 10-year linear regression power for chlorophyll (delta = 250%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

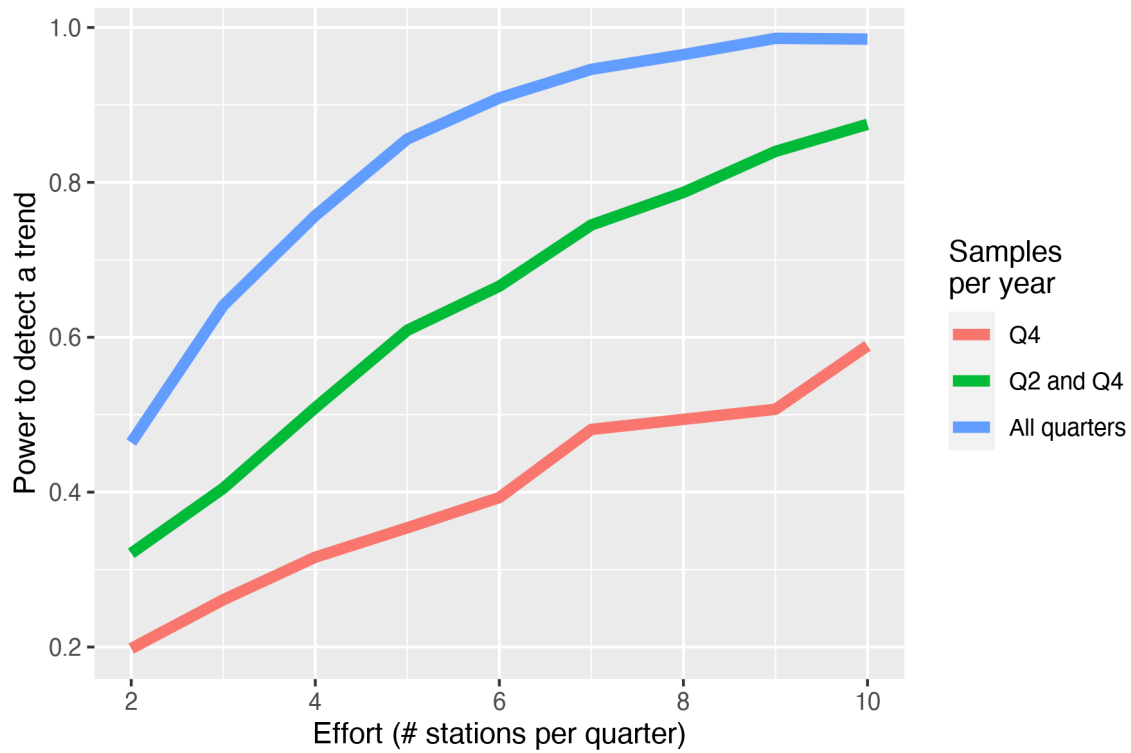


Figure A2. Plot of 10-year linear regression power for nitrate + nitrite (delta = 150%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

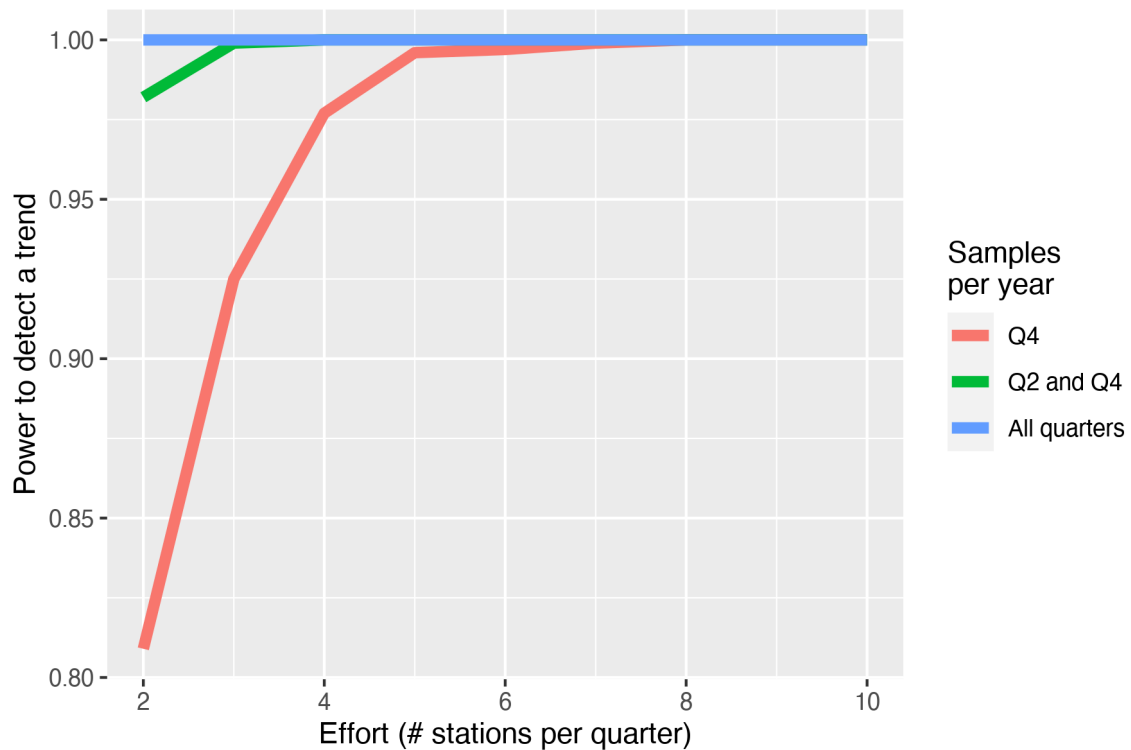


Figure A3. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

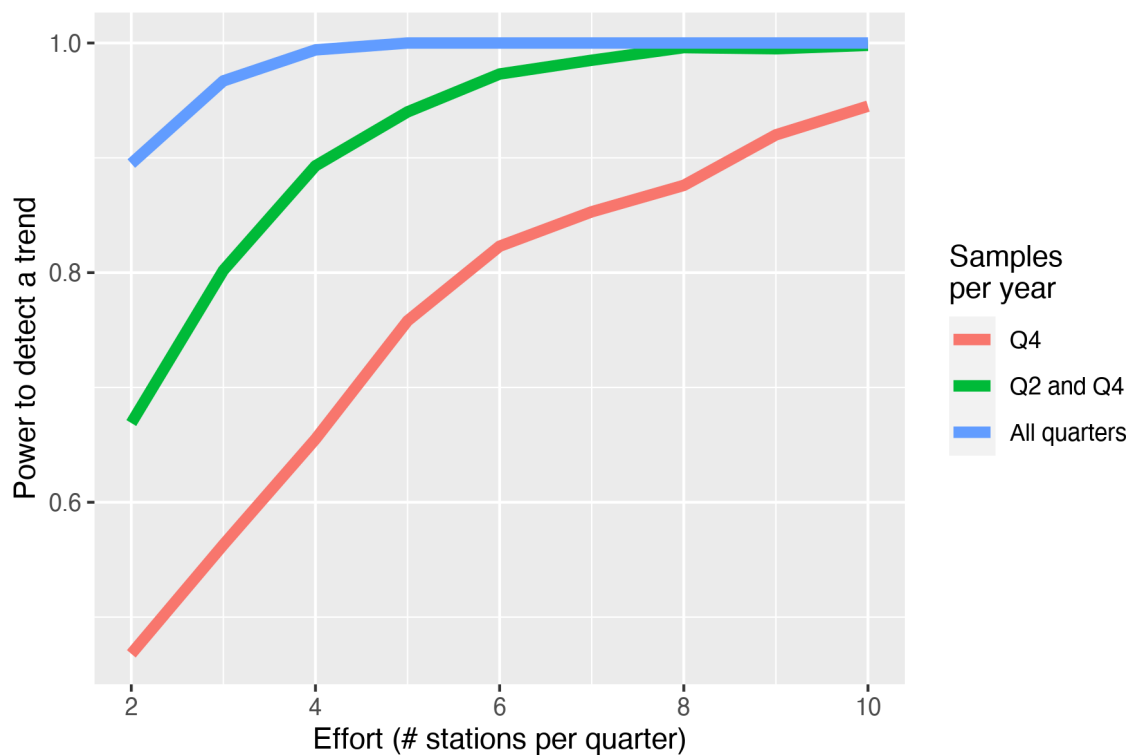


Figure A4. Plot of 10-year linear regression power for salinity (delta = 2%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

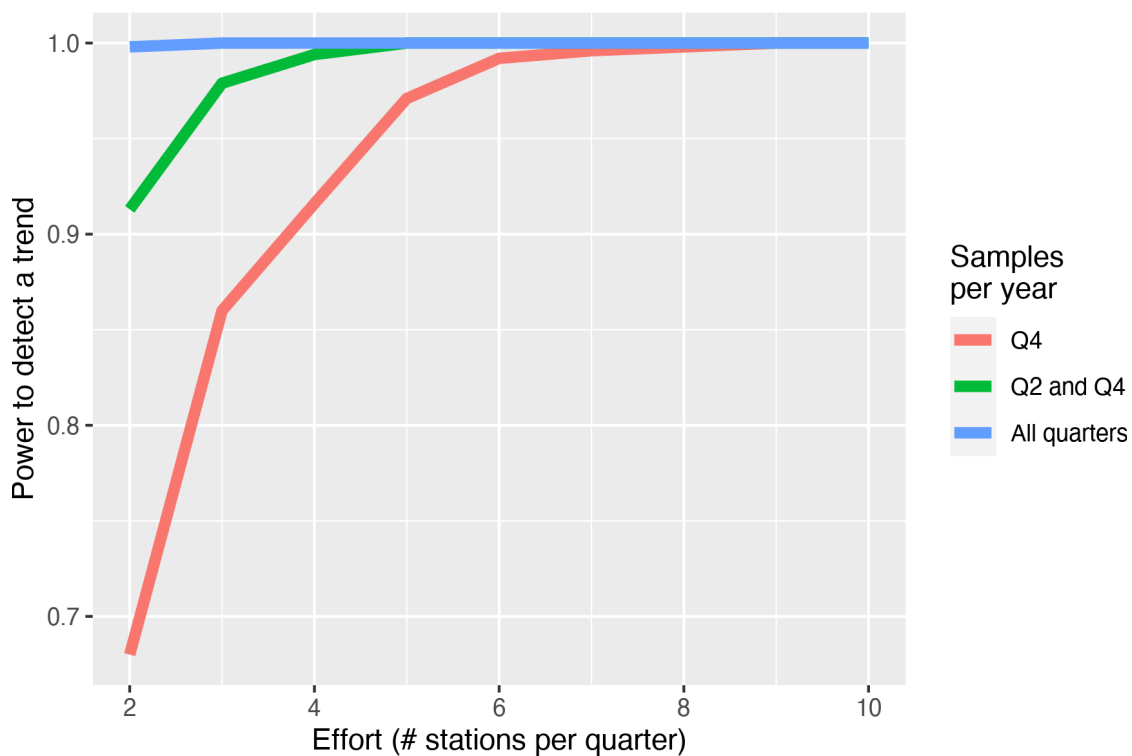


Figure A5. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

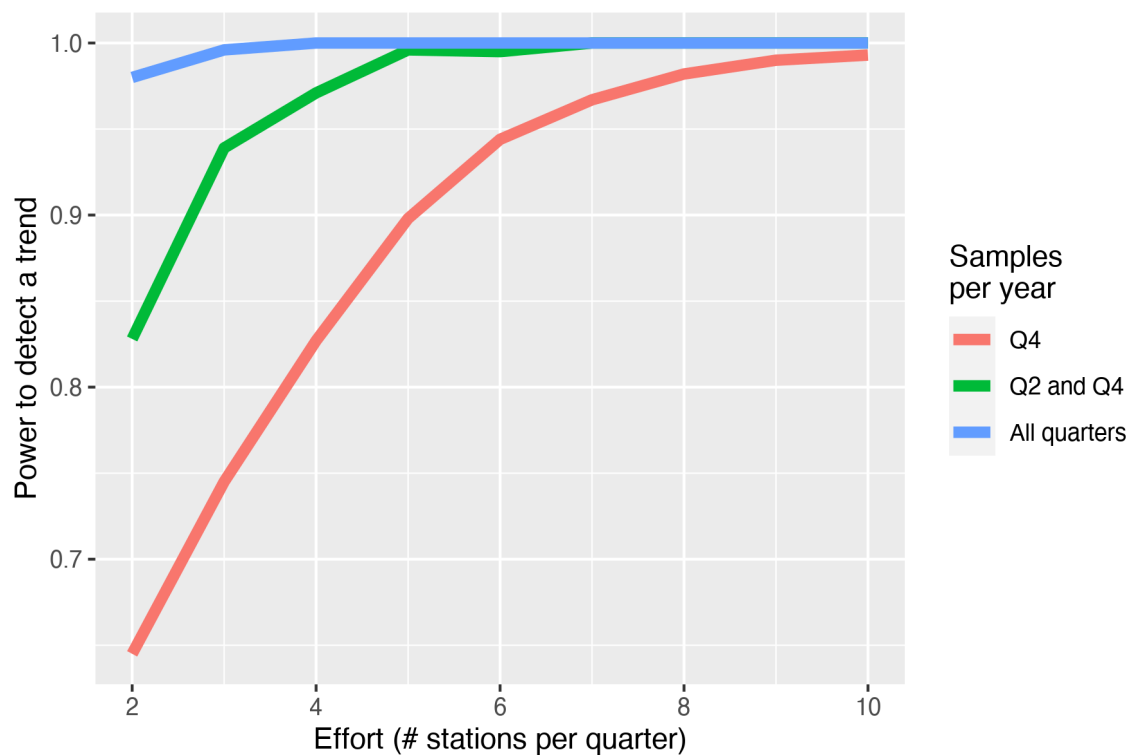


Figure A6. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

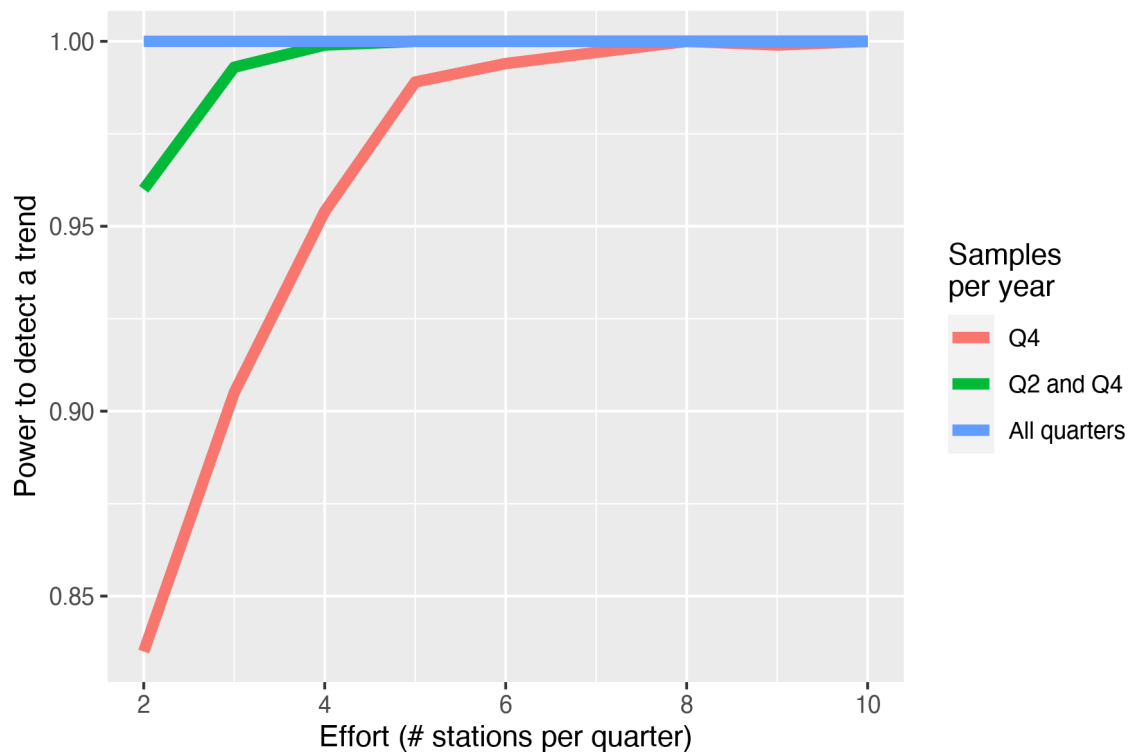


Figure A7. Plot of 10-year linear regression power for turbidity (delta = 150%) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

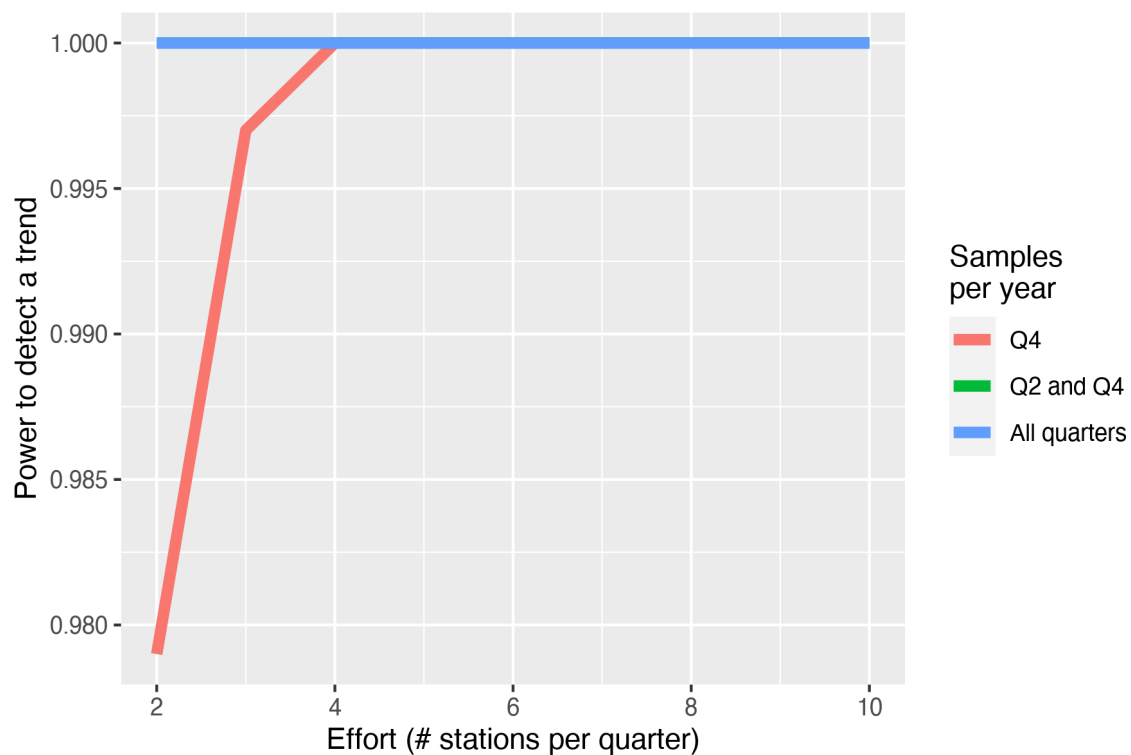


Figure A8. Plot of 10-year linear regression power for temperature ($\delta = 4\%$) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

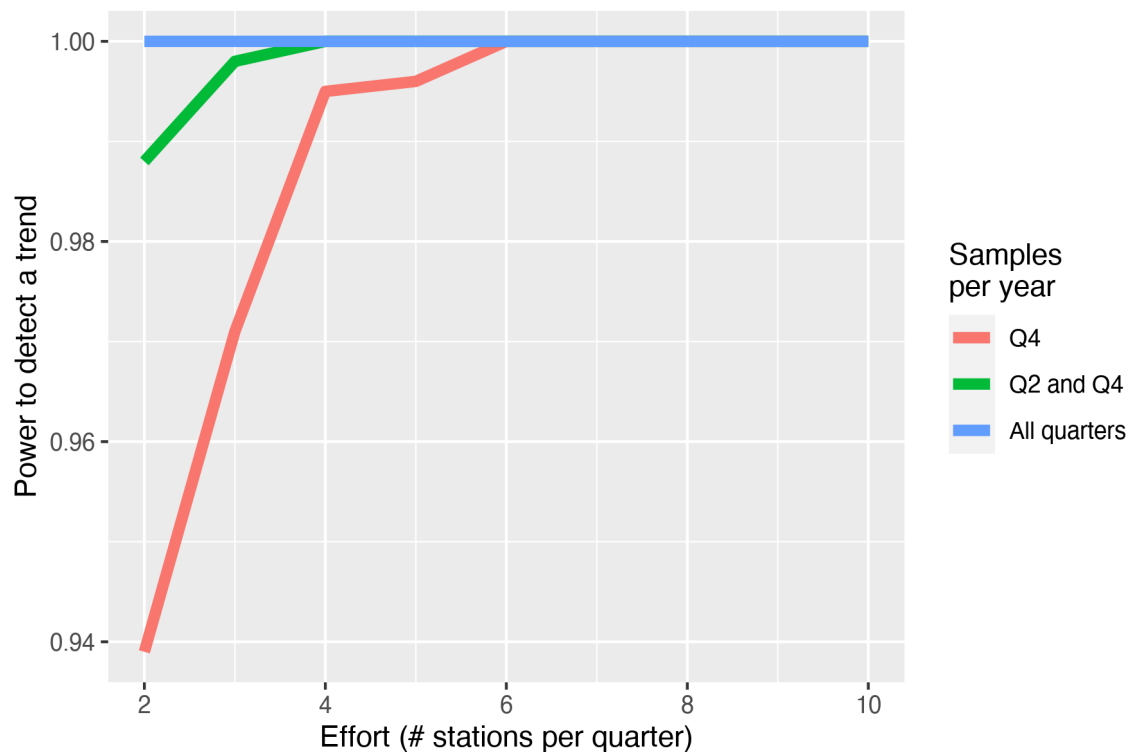


Figure A9. Plot of 10-year linear regression power for pH ($\delta = 0.25$) in non-plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

A.2 Kaloko-Honokōhau National Historical Park—Plume area

Table A3 lists the number of sites required to detect targeted levels of change in water quality metrics in Kaloko-Honokōhau National Historical Park. Figures A10 through A18 plot the 10-year linear regression of power to detect changes in different water quality metrics in plume areas of the park.

Table A3. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

Parameter	Delta	Q4	Q2 and Q4	All Quarters	Wilcoxon test
Chlorophyll	250%	2	2	2	2
Nitrate + Nitrite	150%	2	2	2	2
Oxygen Saturation	10%	2	2	2	2
Salinity	2%	2	2	2	2
Total Dissolved Nitrogen	100%	2	2	2	2
Total Dissolved Phosphorus	100%	2	2	2	2
Turbidity	150%	2	2	2	2
Temperature	4%	2	2	2	2
pH	0.25	2	2	2	2

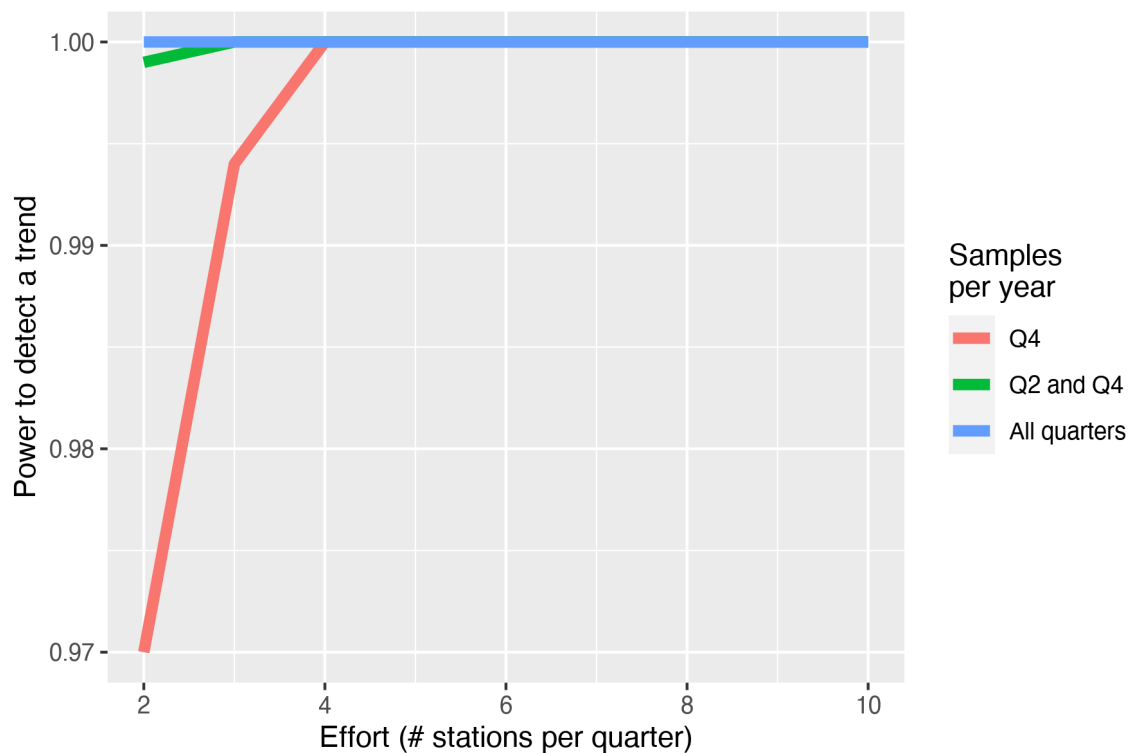


Figure A10. Plot of 10-year linear regression power for chlorophyll ($\delta = 250\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

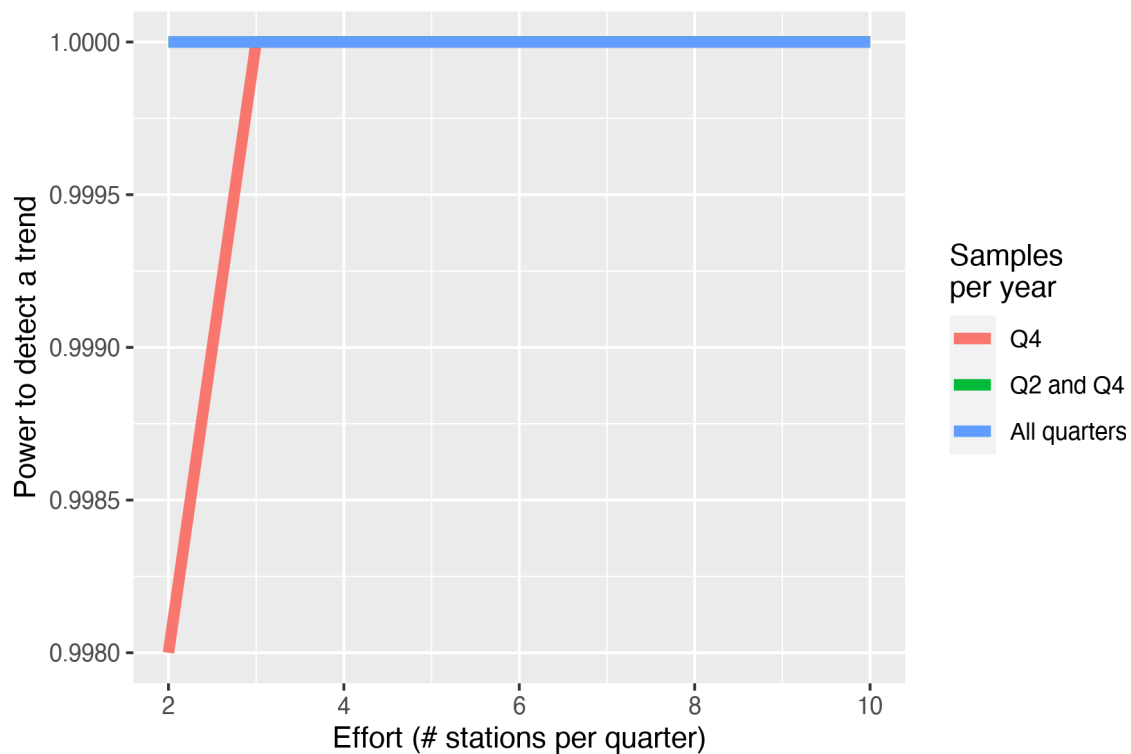


Figure A11. Plot of 10-year linear regression power for nitrate + nitrite ($\delta = 150\%$) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

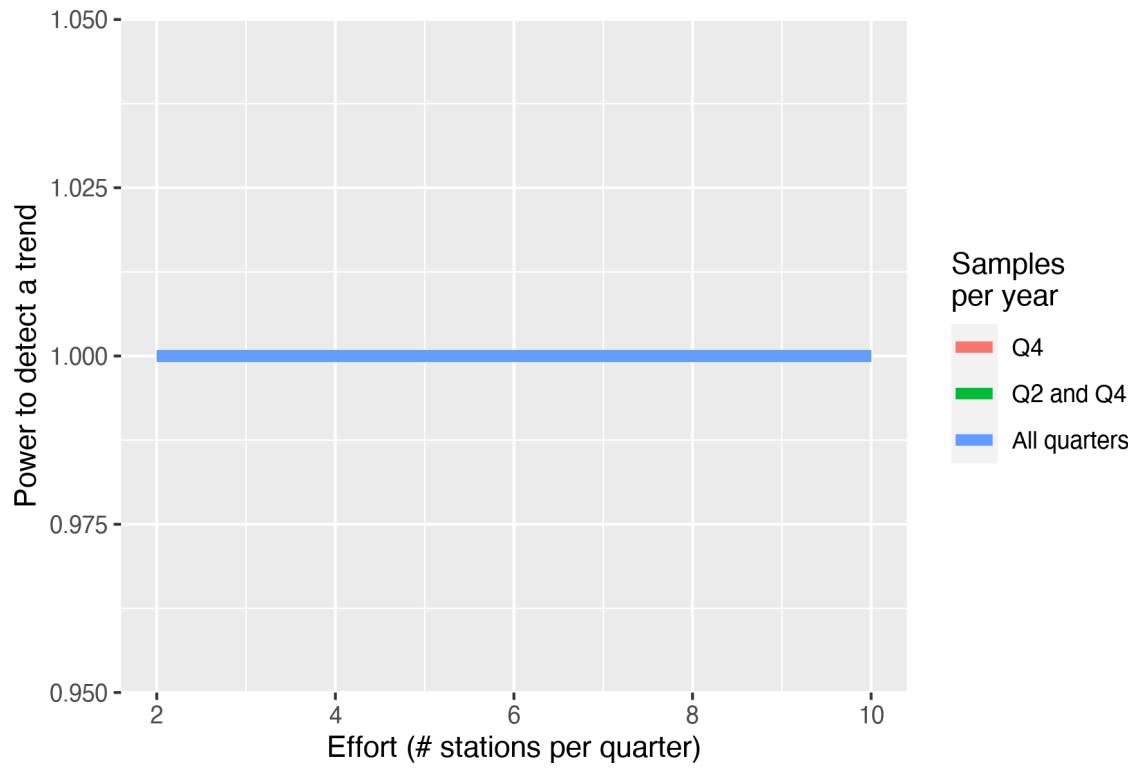


Figure A12. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

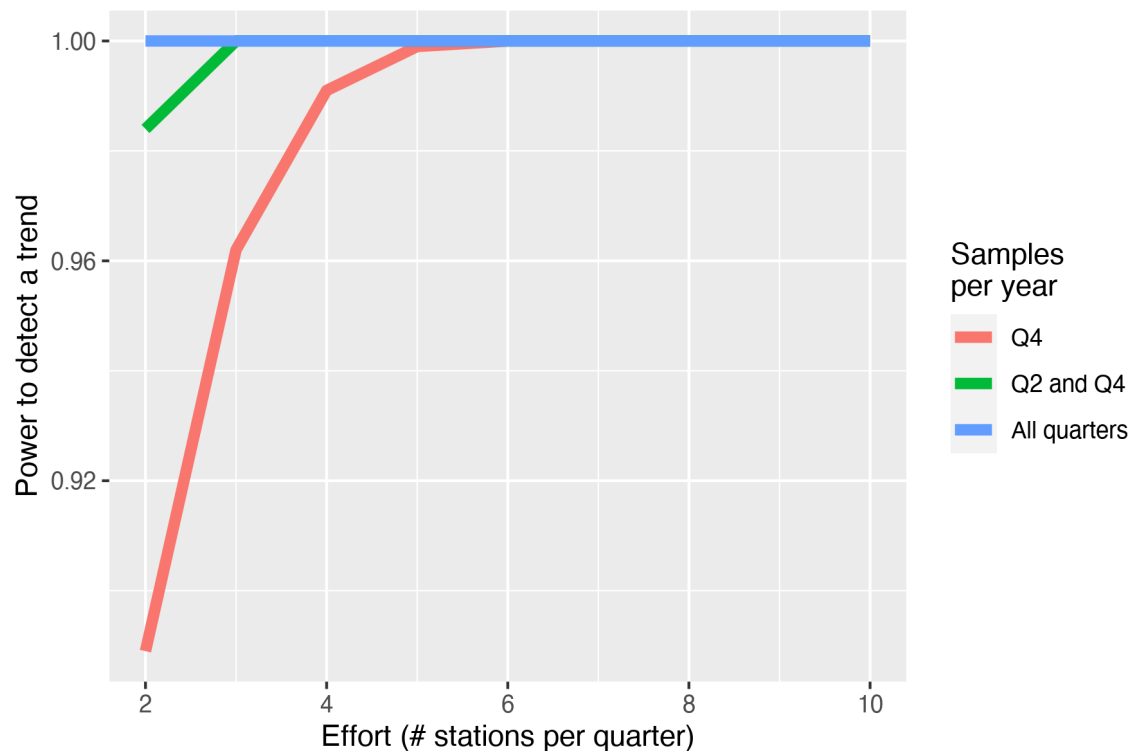


Figure A13. Plot of 10-year linear regression power for salinity (delta = 2%) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

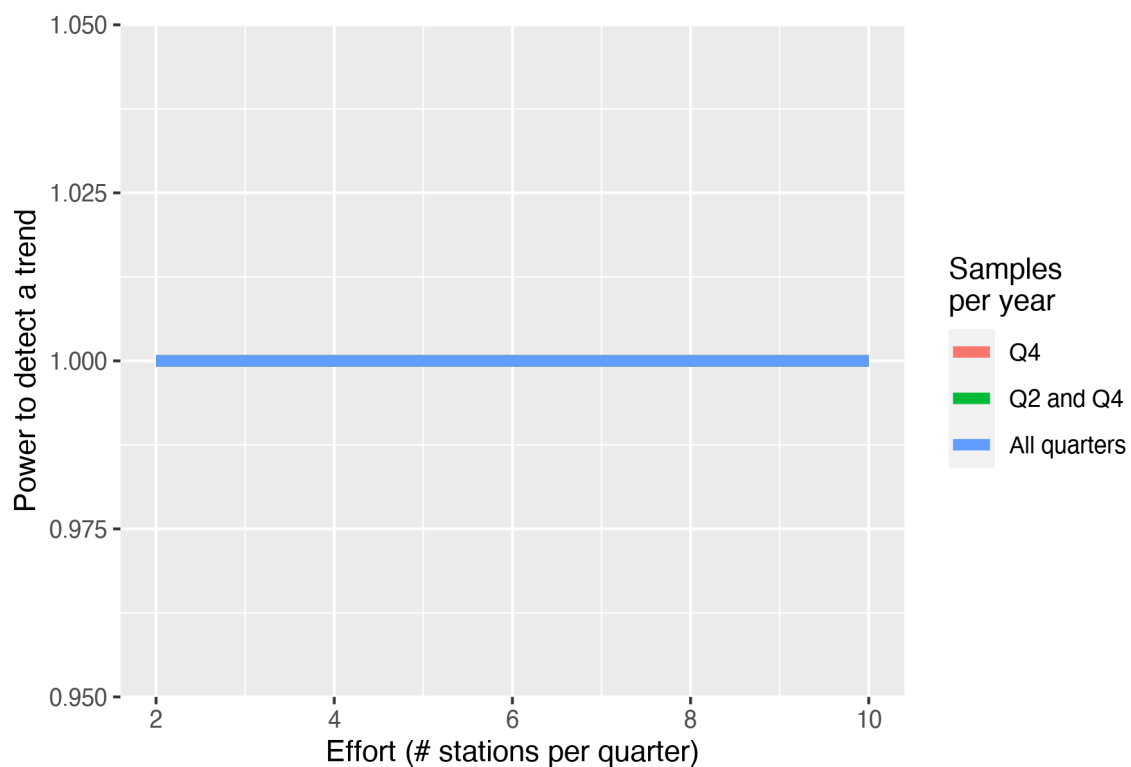


Figure A14. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

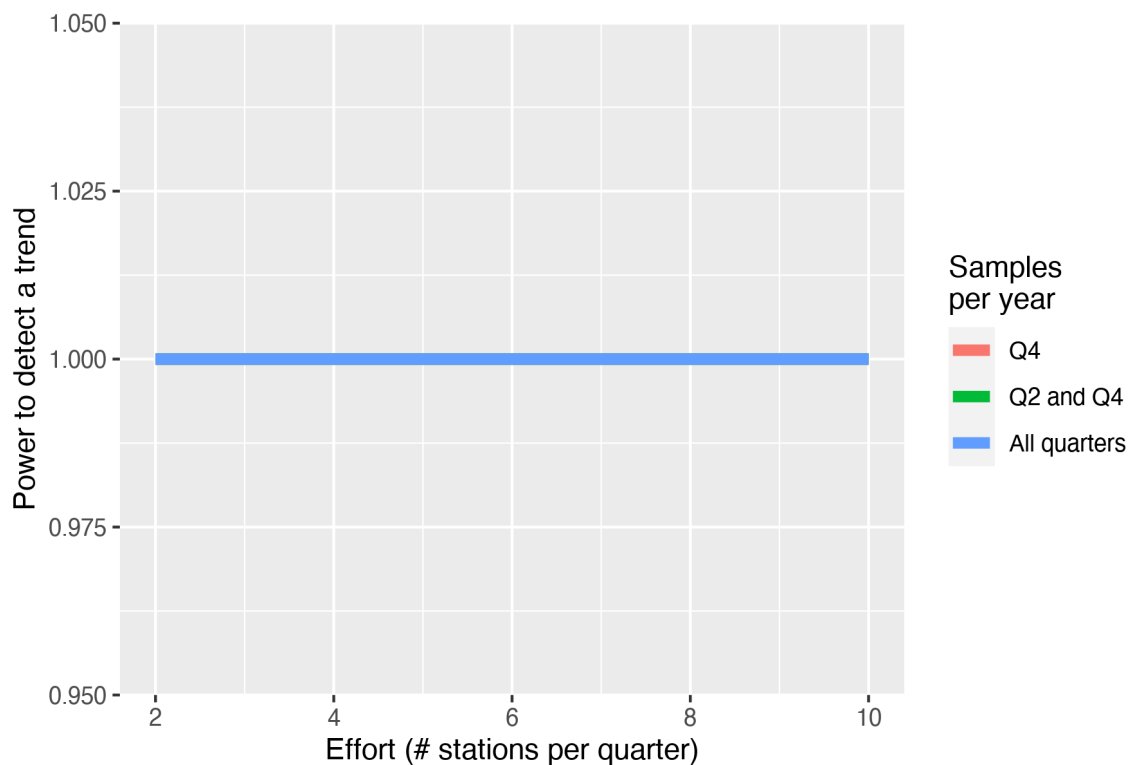


Figure A15. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

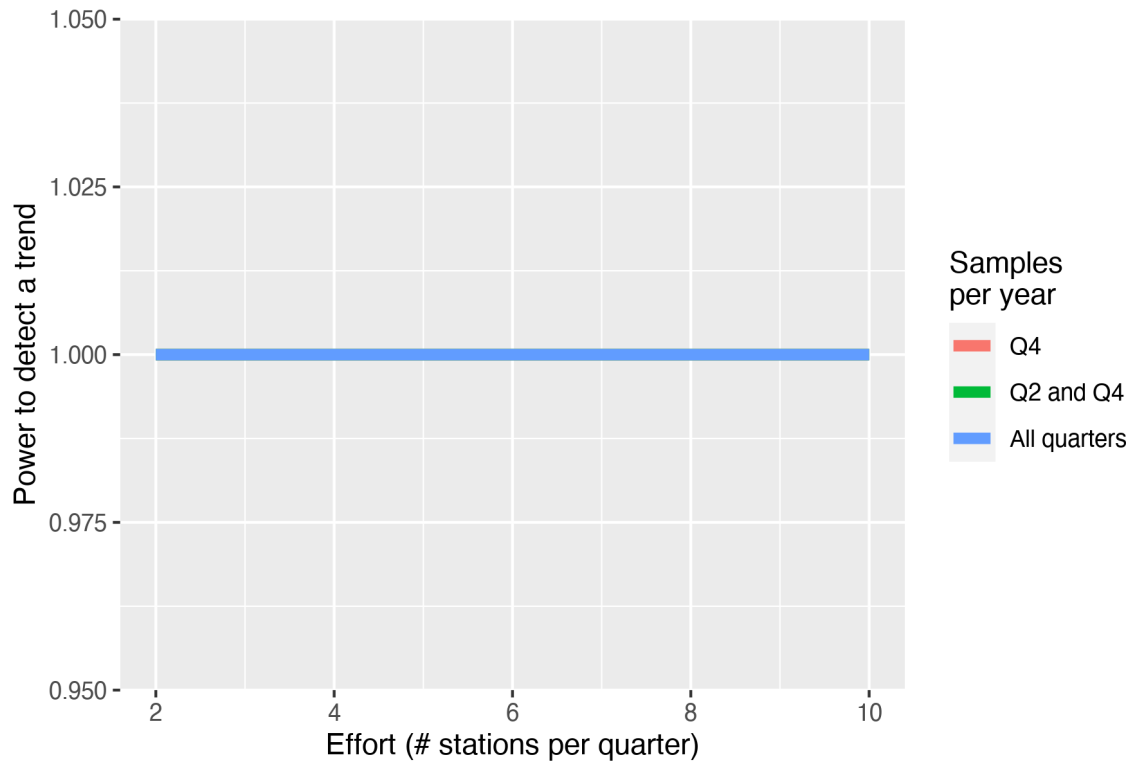


Figure A16. Plot of 10-year linear regression power for turbidity (delta = 150%) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

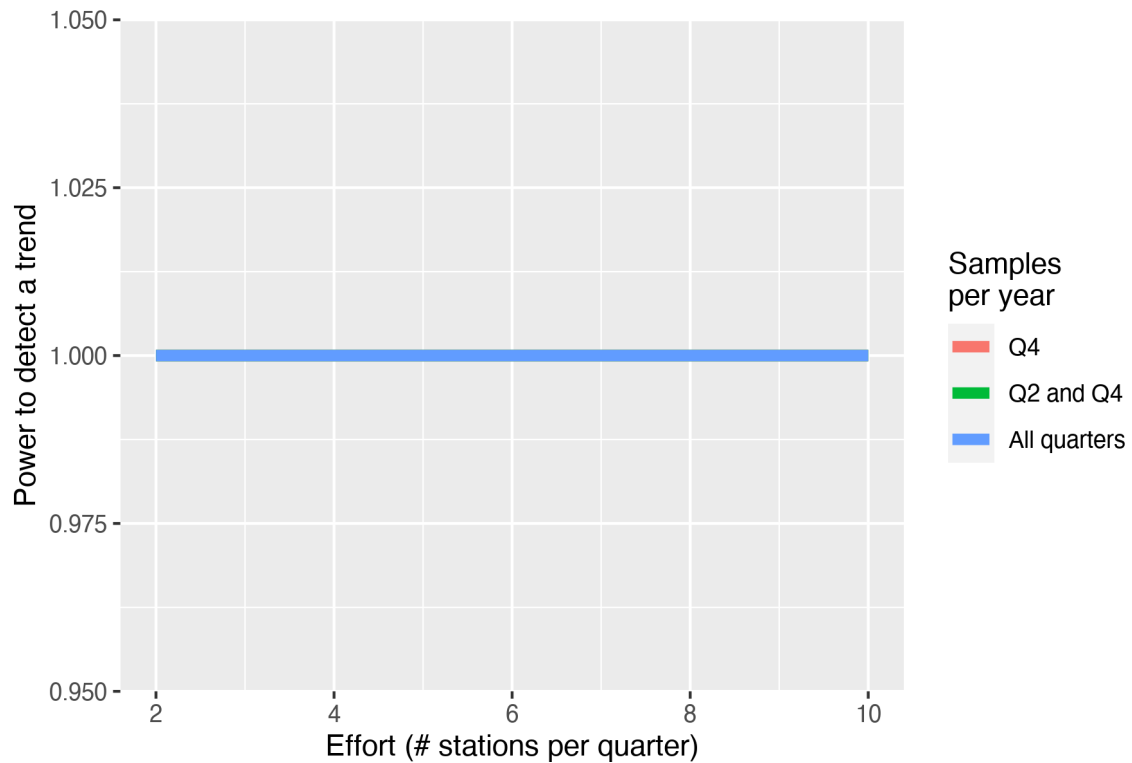


Figure A17. Plot of 10-year linear regression power for temperature (delta = 4%) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

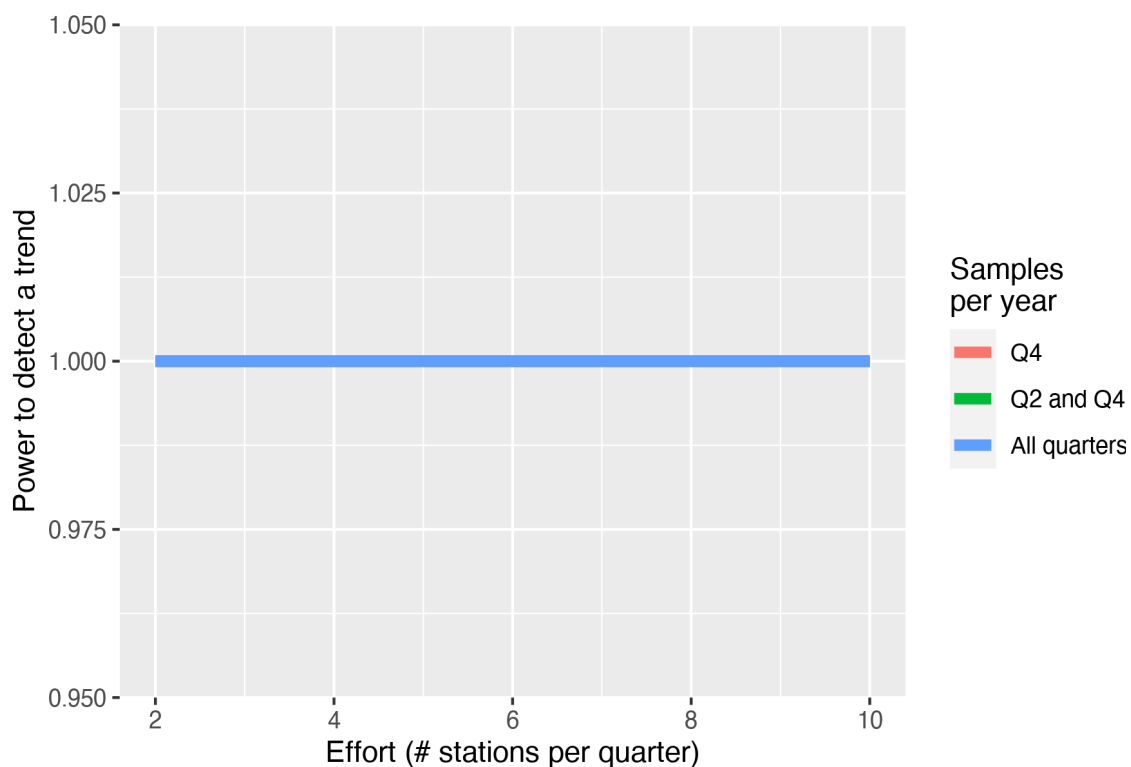


Figure A18. Plot of 10-year linear regression power for pH (delta = 0.25) in plume areas of Kaloko-Honokōhau National Historical Park (80% power, Type I error = 0.05).

A.3 National Park of American Samoa—Ofu Unit

Table A4 lists the number of sites required to detect targeted levels of change in water quality metrics in National Park of American Samoa—Ofu unit. Figures A19 through A27 plot the 10-year linear regression of power to detect changes in different water quality metrics.

Table A4. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in National Park of American Samoa Ofu unit (80% power, Type I error = 0.05).

Parameter	Delta	Q4	Q2 and Q4	All Quarters	Wilcoxon test
Chlorophyll	250%	2	2	2	2
Nitrate + Nitrite	150%	2	2	2	2
Oxygen Saturation	10%	5	3	2	6
Salinity	2%	2	2	2	2
Total Dissolved Nitrogen	100%	2	2	2	2
Total Dissolved Phosphorus	100%	2	2	2	2
Turbidity	150%	2	2	2	2
Temperature	4%	2	2	2	2
pH	0.25	2	2	2	2

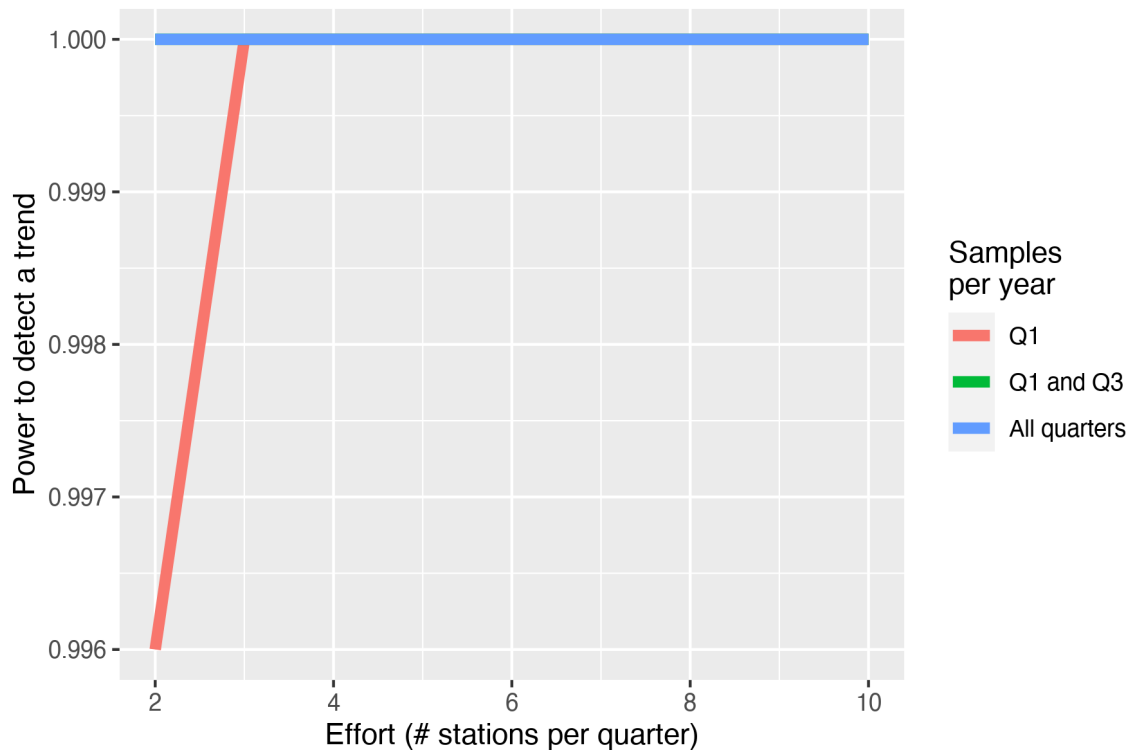


Figure A19. Plot of 10-year linear regression power for chlorophyll ($\delta = 250\%$) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).

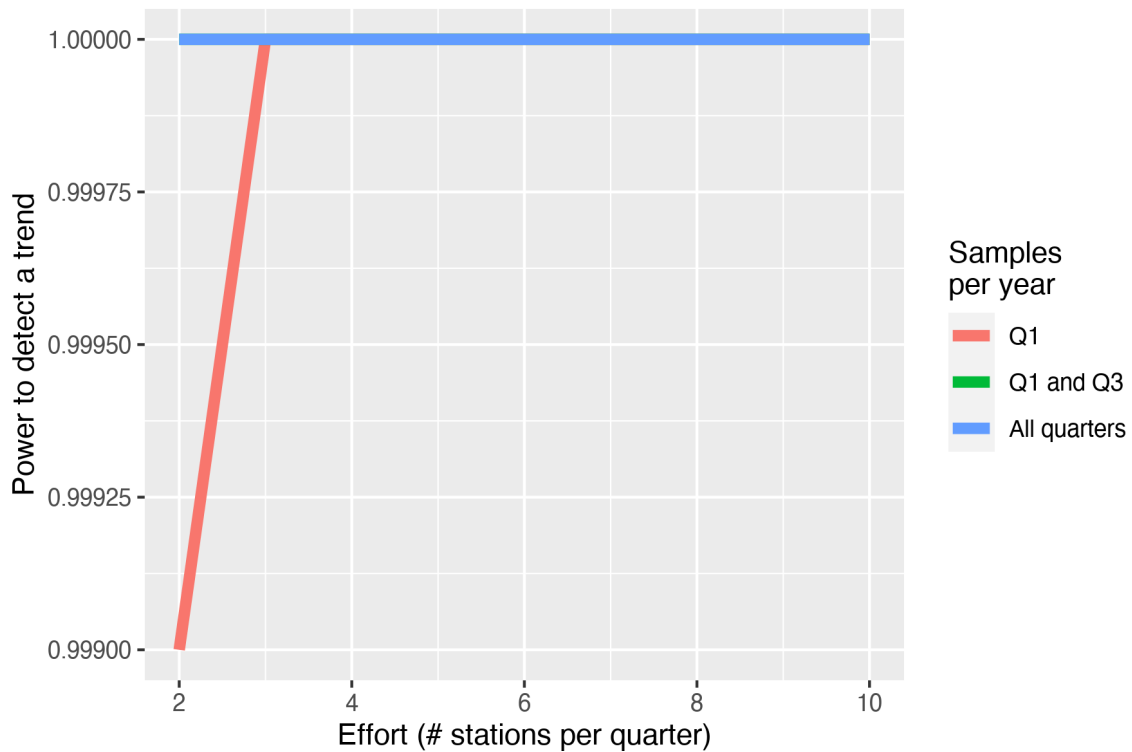


Figure A20. Plot of 10-year linear regression power for nitrate + nitrite ($\delta = 150\%$) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).

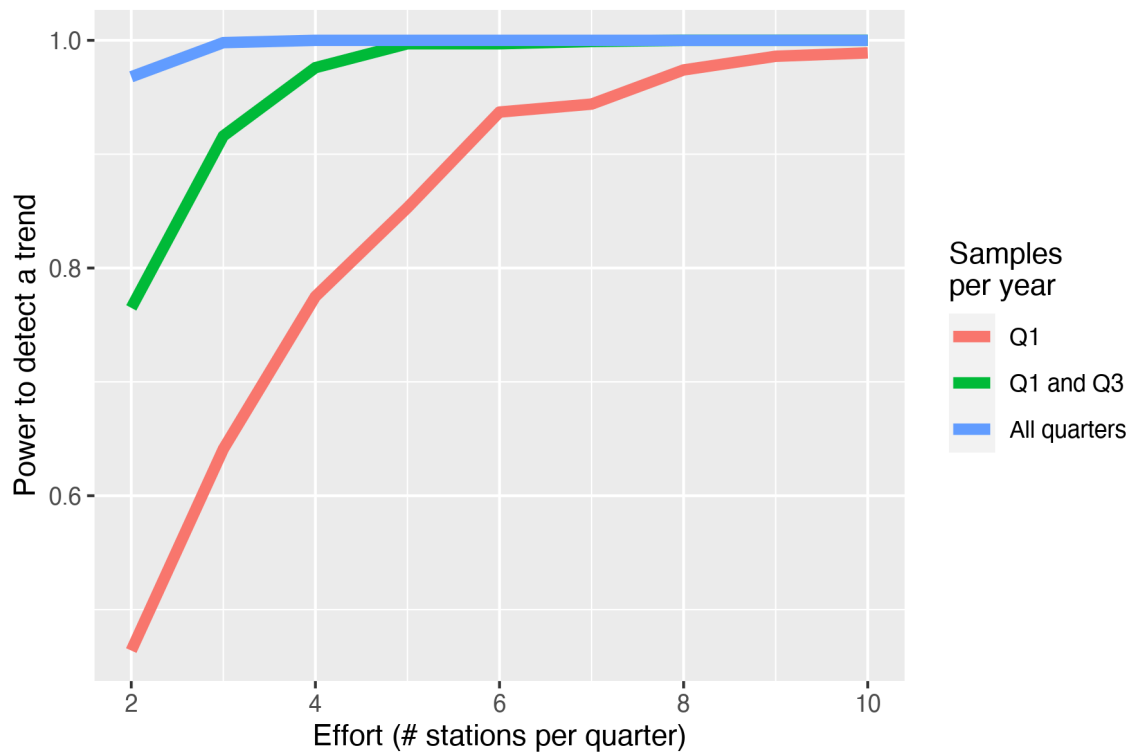


Figure A21. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).

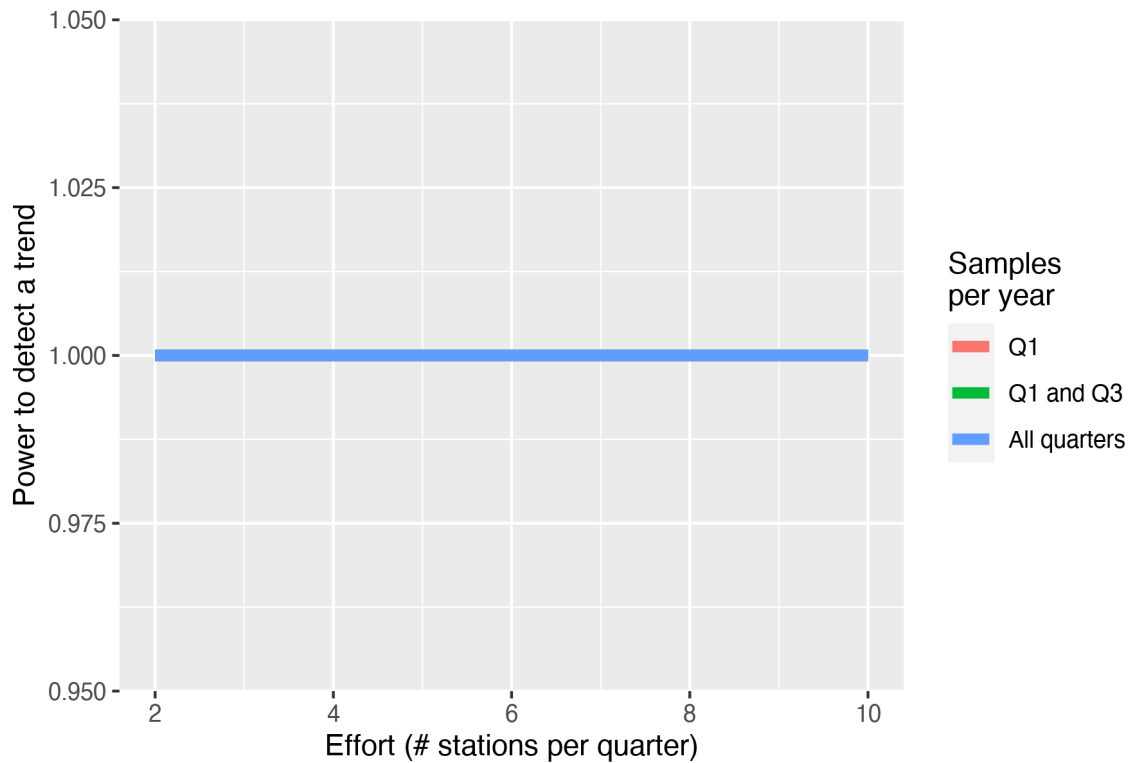


Figure A22. Plot of 10-year linear regression power for salinity (delta = 2%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).

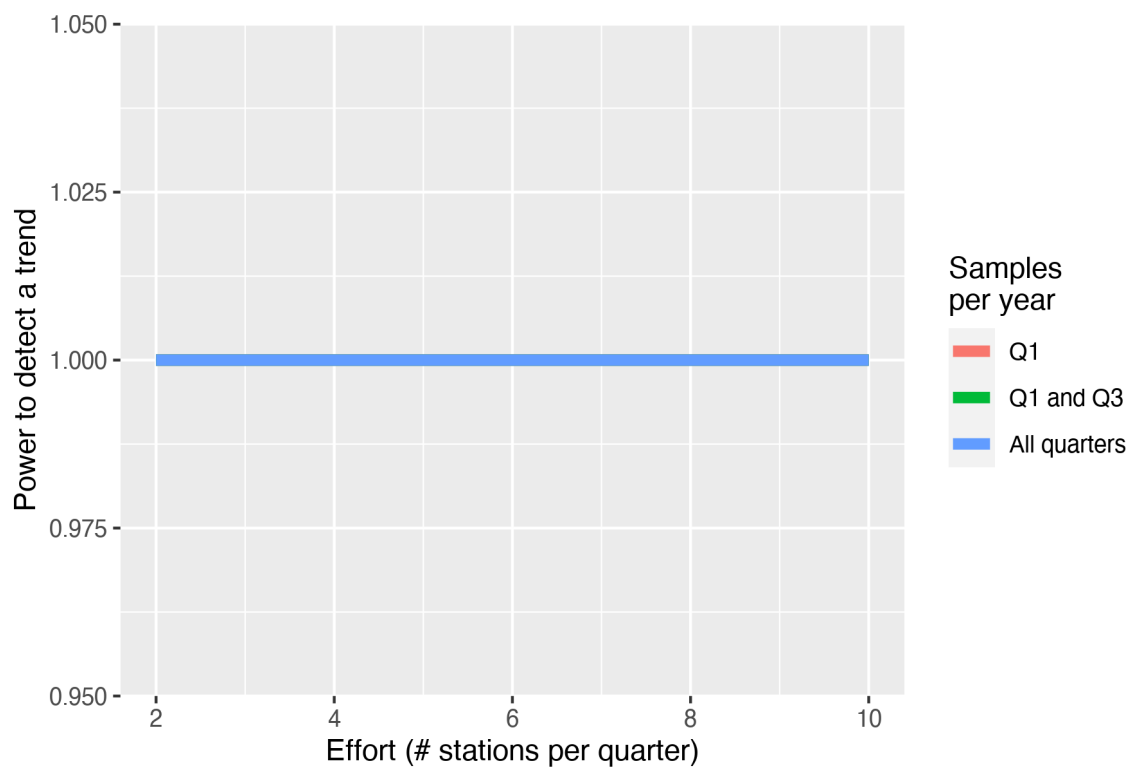


Figure A23. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).

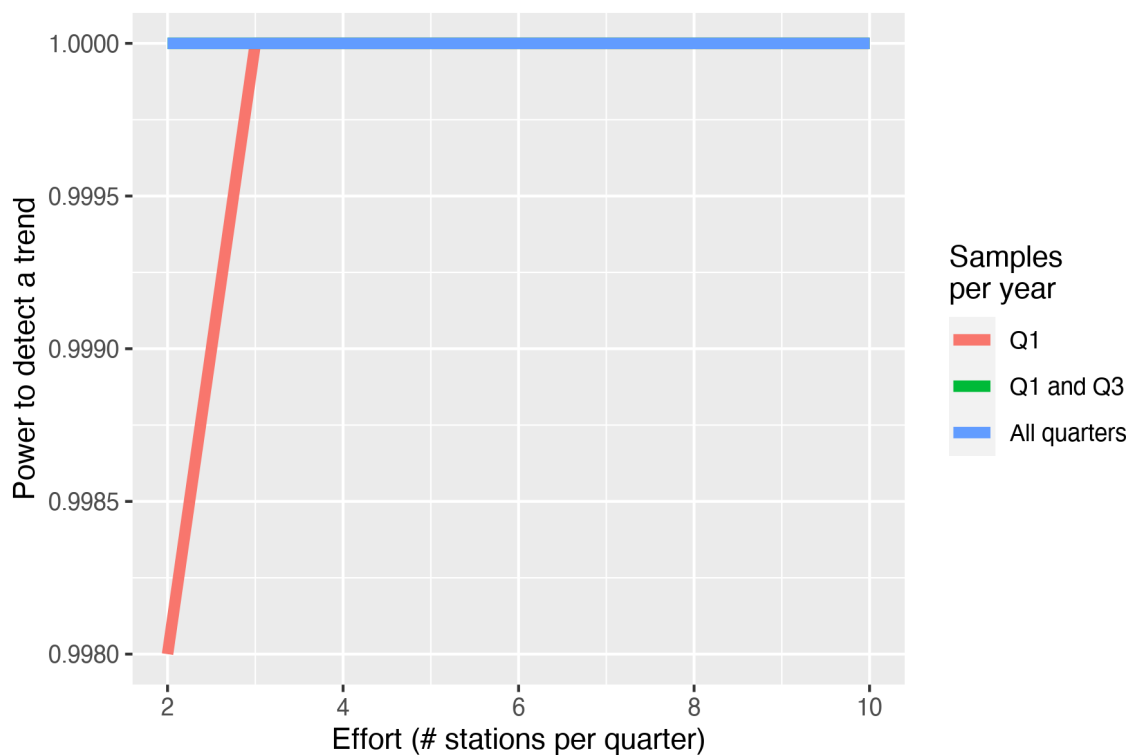


Figure A24. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).

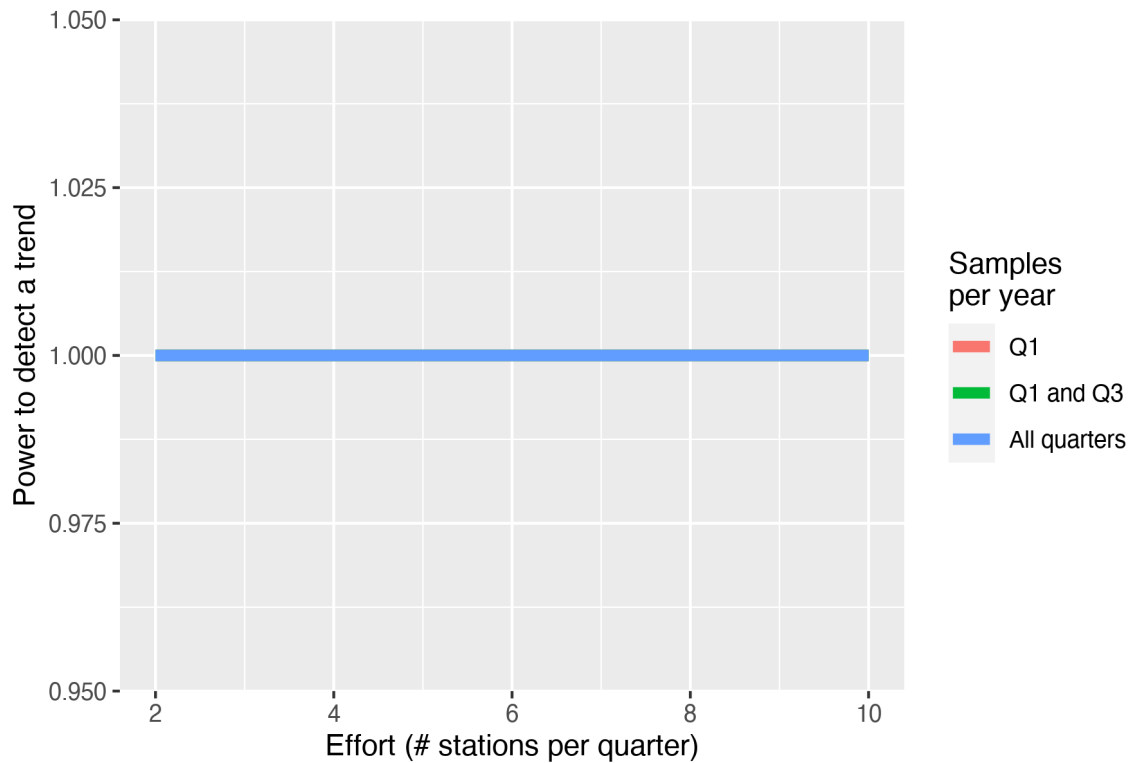


Figure A25. Plot of 10-year linear regression power for turbidity (delta = 150%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).

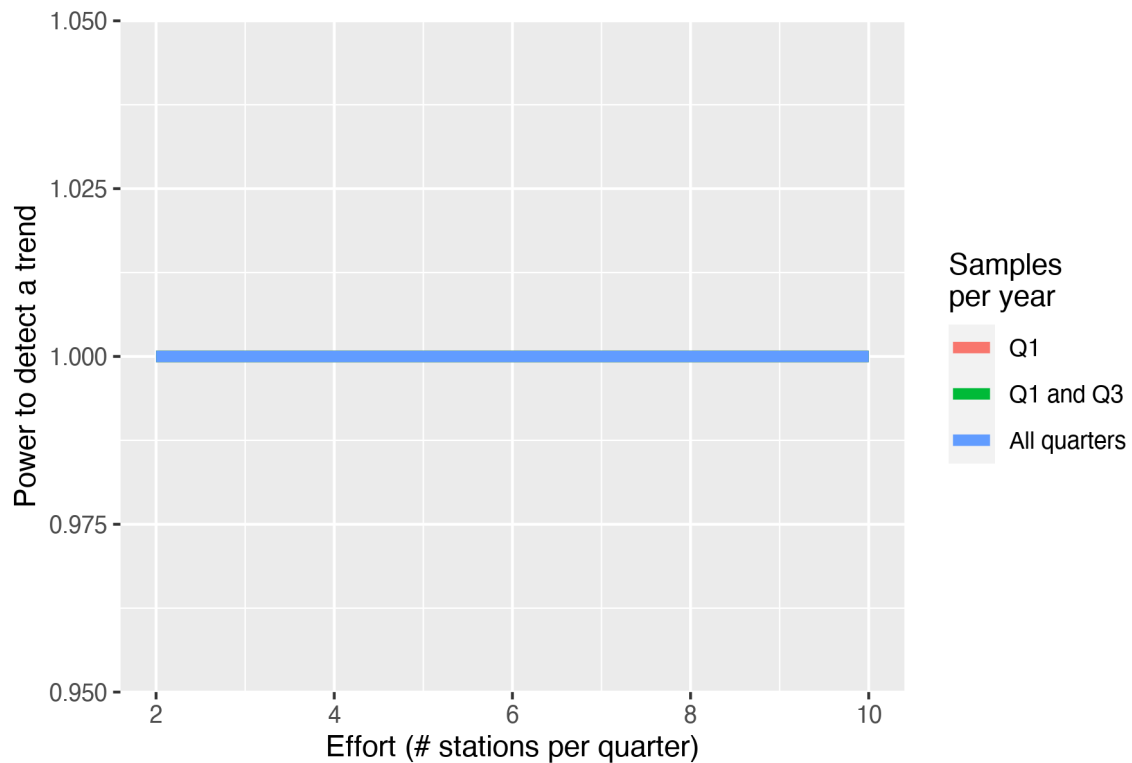


Figure A26. Plot of 10-year linear regression power for temperature (delta = 4%) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).

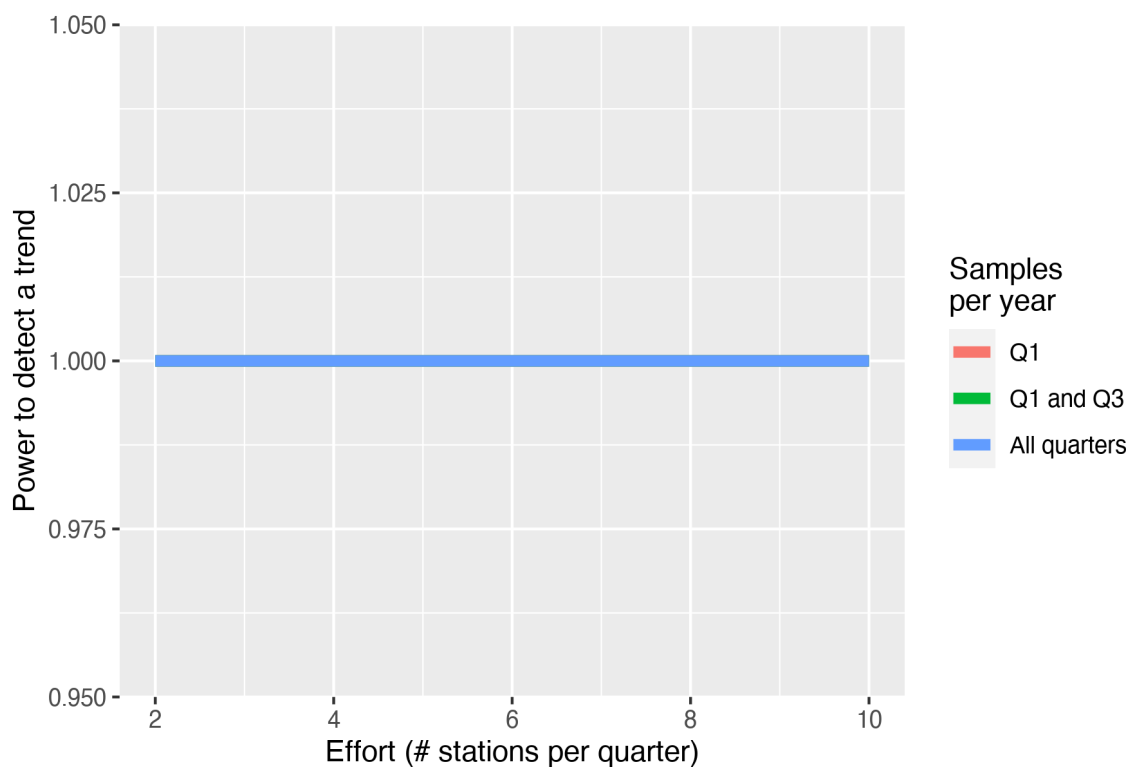


Figure A27. Plot of 10-year linear regression power for pH (delta = 0.25) in the Ofu unit of National Park of American Samoa (80% power, Type I error = 0.05).

A.4 National Park of American Samoa—Tutuila Unit

Table A5 lists the number of sites required to detect targeted levels of change in water quality metrics in National Park of American Samoa—Tutuila unit. Figures A28 through A36 plot the 10-year linear regression of power to detect changes in different water quality metrics.

Table A5. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in National Park of American Samoa Tutuila unit (80% power, Type I error = 0.05).

Parameter	Delta	Q4	Q2 and Q4	All Quarters	Wilcoxon test
Chlorophyll	250%	6	3	2	2
Nitrate + Nitrite	150%	3	2	2	3
Oxygen Saturation	10%	2	3	2	2
Salinity	2%	3	2	2	2
Total Dissolved Nitrogen	100%	2	2	2	2
Total Dissolved Phosphorus	100%	2	2	2	2
Turbidity	150%	9	5	2	7
Temperature	4%	2	2	2	2
pH	0.25	2	2	2	2

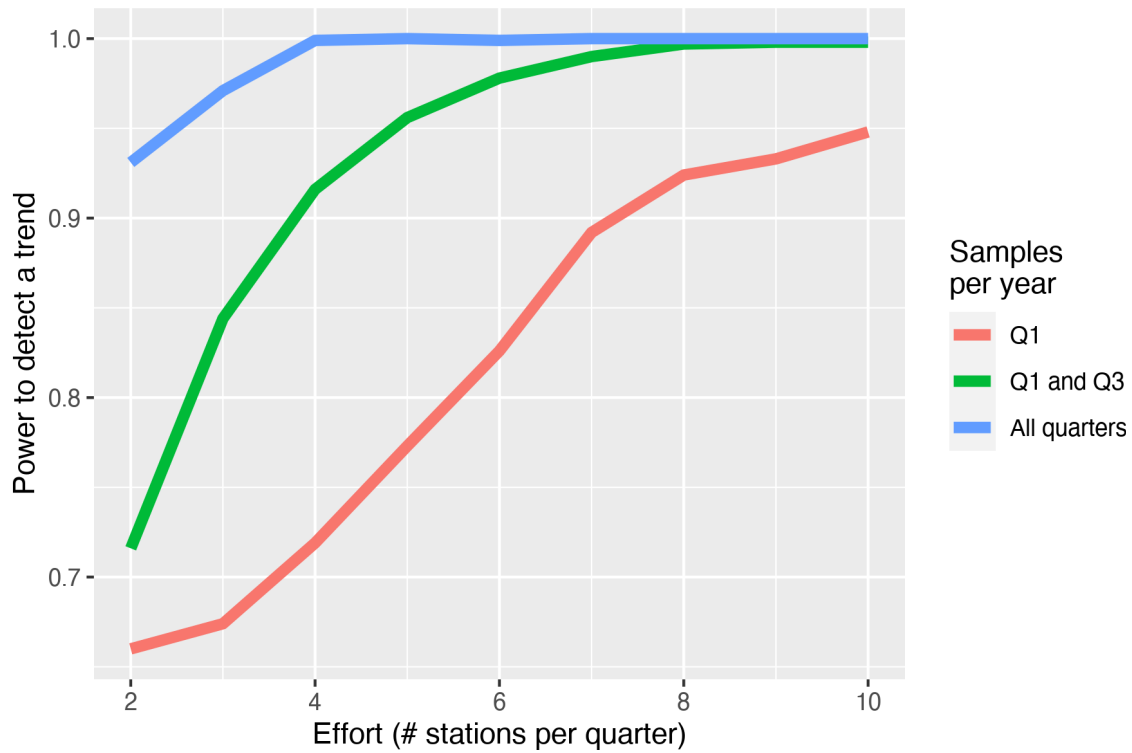


Figure A28. Plot of 10-year linear regression power for chlorophyll ($\delta = 250\%$) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).

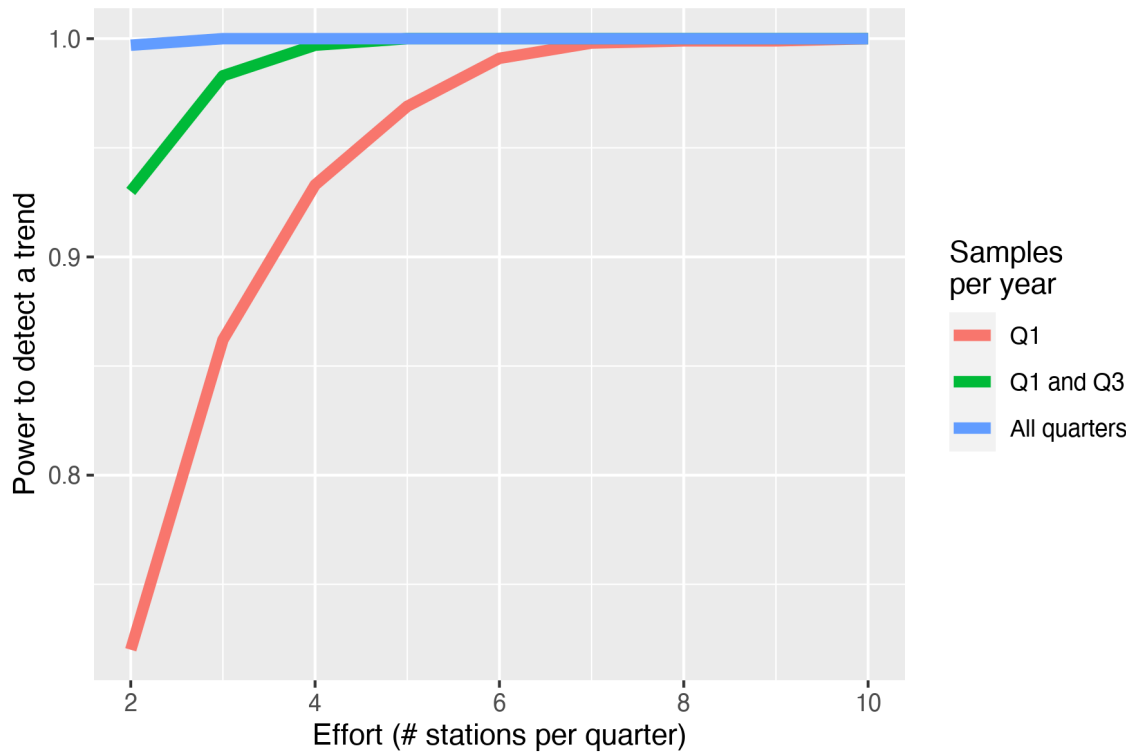


Figure A29. Plot of 10-year linear regression power for nitrate + nitrite ($\delta = 150\%$) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).

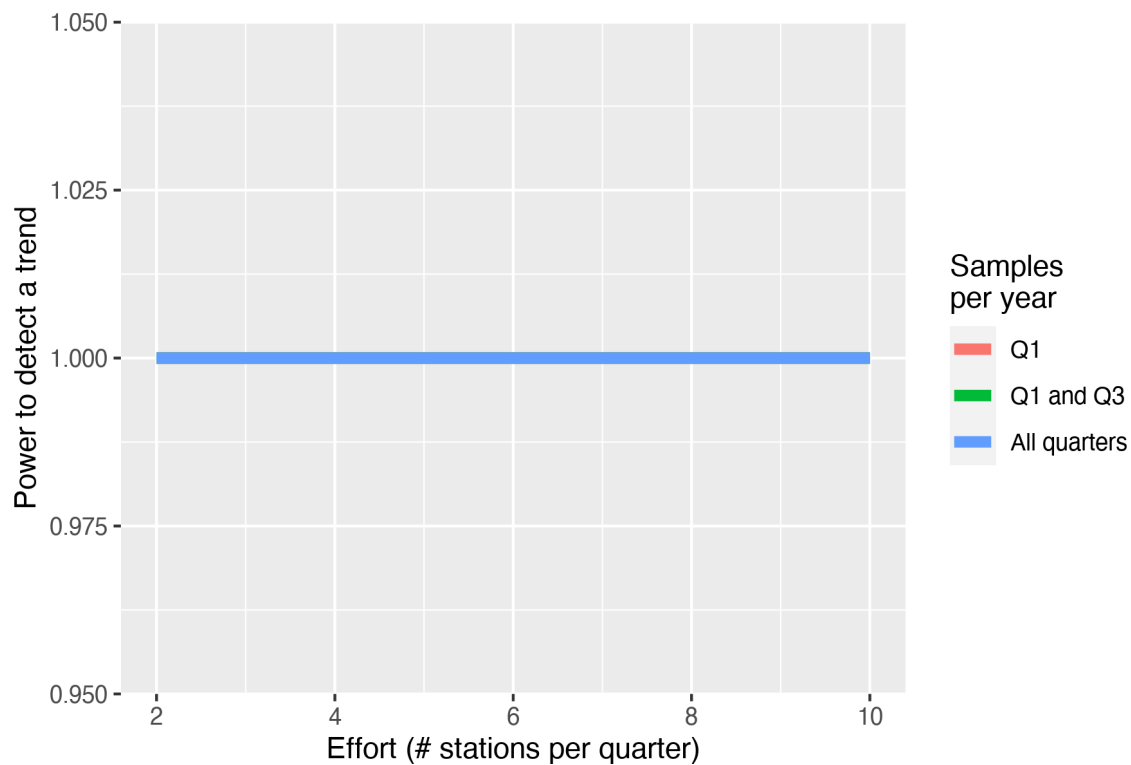


Figure A30. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).

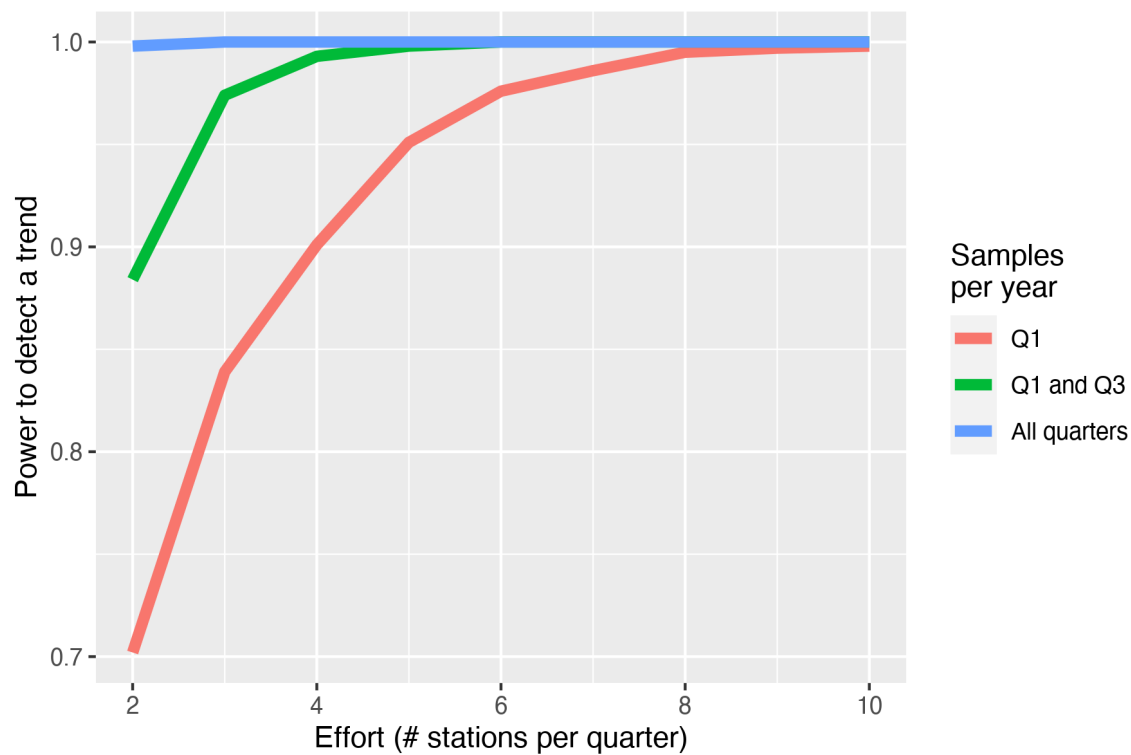


Figure A31. Plot of 10-year linear regression power for salinity (delta = 2%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).

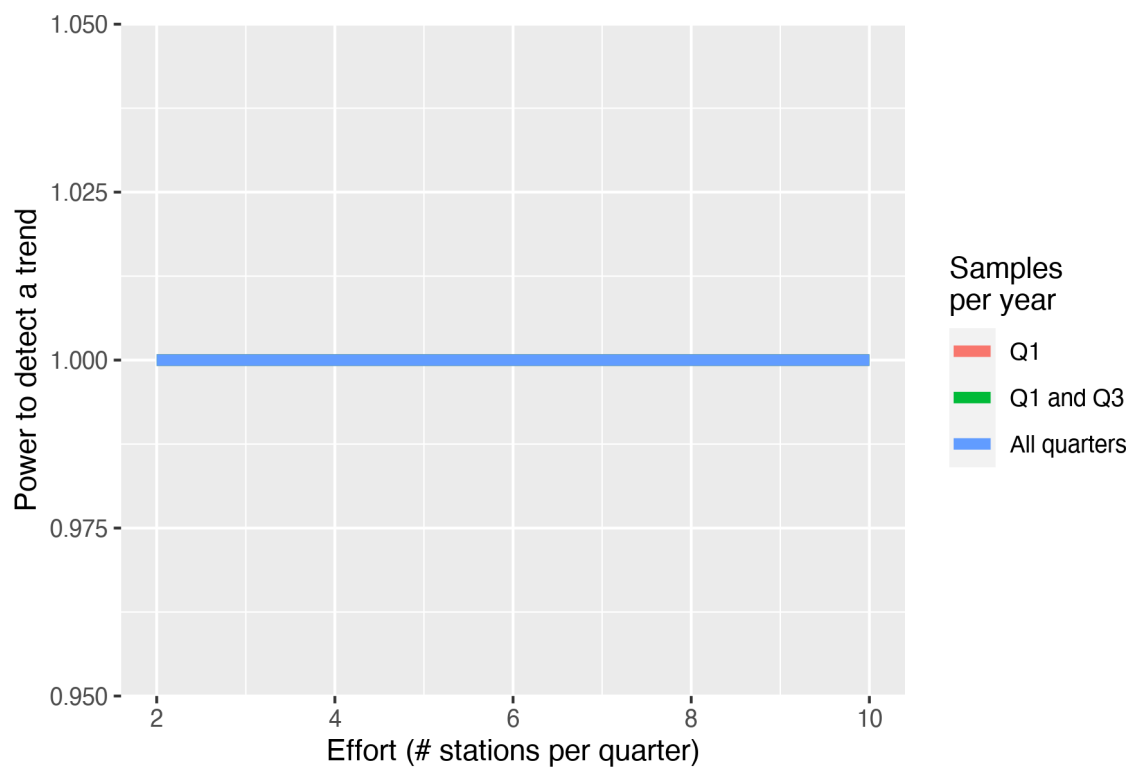


Figure A32. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).

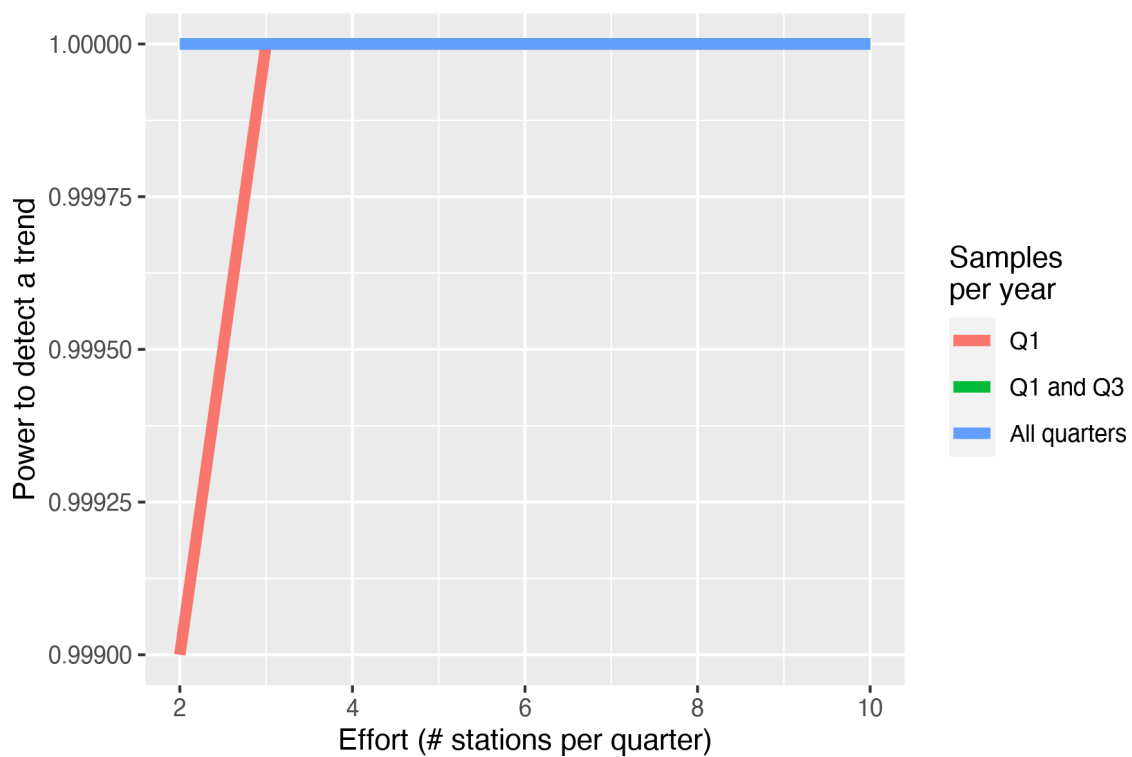


Figure A33. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).

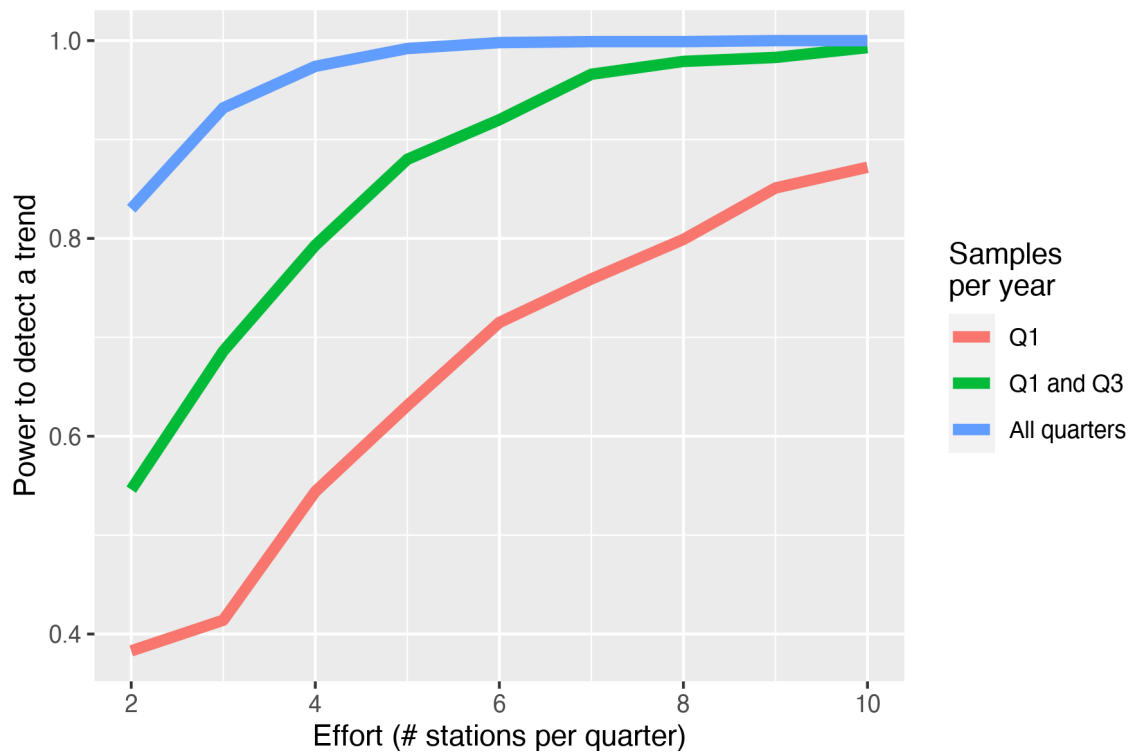


Figure A34. Plot of 10-year linear regression power for turbidity (delta = 150%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).

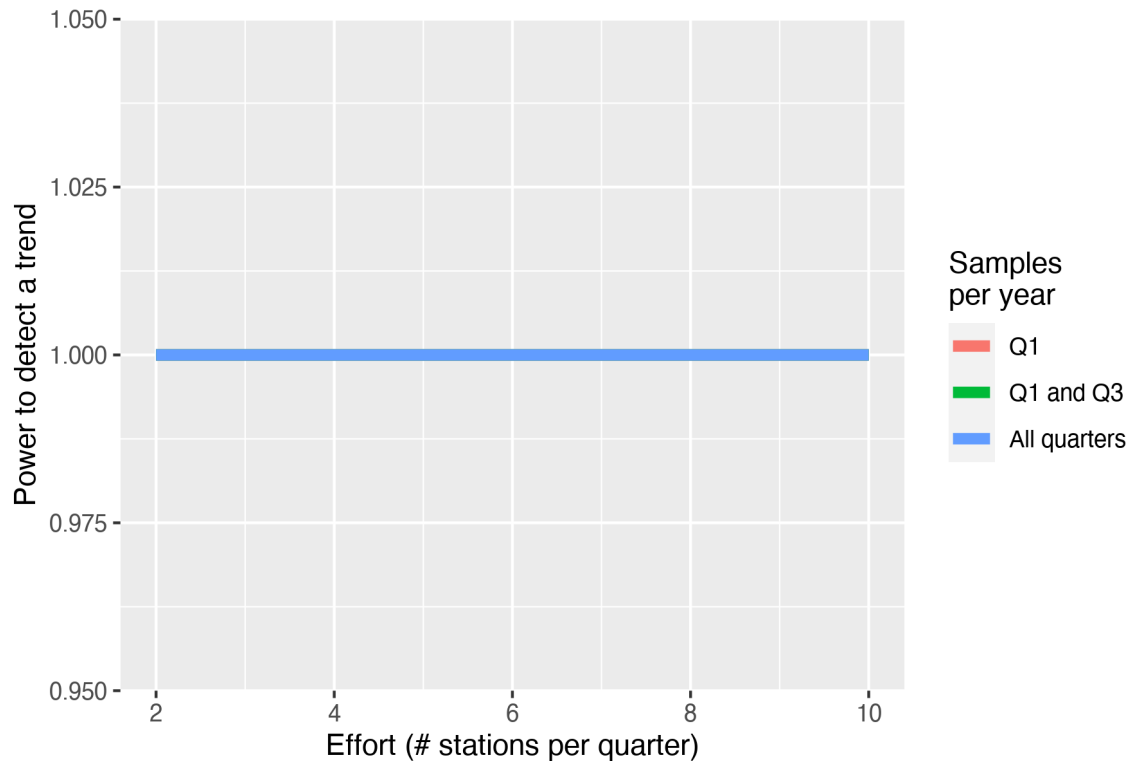


Figure A35. Plot of 10-year linear regression power for temperature (delta = 4%) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).

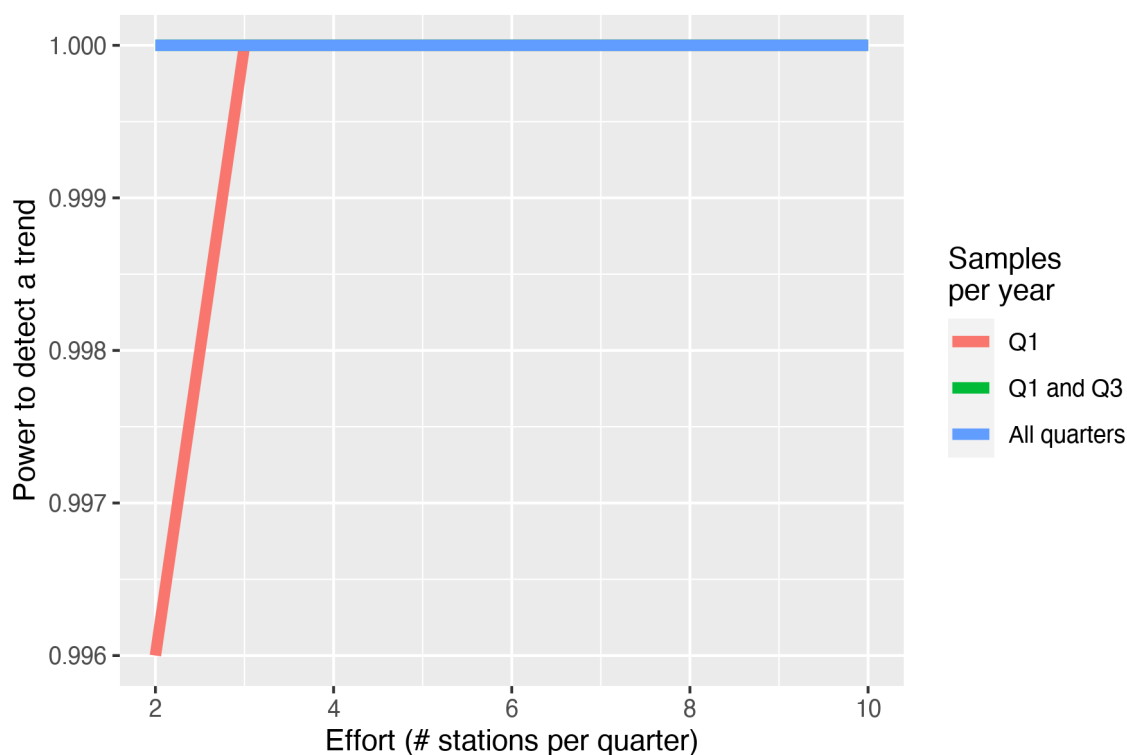


Figure A36. Plot of 10-year linear regression power for pH (delta = 0.25) in the Tutuila unit of National Park of American Samoa (80% power, Type I error = 0.05).

A.5 War in the Pacific National Historical Park—Agat Unit

Table A6 lists the number of sites required to detect targeted levels of change in water quality metrics in War in the Pacific National Historical Park—Agat unit. Figures A37 through A45 plot the 10-year linear regression of power to detect changes in different water quality metrics.

Table A6. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

Parameter	Delta	Q4	Q2 and Q4	All Quarters	Wilcoxon test
Chlorophyll	250%	8	4	2	3
Nitrate + Nitrite	150%	2	2	2	3
Oxygen Saturation	10%	2	2	2	3
Salinity	2%	2	2	2	2
Total Dissolved Nitrogen	100%	2	2	2	2
Total Dissolved Phosphorus	100%	2	2	2	2
Turbidity	150%	3	2	2	5
Temperature	4%	2	2	2	2
pH	0.25	2	2	2	2

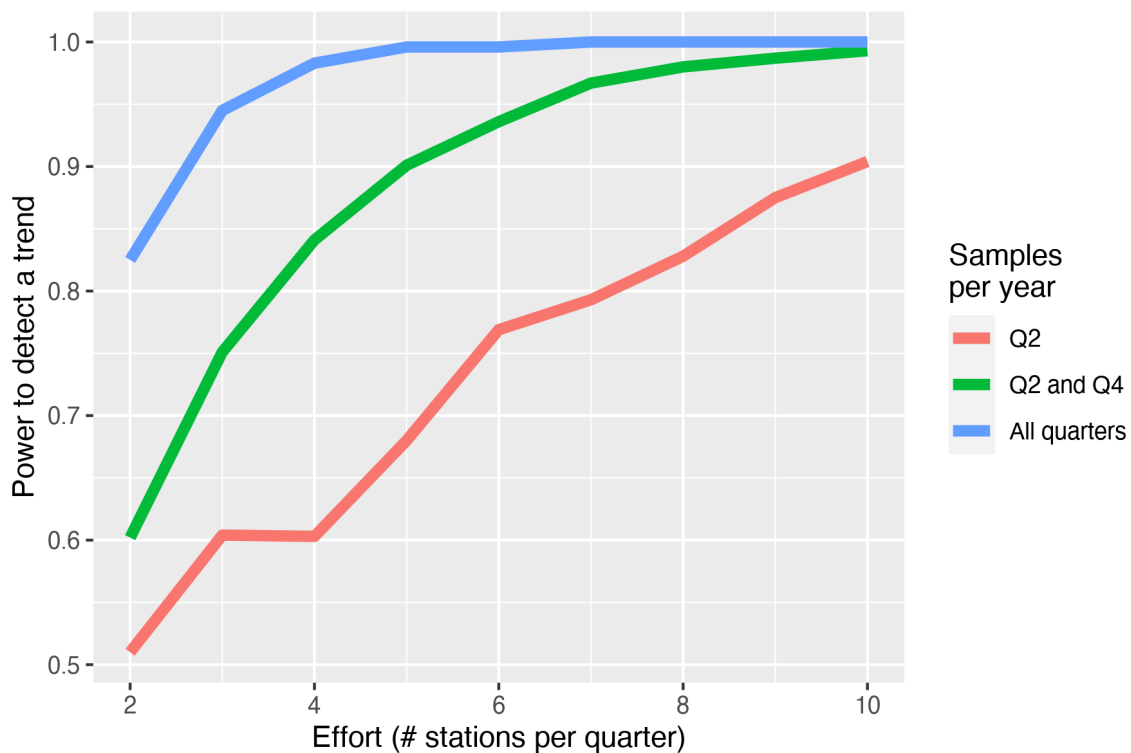


Figure A37. Plot of 10-year linear regression power for chlorophyll ($\delta = 250\%$) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

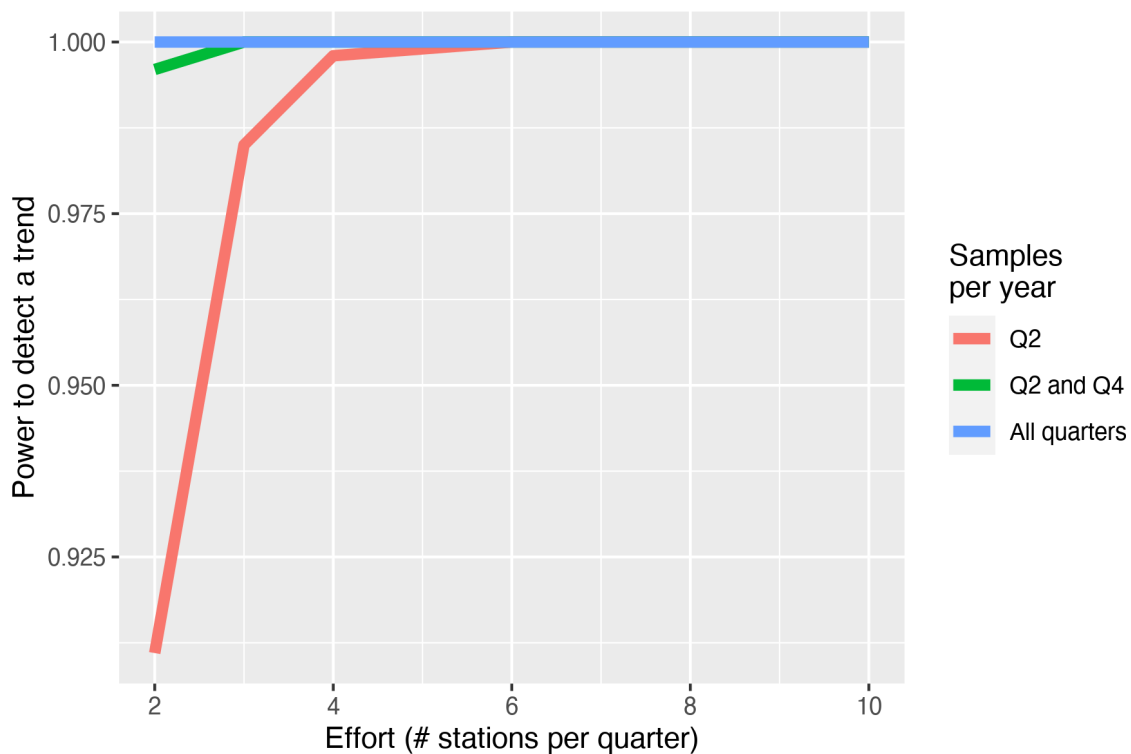


Figure A38. Plot of 10-year linear regression power for nitrate + nitrite ($\delta = 150\%$) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

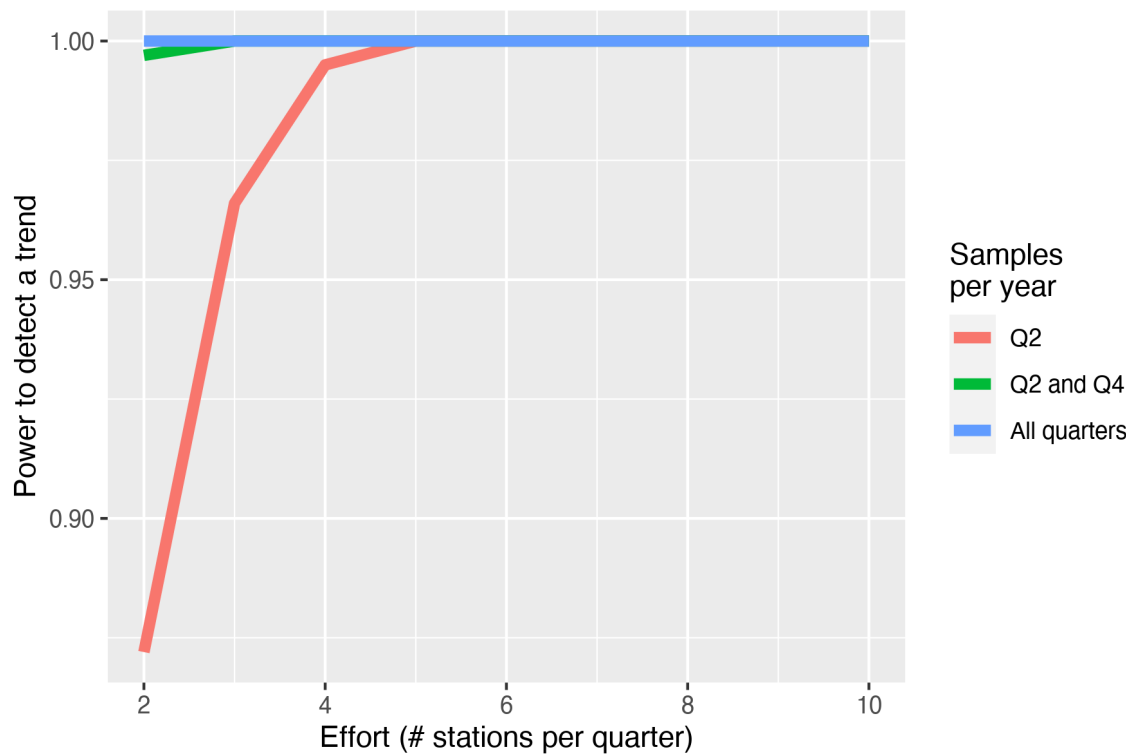


Figure A39. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

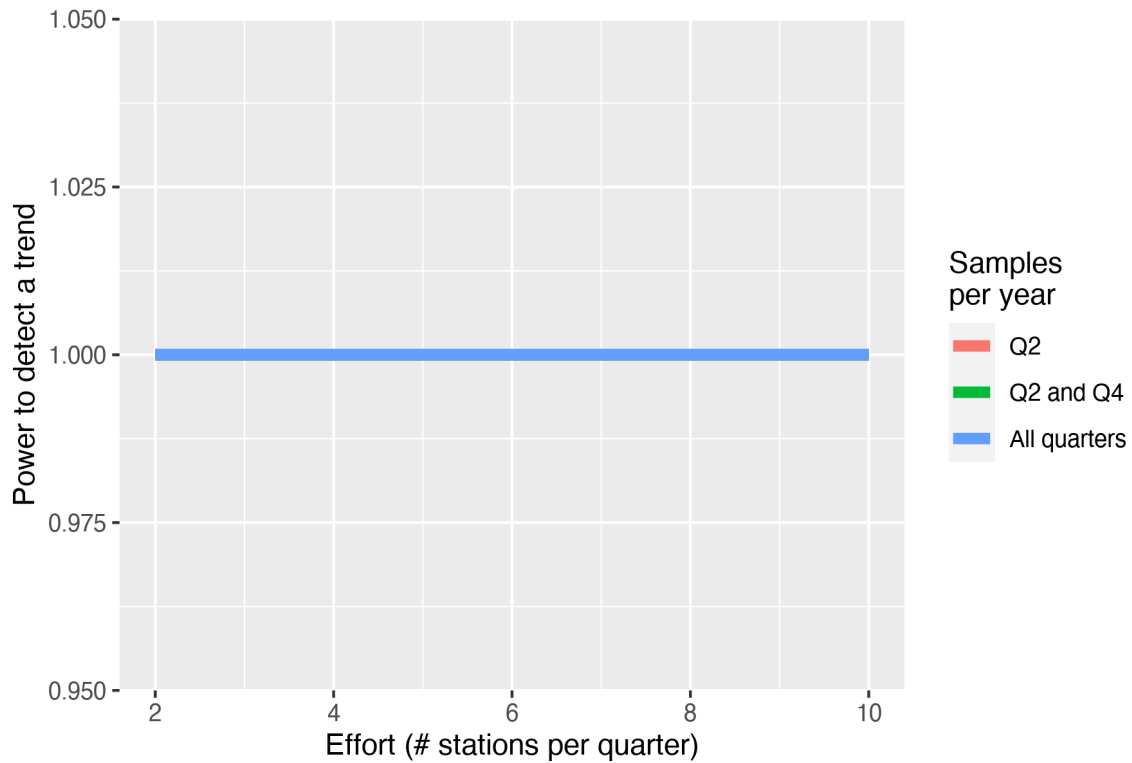


Figure A40. Plot of 10-year linear regression power for salinity (delta = 2%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

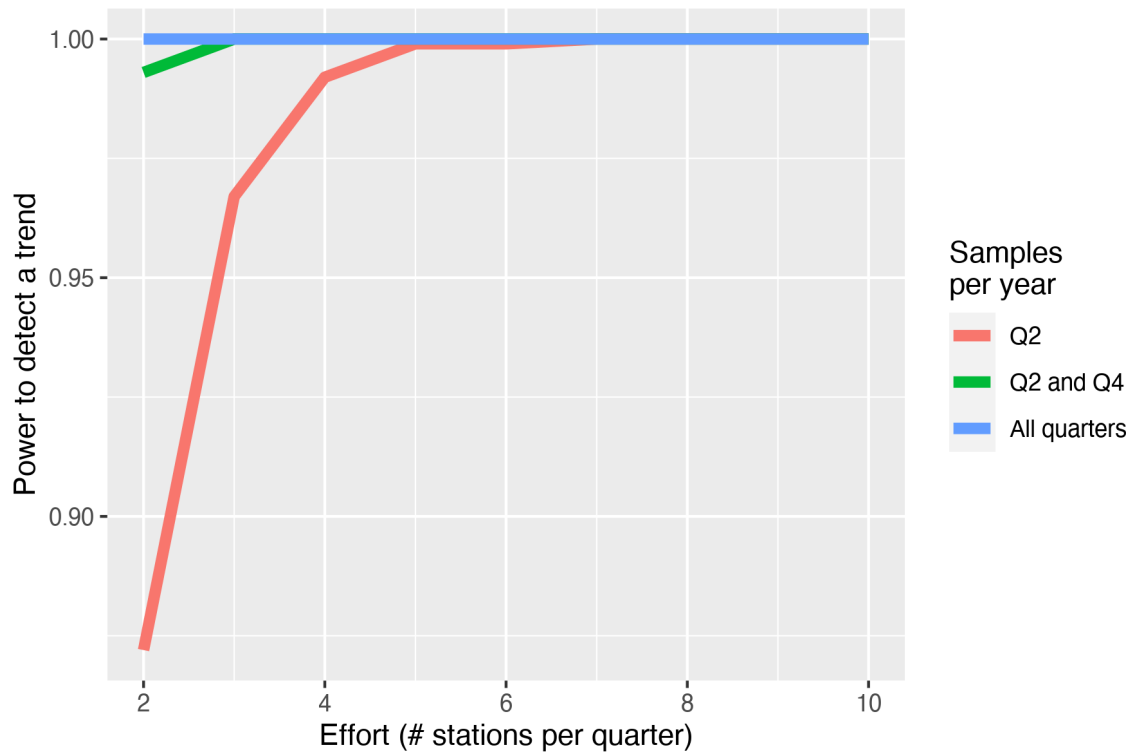


Figure A41. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

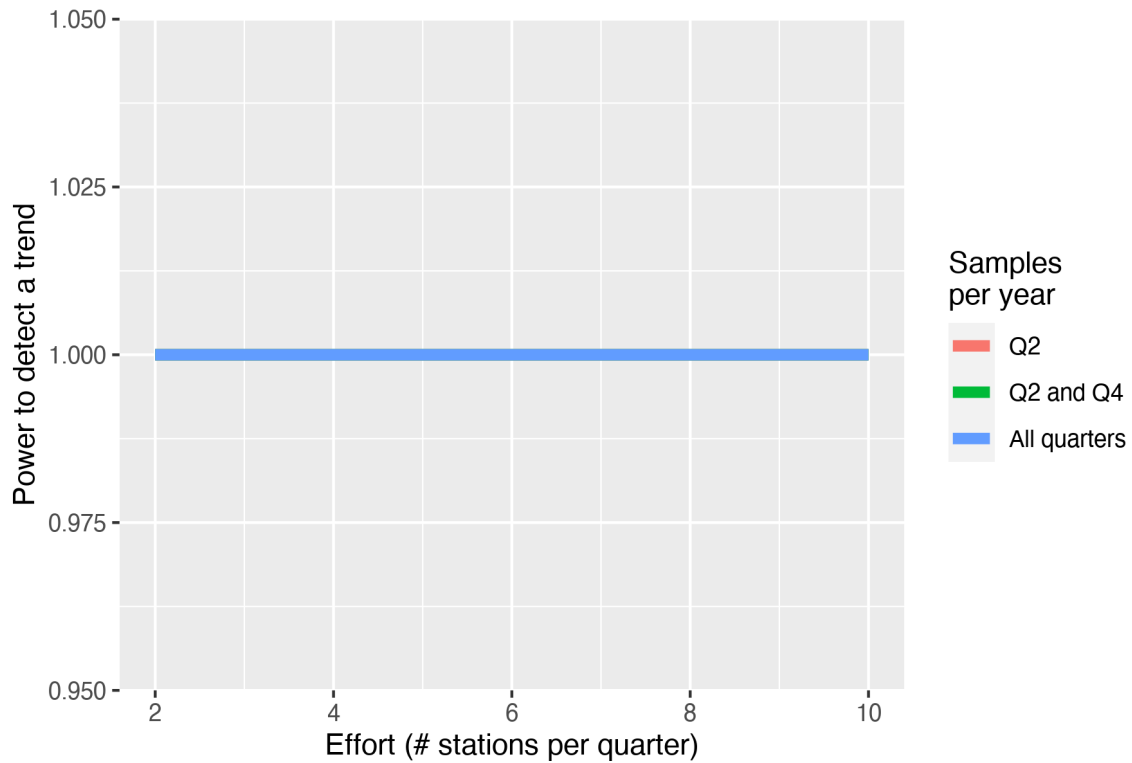


Figure A42. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

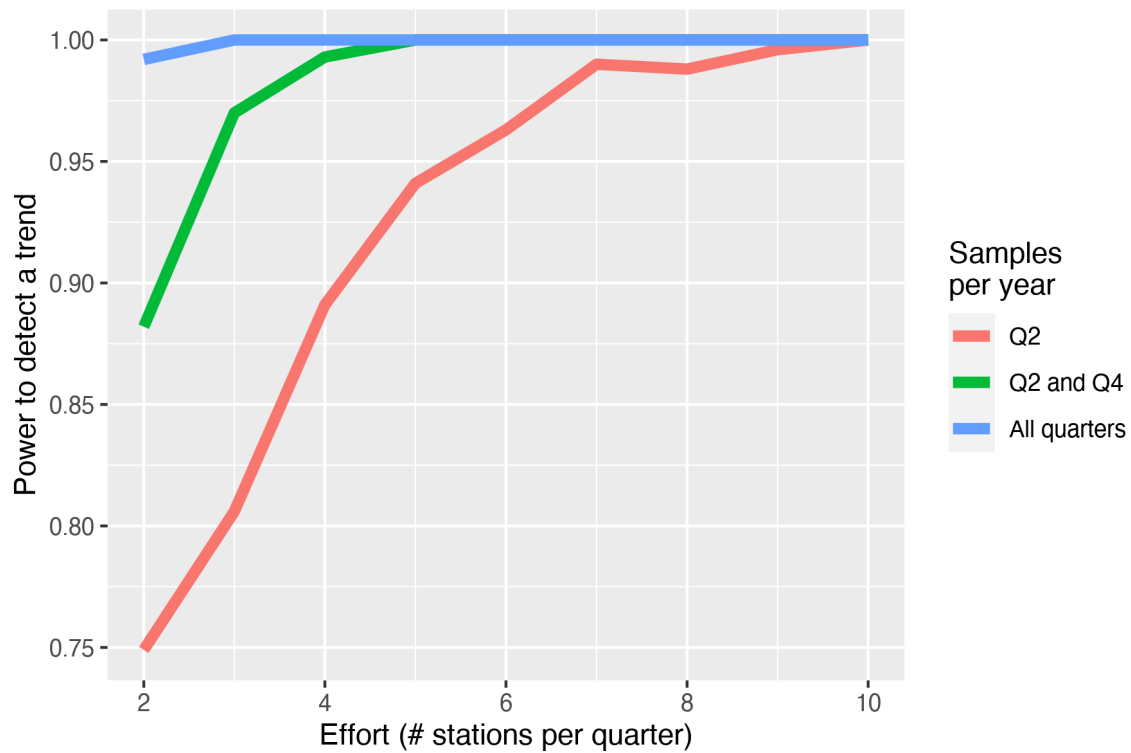


Figure A43. Plot of 10-year linear regression power for turbidity (delta = 150%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

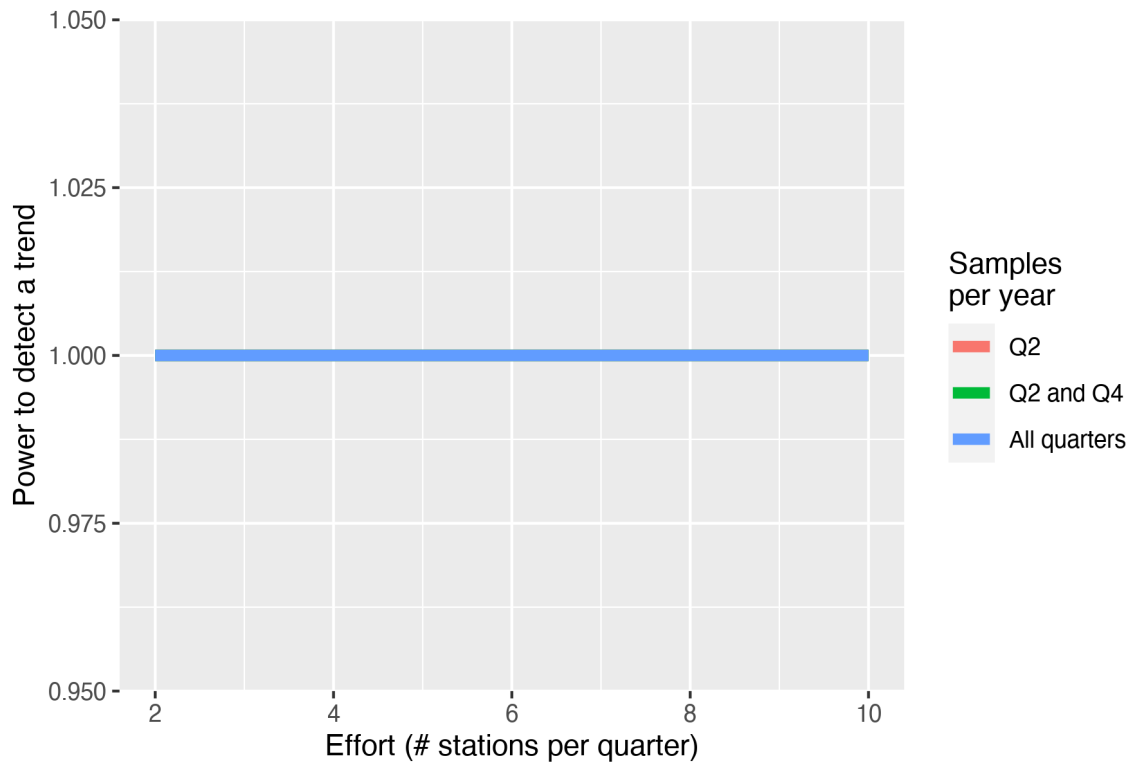


Figure A44. Plot of 10-year linear regression power for temperature (delta = 4%) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

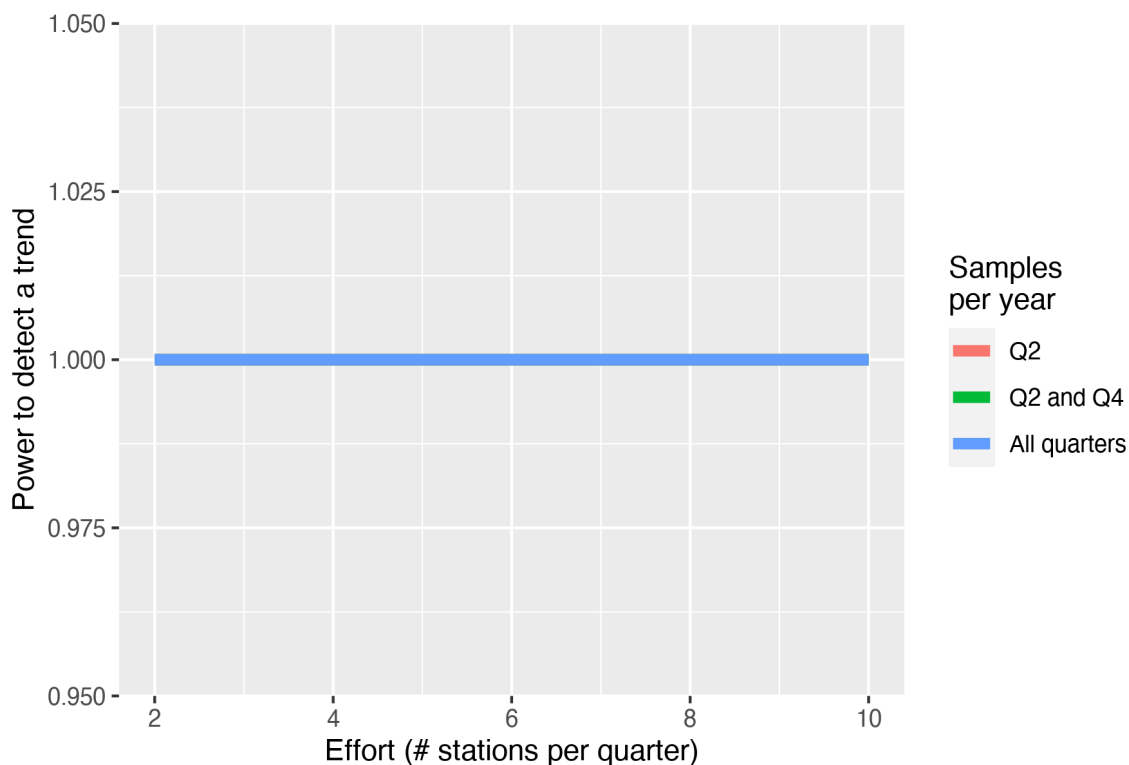


Figure A45. Plot of 10-year linear regression power for pH (delta = 0.25) in War in the Pacific National Historical Park Agat unit (80% power, Type I error = 0.05).

A.6 War in the Pacific National Historical Park—Asan Unit

Table A7 lists the number of sites required to detect targeted levels of change in water quality metrics in War in the Pacific National Historical Park—Asan unit. Figures A46 through A54 plot the 10-year linear regression of power to detect changes in different water quality metrics.

Table A7. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

Parameter	Delta	Q4	Q2 and Q4	All Quarters	Wilcoxon test
Chlorophyll	250%	3	2	2	3
Nitrate + Nitrite	150%	2	2	2	3
Oxygen Saturation	10%	2	2	2	3
Salinity	2%	2	2	2	2
Total Dissolved Nitrogen	100%	2	2	2	2
Total Dissolved Phosphorus	100%	3	2	2	2
Turbidity	150%	4	2	2	5
Temperature	4%	2	2	2	2
pH	0.25	2	2	2	2

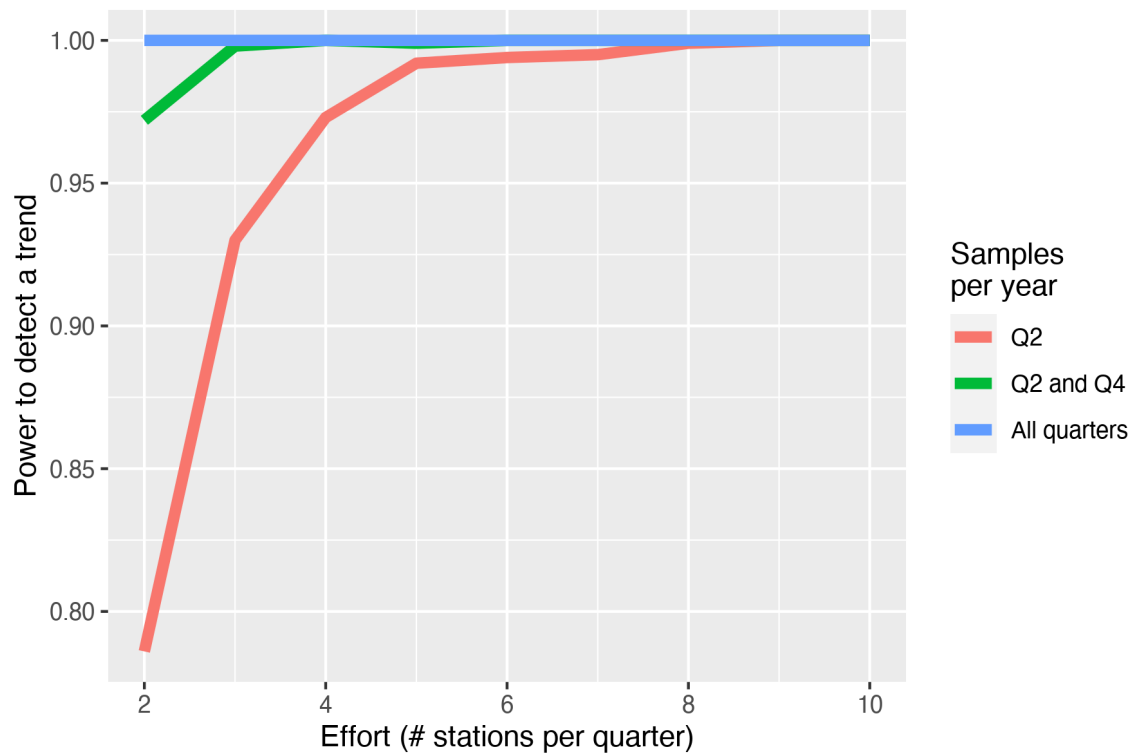


Figure A46. Plot of 10-year linear regression power for chlorophyll (delta = 250%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

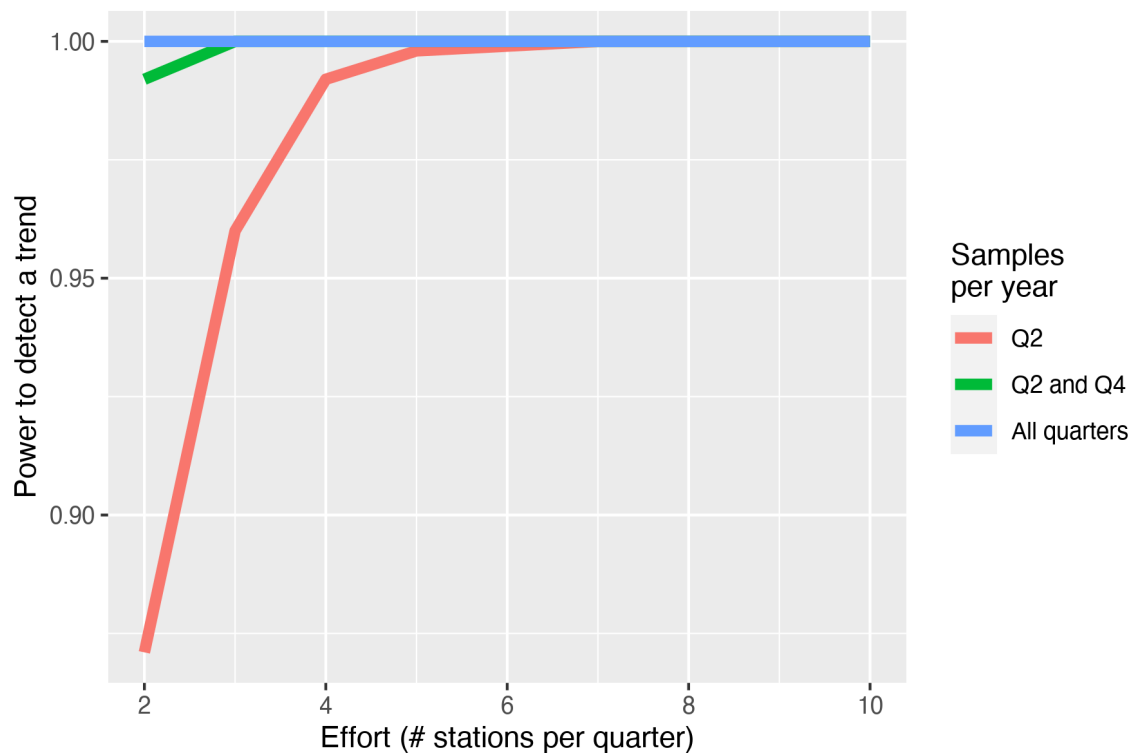


Figure A47. Plot of 10-year linear regression power for nitrate + nitrite (delta = 150%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

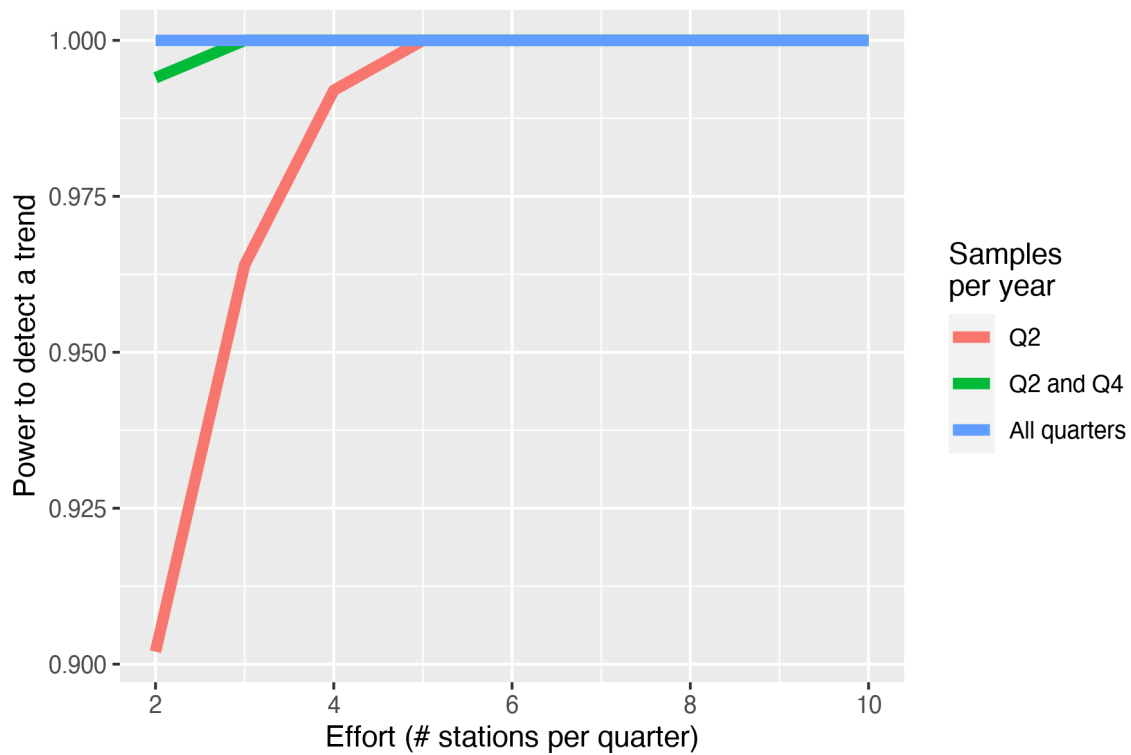


Figure A48. Plot of 10-year linear regression power for oxygen saturation (delta = 10%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

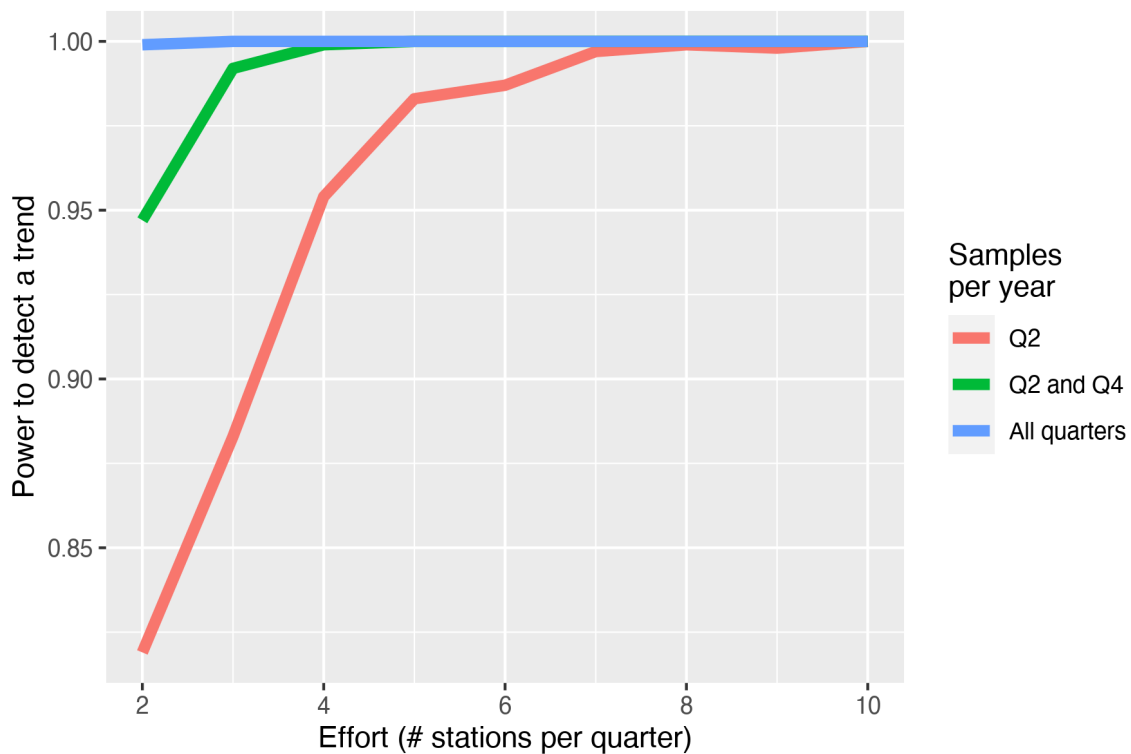


Figure A49. Plot of 10-year linear regression power for salinity (delta = 2%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

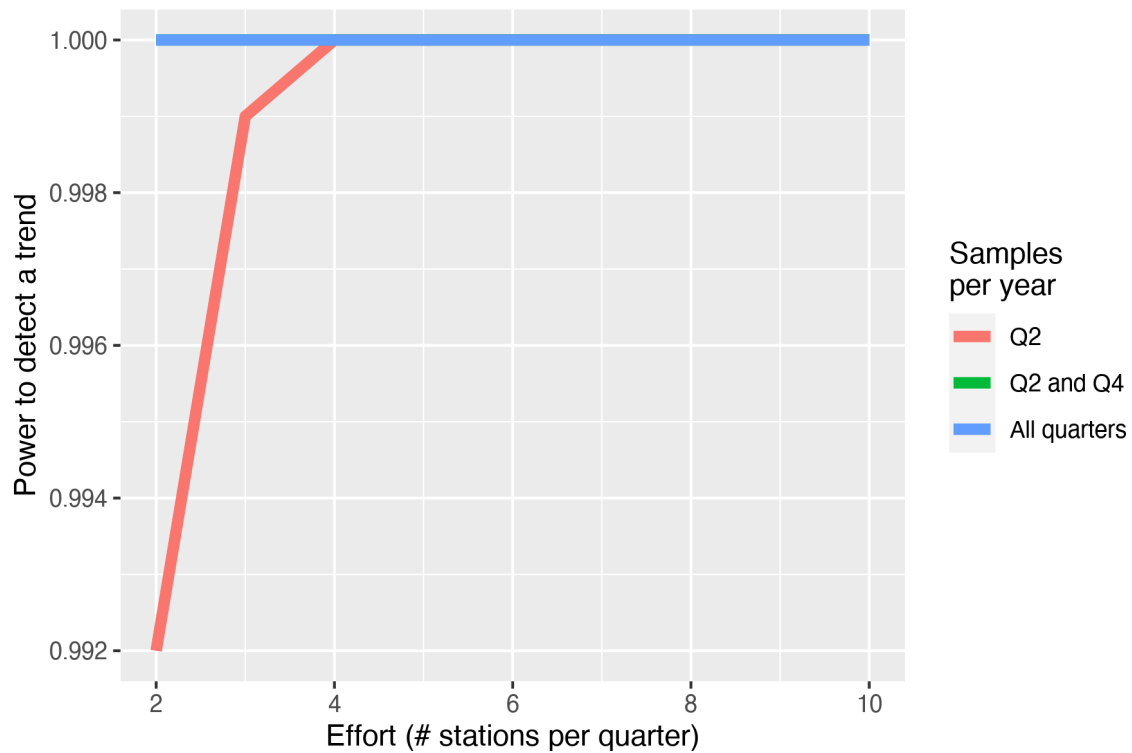


Figure A50. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

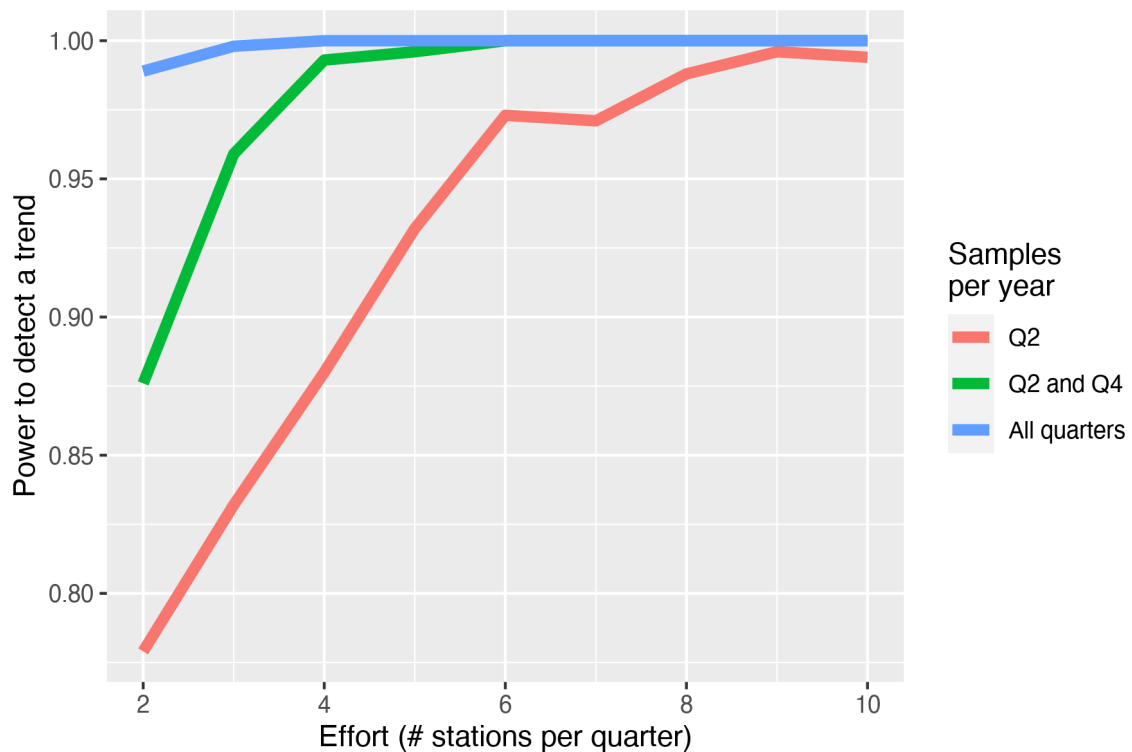


Figure A51. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

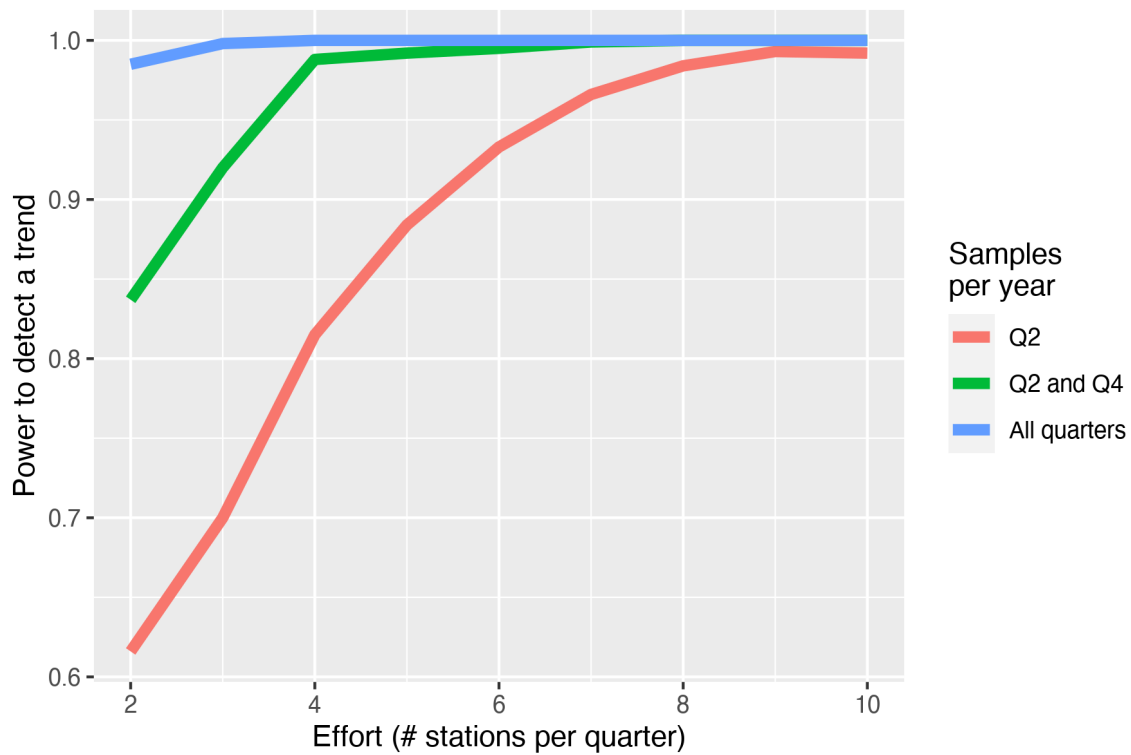


Figure A52. Plot of 10-year linear regression power for turbidity (delta = 150%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

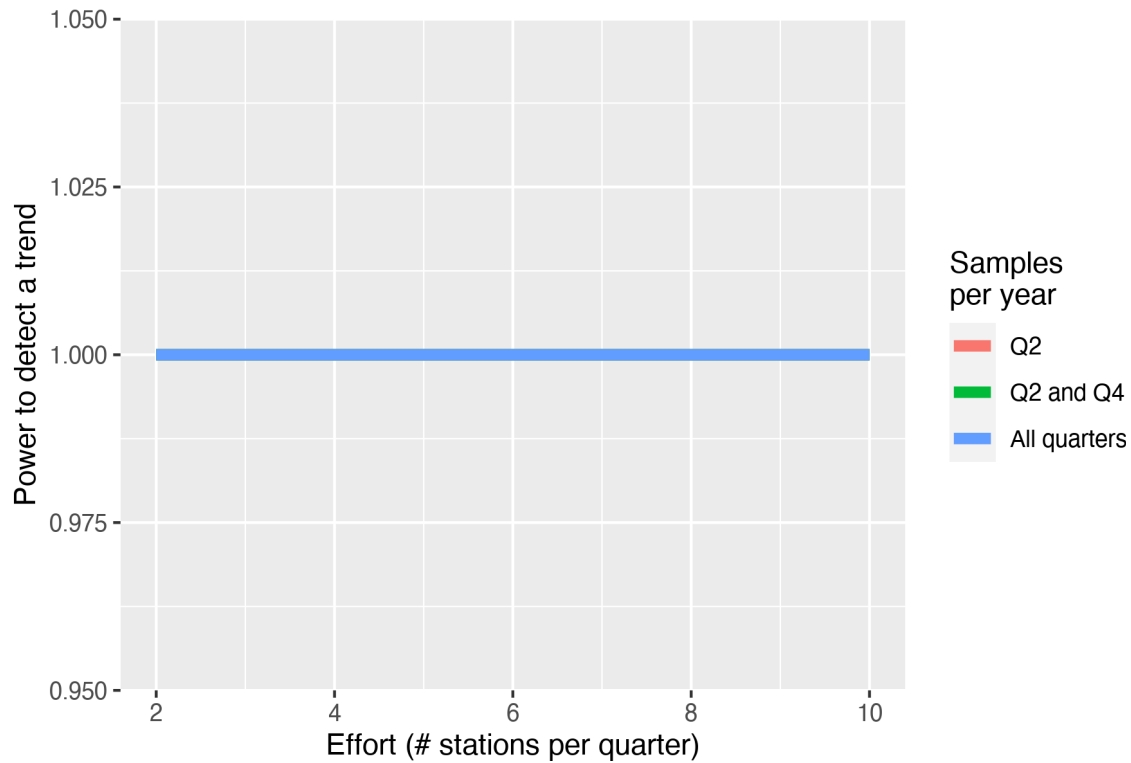


Figure A53. Plot of 10-year linear regression power for temperature (delta = 4%) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

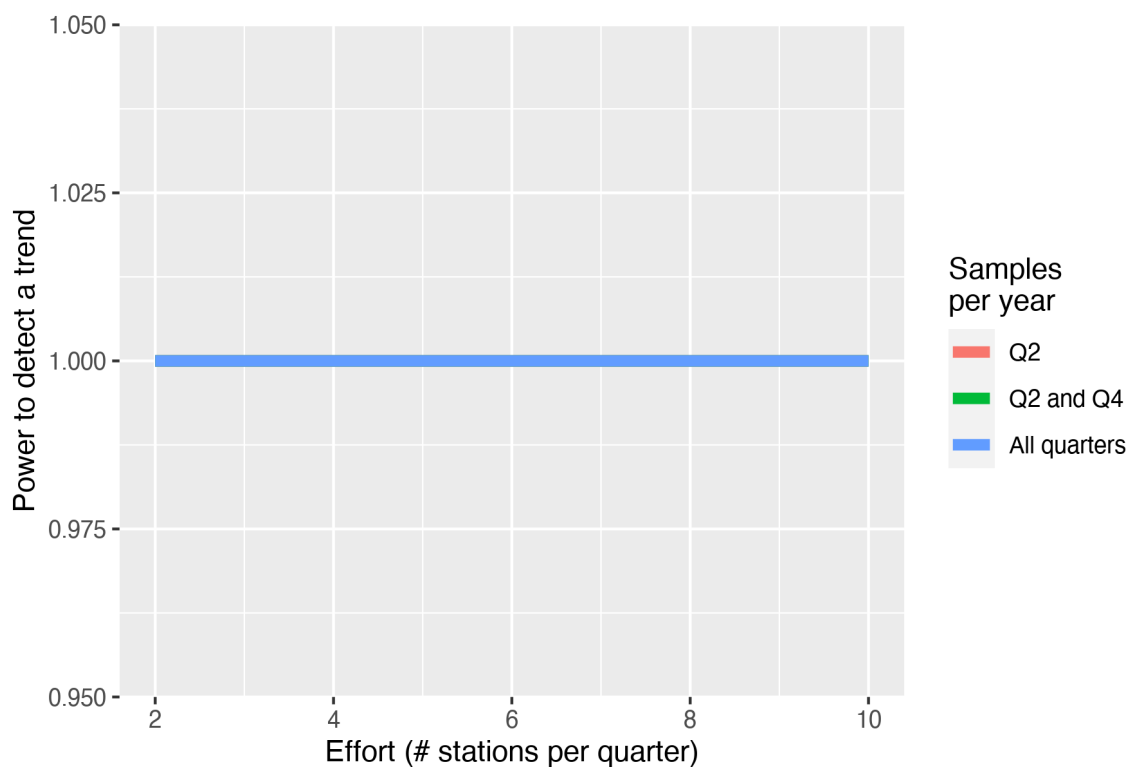


Figure A54. Plot of 10-year linear regression power for pH (delta = 0.25) in War in the Pacific National Historical Park Asan unit (80% power, Type I error = 0.05).

A.7 Kalaupapa National Historical Park

Table A8 lists the number of sites required to detect targeted levels of change in water quality metrics in Kalaupapa National Historical Park. Figures A55 through A63 plot the 10-year linear regression of power to detect changes in different water quality metrics.

Table A8. Minimum number of sites required to detect a linear increase and single quarter change (Wilcoxon test) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

Parameter	Delta	Q4	Q2 and Q4	All Quarters	Wilcoxon test
Chlorophyll	250%	3	2	2	3
Nitrate + Nitrite	150%	2	2	2	2
Oxygen Saturation	10%	2	2	2	2
Salinity	2%	4	2	2	3
Total Dissolved Nitrogen	100%	2	2	2	2
Total Dissolved Phosphorus	100%	2	2	2	2
Turbidity	150%	> 10	7	4	5
Temperature	4%	2	2	2	2
pH	0.25	2	2	2	2

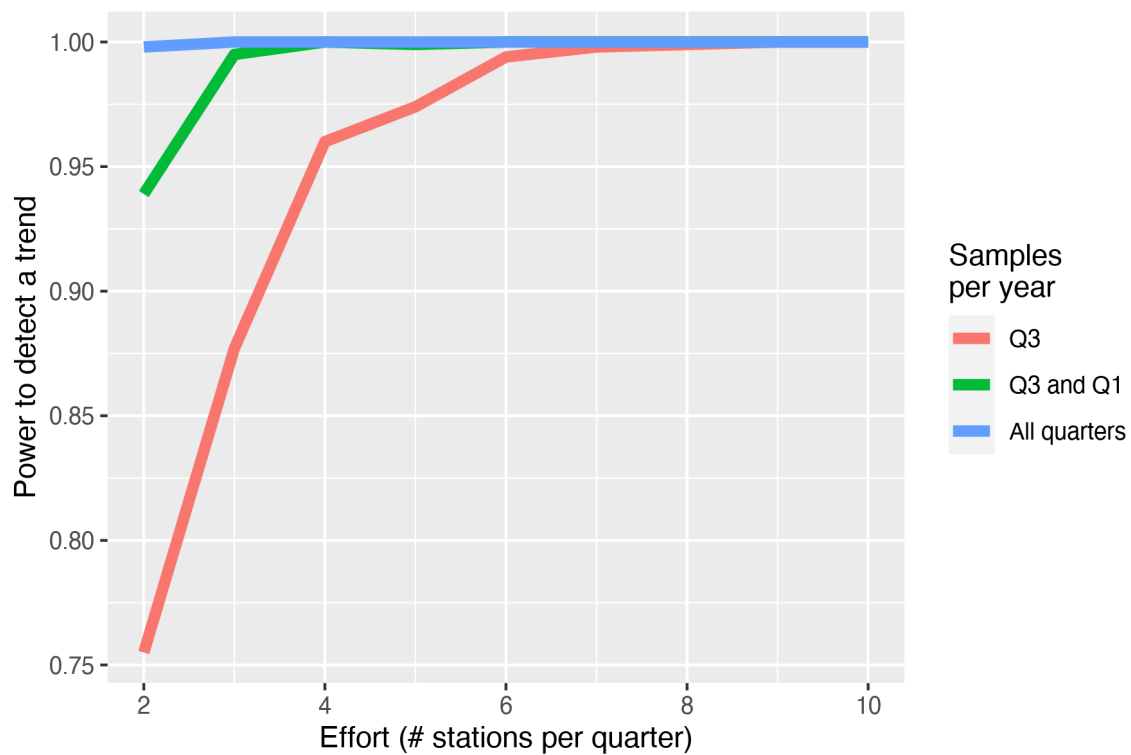


Figure A55. Plot of 10-year linear regression power for chlorophyll ($\delta = 250\%$) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

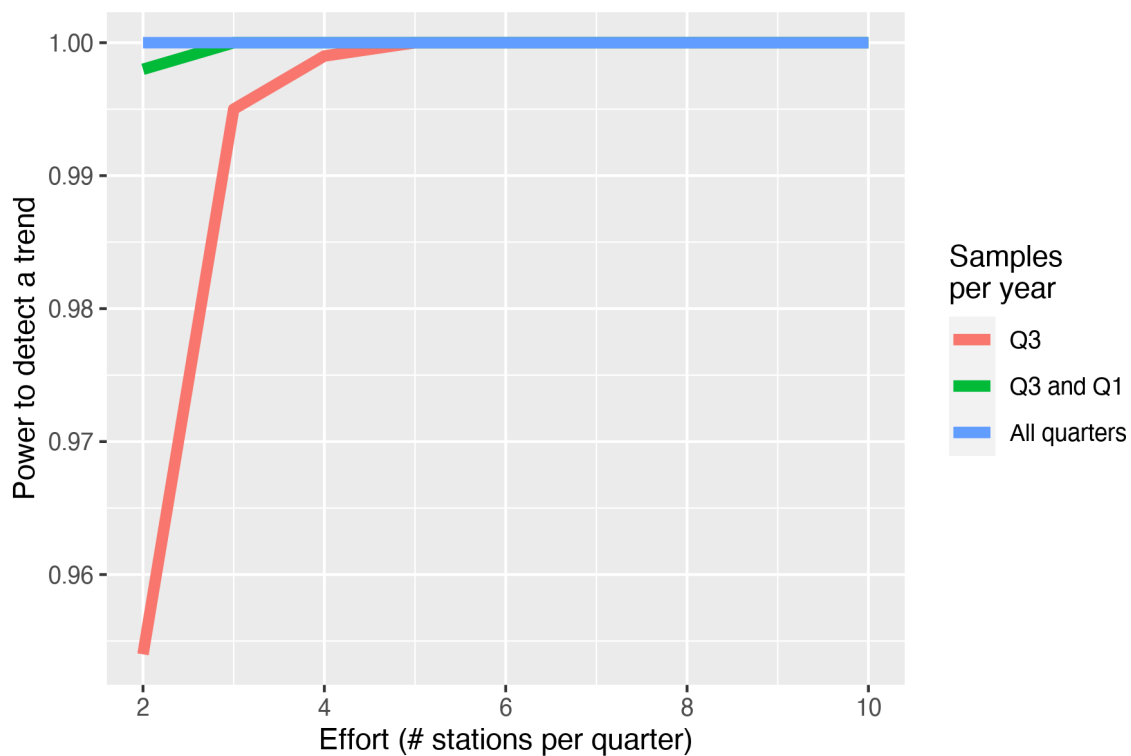


Figure A56. Plot of 10-year linear regression power for nitrate + nitrite ($\delta = 150\%$) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

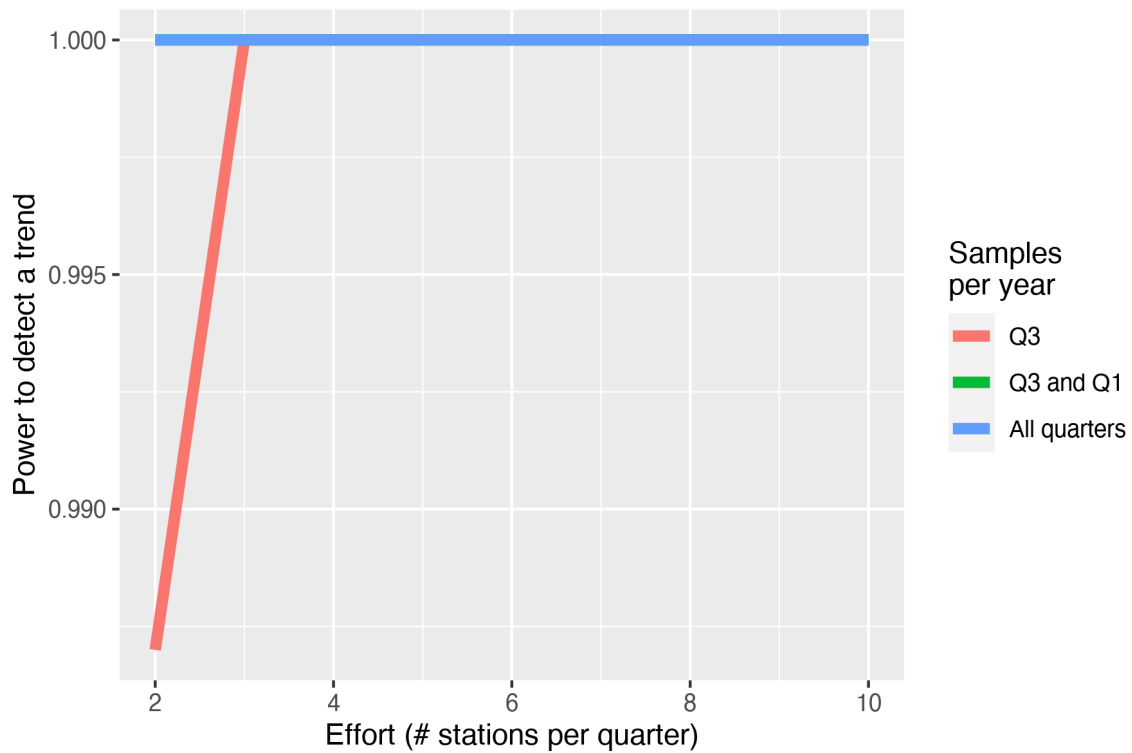


Figure A57. Plot of 10-year linear regression power for oxygen saturation ($\delta = 10\%$) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

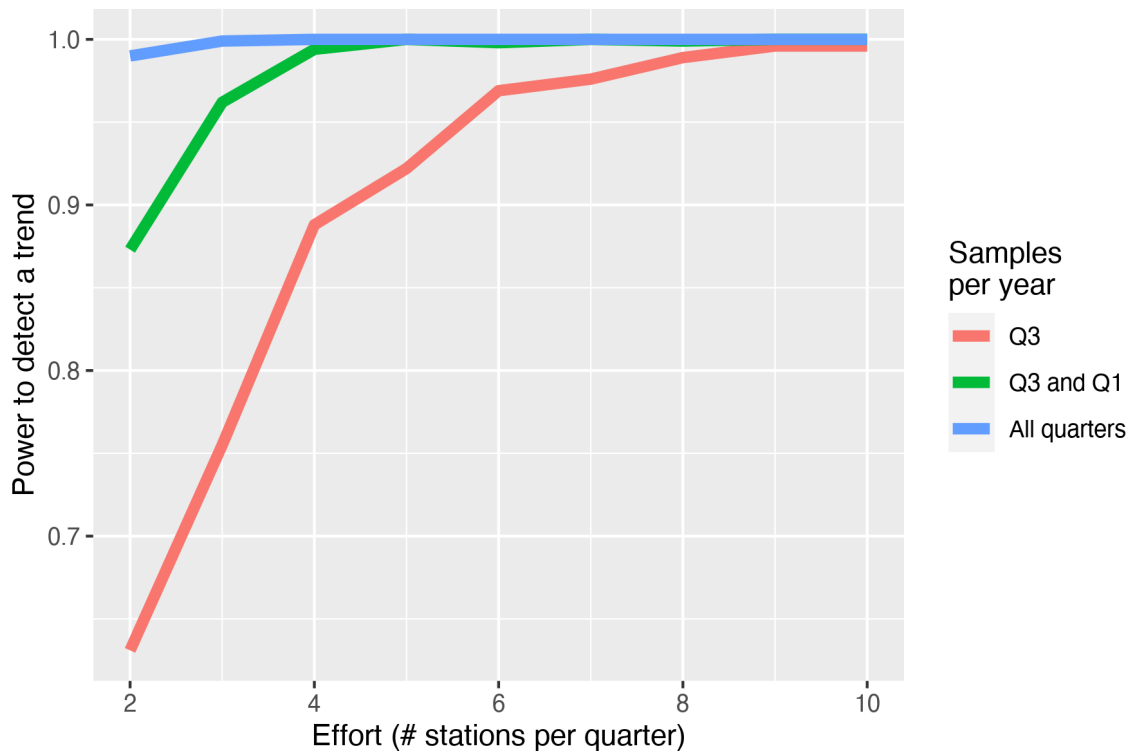


Figure A58. Plot of 10-year linear regression power for salinity ($\delta = 2\%$) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

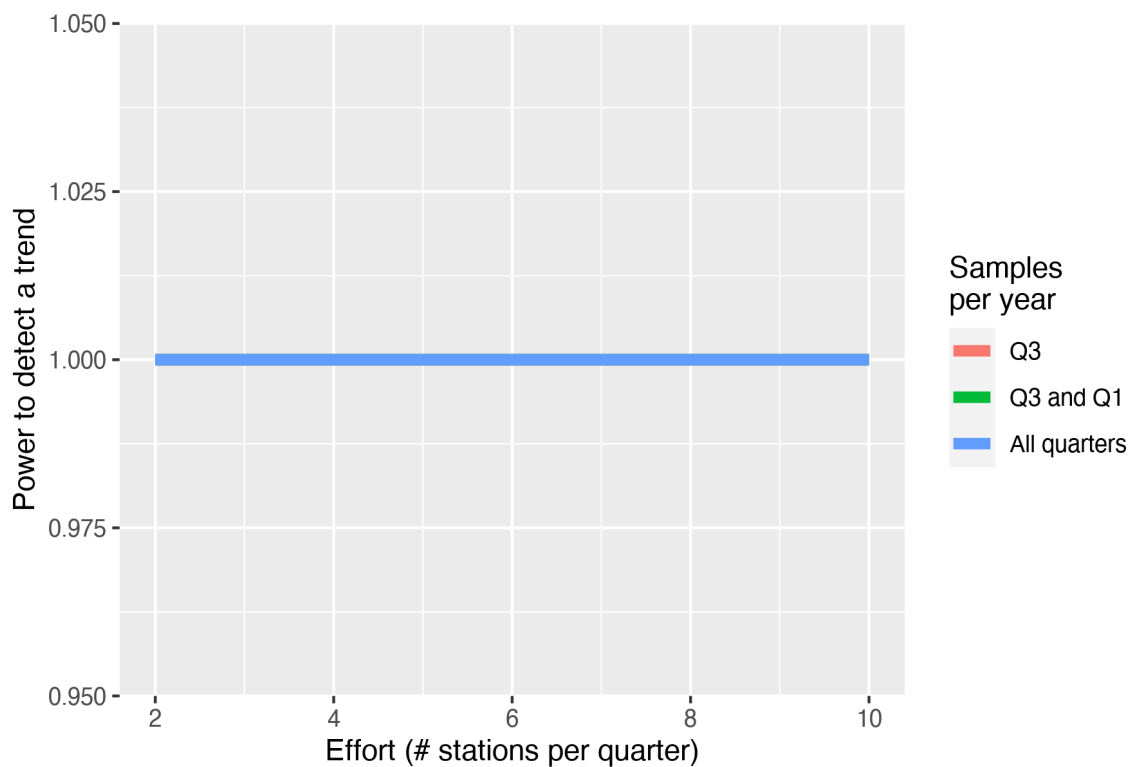


Figure A59. Plot of 10-year linear regression power for total dissolved nitrogen (TDN; delta = 100%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

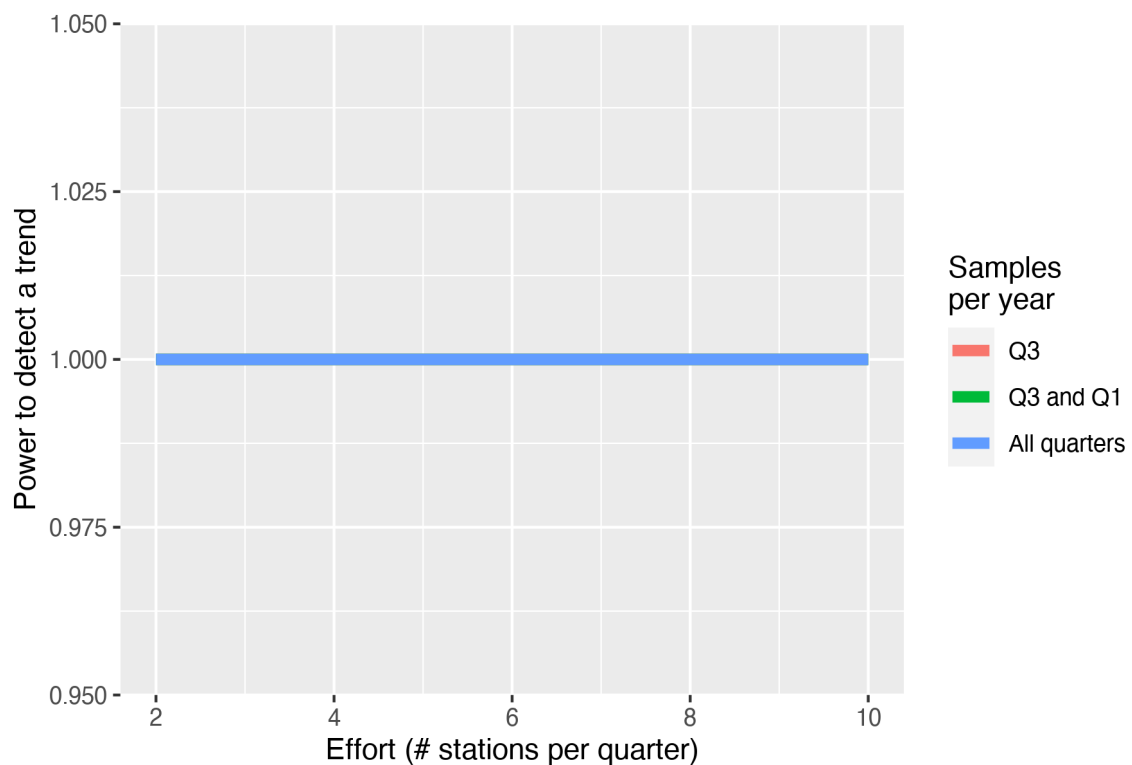


Figure A60. Plot of 10-year linear regression power for total dissolved phosphorus (TDP; delta = 100%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

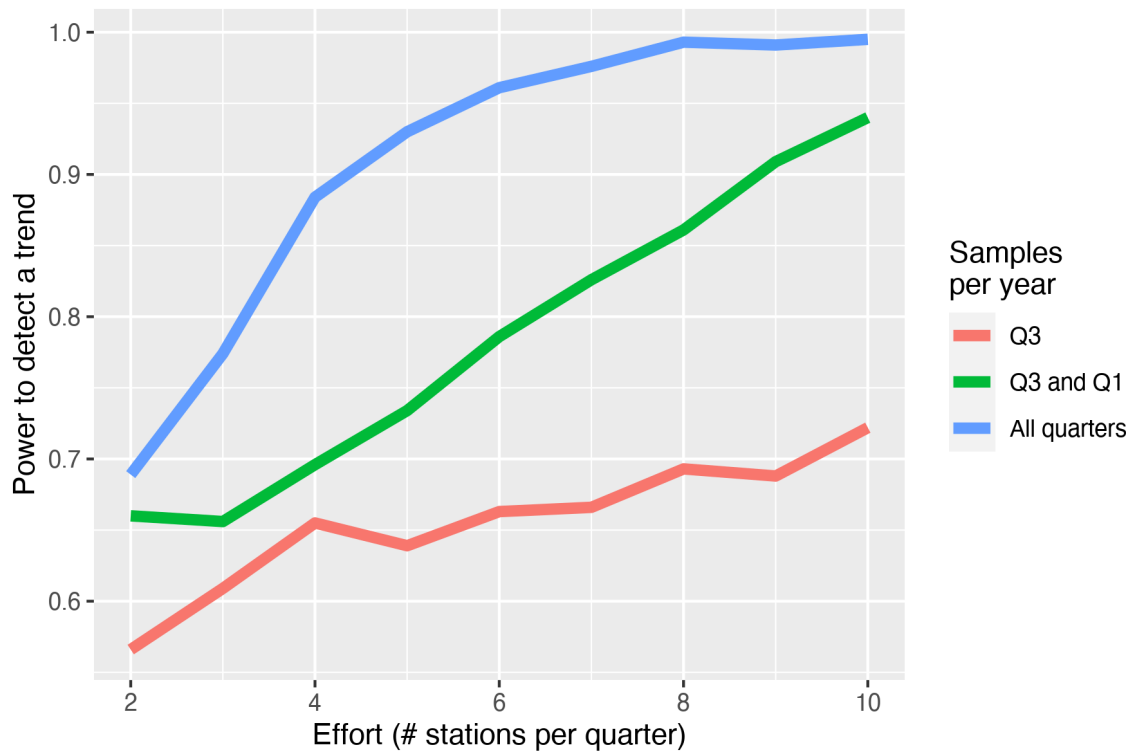


Figure A61. Plot of 10-year linear regression power for turbidity (delta = 150%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

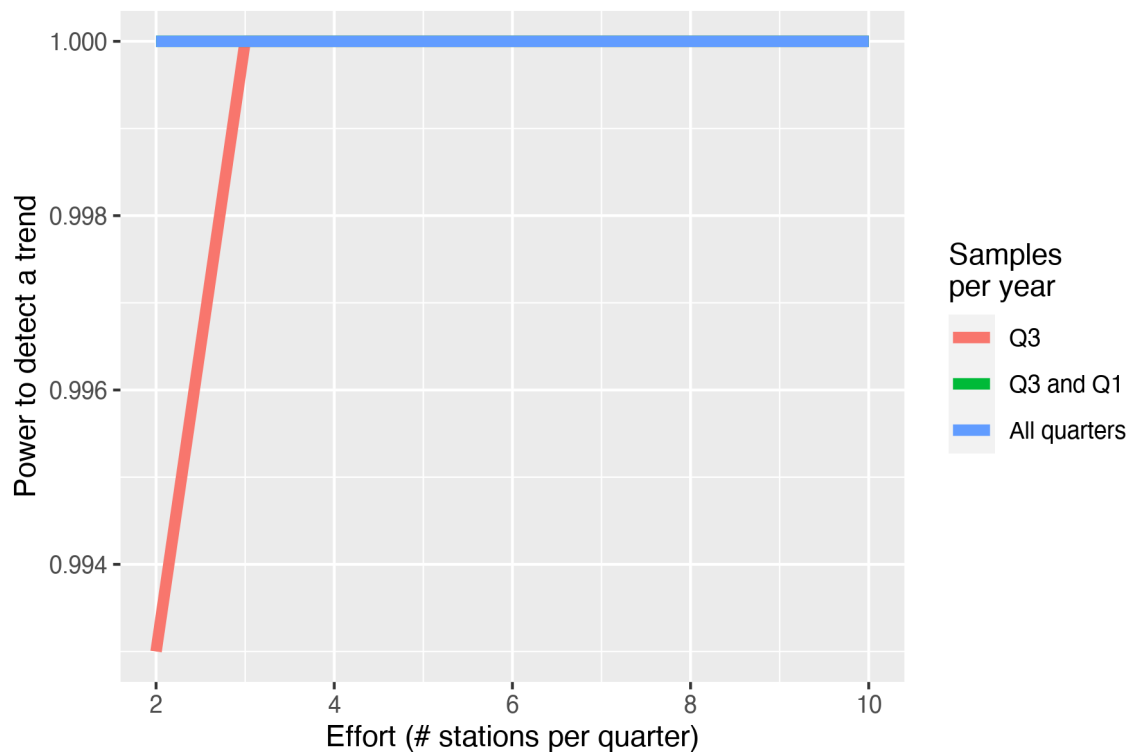


Figure A62. Plot of 10-year linear regression power for temperature (delta = 4%) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

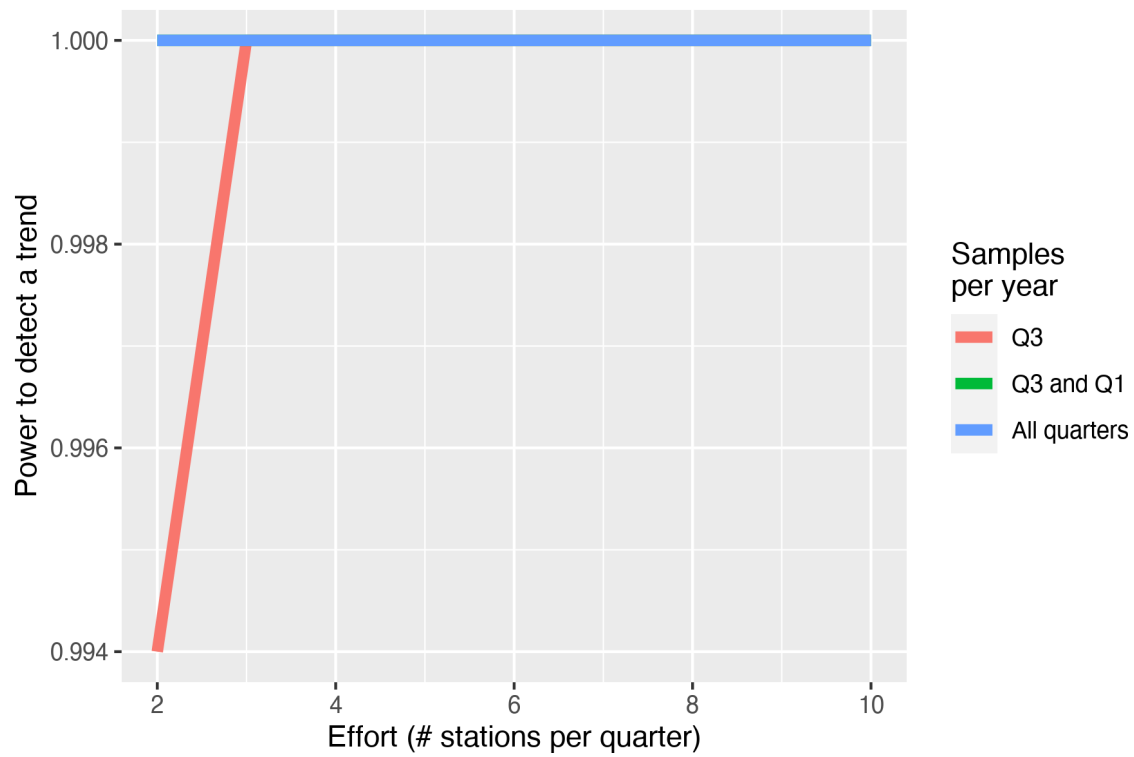


Figure A63. Plot of 10-year linear regression power for pH ($\delta = 4\%$) in Kalaupapa National Historical Park (80% power, Type I error = 0.05).

Appendix B: Database Documentation

The database for this project consists of four types of tables: core tables describing the “who, where, and when” of data collection, project-specific tables, lookup tables that contain domain constraints for other tables, and cross reference tables that link lookup tables with data tables. Although core tables are based on PACN standards, they may contain fields, domains or descriptions that have been added or altered to meet project objectives.

The database includes the following standard tables:

tbl_Sites:	Sample sites: individual parks.
tbl_Locations:	Sample locations: water quality sample stations.
tbl_Events:	Data collection event for a given location.
tbl_Event_Details:	Data collection event details such as environmental conditions.
tbl_Activity:	Water quality activities performed during an event.
tbl_Event_Pics:	Images of the sampling location for a particular event.
tbl_Location_Pics:	Images of the sampling location at the initial visit.

The following are project-specific data tables:

tbl_Analytical_Procedures:	User entered analytical procedures. Imported table structure from NPSTORET.
tbl_Field_Procedures:	User entered field procedures. Imported table structure from NPSTORET.
tbl_Gear_Configurations:	User entered gear configurations. Imported table structure from NPSTORET.
tbl_Lab_Calibration:	Quality assurance/quality check lab sample calibration data for a sampling event.
tbl_Lab_Calibration_Values:	Lab sample calibration values for a quality assurance/quality check lab sample.
tbl_Labs:	User entered labs. Imported table structure from NPSTORET.
tbl_Lab_Sample_Prep:	User entered lab sample preparation procedures. Imported table structure from NPSTORET.
tbl_PreserveTransportStore:	User entered preservation, transport, and storage procedures. Imported table structure from NPSTORET.

tbl_Results: Water quality results.

The following are a few of the more prominent, standard lookup tables:

tlu_ActivityTypes: List of Activity Types from WQX STORET including translation from Modern STORET.

tlu_Addresses: Look up table of addresses. Linked to contacts in tlu_Contacts.

tlu_Characteristics: User entered characteristic definitions (parameters that are measured).

tlu_Contacts: Contacts related to the water quality protocol.

The following are cross reference tables:

xref_Contact_Address: Cross-reference table between contacts and addresses.

xref_Event_Contacts: Cross-reference table between events and contacts.

Figure B1 displays how standard, project-specific, and lookup tables are related within the database.

Table Variables and Descriptions

Descriptions for the tables and their fields are located in Table B1 through Table B36.

Table B1. “tbl_Activity”—User entered or imported water quality activities.

Field Name	Primary?	Field Type	Field Size	Field Description
Activity_ID	Yes	Other	16	Unique record identifier
Activity_Type	No	Long Integer	4	Activity type used for determining data entry form for results
Collection_Time	No	Date/Time	8	Collection time for activity
Comments	No	Memo	0	Activity comment/description
Complete	No	Boolean	1	Activity OK to write out after passing through QA checks
Data_Type	No	Text	50	Type of data collected, i.e., YSI, Nutrient Data
Depth_to_Act	No	Double	8	Distance/depth from surface to the point in water column at which the activity is conducted
Depth_to_Act_Unit	No	Text	2	Units in which the depth to activity is expressed (ft or m)
Event_ID	No	Other	16	Record identifier for tbl_Events
File_Path	No	Text	255	The base file path for the linked text file. This will stay the same no matter where the root folder is.
File_Type	No	Text	255	The type of file used for importing YSI data, attended or unattended
Lab_ID	No	Other	16	Look up to the Laboratory that processed the water sample
Lab_Report_Number	No	Text	50	The lab report number for the submitted water samples that contains the nutrient results.

Table B1 (continued). “tbl_Activity”—User entered or imported water quality activities.

Field Name	Primary?	Field Type	Field Size	Field Description
Label_Number	No	Text	50	Water sample container label number
Last_QA_QC	No	Date/Time	8	Date of last QA/QC check
Processing_Date	No	Date/Time	8	The date that the nutrient data was processed by the lab
QAQC_Sample	No	Text	3	Is this a QA/QC Sample?
Reltv_Depth	No	Text	15	Approximate relative depth at which the activity occurred (Bottom, Midwater, Surface, Subbottom, Near Bottom)
Root_Path	No	Text	255	The root path for the linked text file. This will change upon re-linking of database.
Sonde_Type	No	Text	25	The sonde model used for YSI data collection
Text_File_Path	No	Text	255	The file path for the text file that the data was imported from for the sampling event
Update_TS	No	Date/Time	8	Date/Time of last update – automatically stamp today's date/time in before update event
UserID	No	Text	100	Who last updated the record – automatically filled in by whoever logged on the system

Table B2. “tbl_Analytical_Procedures” —User entered analytical procedures. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field Size	Field Description
Analytical_ID	Yes	Other	16	Analytical procedure unique identifier
Citation	No	Memo	0	Analytical procedure citation
D_Last_update_TS	No	Date/Time	8	Date/Time of Last Update – automatically stamp today's date/time in before update event
D_UserID_code	No	Text	100	Who last updated the record – automatically filled in by whoever logged on the system
Description_text	No	Memo	0	Analytical procedure description text
Equip_Name	No	Text	50	The name of the equipment being used for the analytical procedure
Equip_Type	No	Text	50	The type of equipment being used for the analytical procedure
ID_Code	No	Text	15	Abbreviated name or identifying code for the analytical procedure – for NPSTORET
Name	No	Text	120	Full title of analytical procedure
National_Procedure	No	Text	50	Comparable national procedure

Table B3. “tbl_Db_Revisions” —Database revision history data.

Field Name	Primary?	Field Type	Field Size	Field Description
Revision_ID	Yes	Text	50	Database revision (version) number or code
Revision_Contact_ID	No	Text	100	Link to tlu_Contacts
Revision_Date	No	Date/Time	8	Database revision date
Revision_Desc	No	Memo	0	Revision description
Revision_Reason	No	Memo	0	Reason for the database revision

Table B4. "tbl_Event_Details" —Sampling event details.

Field Name	Primary?	Field Type	Field Size	Field Description
Event_ID	Yes	Other	16	Link to tbl_Events
Direction	No	Text	5	Tidal direction; Ebb, Flood, Slack
Env_Cond	No	Text	14	Weather conditions: Sunny, Partly Sunny, Cloudy, Mostly Sunny, Cloudy, Overcast, Rain
Est_Canopy_Cover	No	Long Integer	4	Estimated canopy cover
Flow	No	Text	12	Flow level; Dry, No Flow, Low, Normal, Above Normal, Flood
Hab_Desc	No	Memo	0	Habitat description
Speed	No	Long Integer	4	Wind speed in mph
Tidal_Stage	No	Text	4	Tidal stage; High, Low, Mid
Water_Depth	No	Double	8	Water depth in meters
Water_Depth_Unit	No	Text	2	Units in which the water depth is expressed (ft or m)
Wave_Ht	No	Long Integer	4	Wave height
Wind_Dir	No	Long Integer	4	Wind direction; 0(N), NE(45), E(90), SE(135), S(180), SW(225), W(270), NW(315)

Table B5. "tbl_Event_Group"—Sampling trip metadata and calibration values.

Field Name	Primary?	Field Type	Field Size	Field Description
Event_Group_ID	Yes	Other	16	An identifier for the event group
Analytical_ID	No	Other	16	Link to tbl_Analytical_Procedures
Chloro_Bias	No	Other	16	Optical Chlorophyll probe bias for sampling trip

Table B5 (continued). "tbl_Event_Group"—Sampling trip metadata and calibration values.

Field Name	Primary?	Field Type	Field Size	Field Description
Chloro_Precision	No	Other	16	Optical Chlorophyll probe precision for sampling trip
Event_Group_Name	No	Text	255	Event group (e.g., season, trip) name: 4- letter park code, 4-letter year and 2-letter month for sampling trip; i.e., HAVO_200809
Field_ID	No	Other	16	Link to tbl_Field_Procedures
Is_Calibrated	No	Boolean	1	Was calibration conducted?
Lab_ID	No	Other	16	Link to tbl_Labs
Lab_Sample_ID	No	Other	16	Link to tbl_Lab_Sample_Prep
NO3_Bias	No	Other	16	NO3 bias provided by lab
NO3_Precision	No	Other	16	NO3 precision provided by lab
ODO_Bias	No	Other	16	Optical Dissolved Oxygen probe bias for sampling trip
ODO_Precision	No	Other	16	Optical Dissolved Oxygen probe precision for sampling trip
pH_Bias	No	Other	16	PH probe bias for sampling trip
pH_Precision	No	Other	16	pH probe precision for sampling trip
PO4_Bias	No	Other	16	PO4 bias provided by lab
PO4_precision	No	Other	16	PO4 precision provided by lab
Preserve_ID	No	Other	16	Link to tbl_PreserverTransportStore
Sonde	No	Text	50	The YSI model used for data collection.
SpC_Bias	No	Other	16	Specific conductivity probe bias for sampling trip

Table B5 (continued). "tbl_Event_Group"—Sampling trip metadata and calibration values.

Field Name	Primary?	Field Type	Field Size	Field Description
SpC_Precision	No	Other	16	Specific conductivity probe precision for sampling trip
Temp_Bias	No	Other	16	Temperature probe bias for sampling trip
Temp_Precision	No	Other	16	Temperature probe precision for sampling trip
TN_Bias	No	Other	16	Total nitrogen bias provided by lab
TN_Precision	No	Other	16	Total nitrogen precision provided by lab
Turb_Bias	No	Other	16	Optical Turbidity probe bias for sampling trip
Turb_Precision	No	Other	16	Optical Turbidity probe precision for sampling trip

Table B6. "tbl_Events"—Sampling events.

Field Name	Primary?	Field Type	Field Size	Field Description
Event_ID	Yes	Other	16	Event identifier
Certified	No	Boolean	1	Whether the data has been certified
Certified_by	No	Text	100	Person who certified data for accuracy and completeness
Certified_date	No	Date/Time	8	Date on which data were certified
Colocation_Protocol_Name	No	Text	100	The name of the protocol that is being collocated with water quality
Comments	No	Memo	0	Comments about sampling event.
End_Date	No	Date/Time	8	Ending date for the event
End_Time	No	Date/Time	8	Ending time for the event

Table B6 (coninued). "tbl_Events"—Sampling events.

Field Name	Primary?	Field Type	Field Size	Field Description
End_Time_Zone	No	Text	4	End Time Zone for Visit (needed because a Visit could extend across Daylight Savings/Standard Times)
Event_Group_ID	No	Other	16	Link to tbl_Event_Group
External_Flag	No	Boolean	1	Populated if there is an external event that makes the data unfit for use in long term analysis.
External_Flag_Type	No	Text	50	Type of external event that makes the data unfit for use in long term analysis, e.g., flood conditions or high surf.
Lab_Cal_ID	No	Text	255	Link to lab calibration sample ID. Precision and bias for TN, NO3, and PO4 in the results table will be populated based on the sample used for calibration.
Location_ID	No	Other	16	Link to tbl_Locations
Nutrient_Verified	No	Boolean	1	Whether the nutrient data has been verified. Added field in 2013.
Nutrient_Verified_by	No	Text	100	Person who verified accurate data transcription of the nutrient results. Added field in 2013.
Nutrient_Verified_date	No	Date/Time	8	Date on which nutrient data were verified. Added field in 2013.
QA_notes	No	Memo	0	Quality assurance comments for the selected sampling event
Start_Date	No	Date/Time	8	Starting date for the event
Start_Time	No	Date/Time	8	Starting time for the event
Start_Time_Zone	No	Text	4	Start Time Zone for Visit

Table B6 (coninued). "tbl_Events"—Sampling events.

Field Name	Primary?	Field Type	Field Size	Field Description
Update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
UserID	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system
Verified	No	Boolean	1	Whether the data has been verified (includes YSI data)
Verified_by	No	Text	100	Person who verified accurate data transcription (includes YSI data)
Verified_date	No	Date/Time	8	Date on which data were verified (includes YSI data)

Table B7. "tbl_Events_Pics" —User entered station visit picture links.

Field Name	Primary?	Field Type	Field Size	Field Description
Event_Pic_ID	Yes	Other	16	Unique record identifier
Base_Path	No	Text	255	The base file path for the linked text file. This will stay the same no matter where the root folder is.
Description	No	Memo	0	Description of the image
Event_ID	No	Other	16	Unique identifier for tbl_Events
File_Name	No	Text	255	File name of the linked image
File_Path	No	Text	255	File path of the linked image
Picture_Date	No	Date/Time	8	Date the image was taken

Table B7 (continued). "tbl_Events_Pics" —User entered station visit picture links.

Field Name	Primary?	Field Type	Field Size	Field Description
Root_Path	No	Text	255	The root path for the linked text file. This will change upon re-linking of database.
Update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
UserID	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system

Table B8. "tbl_Field_Procedures"—User entered field procedures. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field Size	Field Description
Field_ID	Yes	Other	16	Unique field procedure identifier
Citation	No	Text	50	Field procedure citation
D_Last_update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
D_UserID_code	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system
Description_text	No	Memo	0	Descriptive text that provides more information about the field sampling procedure
Field_gear_type	No	Text	25	Category of field gear used (e.g., Water Sampler, Net/Vertical Tow, Benthic Dredge, Benthic Corer, etc.)
ID_Code	No	Text	10	Short name or code for field sampling procedure - for NPSTORET
Name	No	Text	60	Full name of the sampling procedure

Table B9. "tbl_Gear_Configuration"—User entered gear configurations. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field Size	Field Description
Gear_ID	Yes	Other	16	Gear configuration unique identifier
D_Last_update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
D_UserID_code	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system
Description_Text	No	Memo	0	Specification/details about the tear configuration
Gear_Name	No	Text	50	The name of the gear for the configuration
Gear_Type	No	Text	50	The type of gear for the configuration
ID_Code	No	Text	10	Code identifying gear configuration within the organization - for NPSTORET
Model_Number	No	Text	50	The model number of the gear.
Name	No	Text	30	Name of the gear configuration

Table B10. "tbl_General_Standards"—General standards for water quality parameters.

Field Name	Primary?	Field Type	Field Size	Field Description
Standard_ID	Yes	Other	16	Unique identifier for the general standard.
Criteria	No	Double	8	The numeric criteria that a parameter cannot exceed.
Parameter	No	Text	255	The parameter the criteria is for.
Season	No	Text	255	Which season, if any, the standard applies to.
Standard_type	No	Text	255	Which type of standard the criteria is for, marine or freshwater.

Table B10 (continued). "tbl_General_Standards"—General standards for water quality parameters.

Field Name	Primary?	Field Type	Field Size	Field Description
State	No	Text	255	Which state the general standard is for
Threshold	No	Text	255	The type of threshold the criteria is for, whether this is the lowest value it cannot exceed, or the highest.

Table B11. "tbl_Lab_Calibration"—Quality assurance/quality check lab sample calibration data for a sampling event.

Field Name	Primary?	Field Type	Field Size	Field Description
Lab_Cal_ID	Yes	Other	16	An identifier for the event group
Analytical_ID	No	Other	16	Link to tbl_Analytical_Procedures
Comments	No	Memo	0	Comments about blank or standard
Field_ID	No	Other	16	Link to tbl_Field_Procedures
Lab_ID	No	Other	16	Link to tbl_Labs
Lab_Sample_ID	No	Other	16	Link to tbl_Lab_Sample_Prep
NO3_Bias	No	Other	16	NO3 bias provided by lab
NO3_Precision	No	Other	16	NO3 precision provided by lab
Preserve_ID	No	Other	16	Link to tbl_PreserverTransportStore
QA_Sample_Name	No	Text	255	Lab sample ID; four letter park code and lab sample processing date
Sampling_Event_Date	No	Date/Time	8	Sampling event date on which the sample was taken
TN_Bias	No	Other	16	Total nitrogen bias provided by lab

Table B11 (continued). "tbl_Lab_Calibration"—Quality assurance/quality check lab sample calibration data for a sampling event.

Field Name	Primary?	Field Type	Field Size	Field Description
TN_Precision	No	Other	16	Total nitrogen precision provided by lab
TP_Bias	No	Other	16	TP bias provided by lab
TP_precision	No	Other	16	TP precision provided by lab

Table B12. "tbl_Lab_Calibration_Values"—Lab sample calibration values for a quality assurance/quality check lab sample.

Field Name	Primary?	Field Type	Field Size	Field Description
Expected	No	Double	8	The expected value of the sample, i.e., distilled water values are 0.
Lab_Cal_ID	No	Other	16	Link to tbl_Lab_Calibration
Measured	No	Double	8	The measured value that the lab came up with.
Parameter	No	Text	10	The parameter that is being calibrated, i.e., NO3, PO4, or TN.
Sample_ID	No	Text	50	The sample ID for the blank or standard
Sample_Type	No	Text	15	The sample type, i.e., Original, Duplicate, or Spike

Table B13. "tbl_Lab_QC"—Laboratory quality control values.

Field Name	Primary?	Field Type	Field Size	Field Description
Lab_QC_ID	Yes	Text	50	Unique identifier for lab QC records
Expected_Value	No	Other	16	The expected value for the parameter being tested

Table B13 (continued). "tbl_Lab_QC"—Laboratory quality control values.

Field Name	Primary?	Field Type	Field Size	Field Description
Measured_Value	No	Other	16	The actual measured value for the parameter being tested
Parameter	No	Text	15	The parameter tested in the sample
Sample_Date	No	Date/Time	8	Date the sample was taken
Sample_ID	No	Text	25	The sample ID code
Sample_Type	No	Text	15	The sample type, i.e., Original, Duplicate, or Spike
Spike_Conc	No	Other	16	No description

Table B14. "tbl_Lab_Sample_Prep"—User entered lab sample preparation procedures. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field Size	Field Description
Lab_Sample_ID	Yes	Other	16	Lab sample preparation procedure unique identifier
D_Last_update_TS	No	Date/Time	8	Date/Time of Last Update - automatically stamp today's date/time in before update event
D_UserID_code	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system
Description_Text	No	Memo	0	Lab sample preparation procedure description text
ID_Code	No	Text	15	Abbreviated name or identifying code for the lab sample preparation procedure - for NPSTORET
Name	No	Text	120	Full title for the lab sample preparation procedure

Table B15. "tbl_Labs"—User entered labs. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field Size	Field Description
Lab_ID	Yes	Other	16	Laboratory unique identifier
Address_ID	No	Other	16	Link to tlu_Addresses
City	No	Text	50	City of the lab
Comments	No	Text	50	Any comments about the lab
D_Last_update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
D_UserID_Code	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system
Electronic_address	No	Text	50	Email address of the lab
ID_Code	No	Text	8	Lab ID Code - for NPSTORET
Name	No	Text	60	Lab Name
State	No	Text	2	State of the lab
Street_Address	No	Text	50	Street address of the lab
Zip_code	No	Text	5	Zip code of lab

Table B16. "tbl_Locations"—Sampling unit locations.

Field Name	Primary?	Field Type	Field Size	Field Description
Location_ID	Yes	Other	16	Location identifier
Accuracy_Notes	No	Text	255	Positional accuracy notes
Colocation	No	Text	25	Is this a station that is colocated with another protocol? If so, which protocol?

Table B16 (continued). "tbl_Locations"—Sampling unit locations.

Field Name	Primary?	Field Type	Field Size	Field Description
County	No	Text	25	Name of Station's primary County reported in all capitol letters
Decimal Degrees Latitude	No	Double	8	Decimal Degrees Latitude
Decimal Degrees Longitude	No	Double	8	Decimal Degrees Longitude
Depth Units	No	Text	2	Depth units of measure (cm, m, mi, km, in, ft)
Distance_Shore	No	Other	16	Anchialine pool distance from the shore in meters.
Elev_Datum	No	Text	50	Elevational datum
Elev_Method	No	Text	50	Elevational method
Elevation	No	Double	8	Station's elevation (XXXXX.XXX)
Elevation Date	No	Date/Time	8	Date elevation was determined
Elevation Units	No	Text	2	Elevation units of measure (ft or m). Required if Elevation is given
Est_H_Error	No	Single	4	Estimated horizontal accuracy
Establishment Date	No	Date/Time	8	Date on which Station was established (MM-DD-YYYY)
Geo_Datum	No	Text	50	Datum of mapping ellipsoid
Geo_Method	No	Text	50	Geospatial method
HUC	No	Text	8	Station's 8-digit Hydrologic Unit Code
Latitude Direction	No	Text	5	Latitude direction. Defaults to N
Loc_discontinued	No	Date/Time	8	Date the station was discontinued, or no longer used for sampling

Table B16 (continued). "tbl_Locations"—Sampling unit locations.

Field Name	Primary?	Field Type	Field Size	Field Description
Loc_Name	No	Text	25	If collocated with the anchialine pool protocol, the anchialine pool name. If collocated with the stream protocol, the stream name.
Loc_Notes	No	Memo	0	MA. General notes on the location (Loc_Notes); Information specific to the station
Loc_Type	No	Text	25	Station's primary classification; freshwater, marine, anchialine, or groundwater
Longitude Direction	No	Text	4	Longitude direction. Defaults to W
NHD Reach ID	No	Text	14	NHD 14-digit Reach ID
NPSTORET_Station_ID	No	Text	255	The Station ID in the format required by NPSTORET
NRCS Watershed ID	No	Text	12	Valid NRCS Watershed ID for Station
OceanName	No	Text	14	Ocean Name for Ocean Stations (Atlantic Ocean, Pacific Ocean, Arctic Ocean, Caribbean Sea, Gulf of Mexico)
OceanShoreRelation	No	Text	10	Ocean station's shore relation: Near Shore or Far Shore
Plume	No	Boolean	1	Sampling sites are south of FKAHO11_mr, used for analysis that is related to a continuous nutrient plume near the harbor mouth.
Pool_Group	No	Text	255	Pool's identified group based on location
Primary_Type	No	Text	50	Station's primary classification
Samp_Frame	No	Text	25	The number of times per year the site is sampled.

Table B16 (continued). "tbl_Locations"—Sampling unit locations.

Field Name	Primary?	Field Type	Field Size	Field Description
Secondary_Type	No	Text	30	Station's secondary type classification. Required if Primary Type = Canal, Facility, or Wetland
Site_ID	No	Other	16	Link to tbl_Sites
State	No	Text	2	Two-digit postal abbreviation of Station's primary State
Station_ID	No	Text	30	Unique station identifier
Station_Name	No	Text	100	Name of the station
Station_Type	No	Text	15	Station type, fixed or temporary
Stream_Mouth	No	Other	16	The distance from the Station to the mouth of the stream in meters.
Stream_Trib	No	Other	16	For HALE only, the distance along the watercourse section until it merged with the larger watercourse, i.e., Piiwai and Upper Palikea into Lower Palikea.
Travel Directions	No	Memo	0	Travel directions (by route, track, path, waterway, etc.) to reach the station
Unit_Code	No	Text	12	Park, Monument or Network code
Update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
UserID	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system
Water Depth	No	Double	8	Typical Depth of Water at sampling location

Table B17. "tbl_Locations_Pics"—User entered station picture links.

Field Name	Primary?	Field Type	Field Size	Field Description
Location_Pic_ID	Yes	Other	16	Unique record identifier
Base_Path	No	Text	255	The base file path for the linked text file. This will stay the same no matter where the root folder is.
Description	No	Memo	0	Description of the image
File_Name	No	Text	255	File name of linked image
File_Path	No	Text	255	File path of linked image
Location_ID	No	Other	16	Unique identifier for tbl_Locations
Picture_Date	No	Date/Time	8	Date the image was taken
Root_Path	No	Text	255	The root path for the linked text file. This will change upon re-linking of database.
Update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
UserID	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system

Table B18. "tbl_PreserveTransportStore"—User entered preservation, transport, and storage procedures. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field Size	Field Description
Preserve_ID	Yes	Other	16	Preserve, transport, and storage unique identifier
Container_color	No	Text	10	Color of container used to collect and transport the sample

Table B18 (continued). "tbl_PreserveTransportStore"—User entered preservation, transport, and storage procedures. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field Size	Field Description
Container_size_msr	No	Single	4	Size of container used to collect and transport the sample
Container_size_un	No	Text	3	Units of container size
Container_type_nm	No	Text	32	Type of container used to collect and transport the sample
D_Last_update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
D_UserID_code	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system
ID_Code	No	Text	10	Short name or code for sample preservation, transport, and storage procedure - for NPSTORET
Name	No	Text	30	Full name of the sample preservation, transport, and storage procedure
Presrv_strge_prcdr	No	Memo	0	Chemical preservation and storage procedure description
Temp_presrv_type	No	Text	25	Name of the type of physical preservation

Table B19. "tbl_QA_Results"

Field Name	Primary?	Field Type	Field Size	Field Description
Data_scope	No	Byte	1	No description
Is_done	No	Boolean	1	No description
QA_user	No	Text	100	No description

Table B19 (continued). "tbl_QA_Results"

Field Name	Primary?	Field Type	Field Size	Field Description
Query_description	No	Memo	0	No description
Query_expression	No	Memo	0	No description
Query_name	No	Text	100	No description
Query_result	No	Text	50	No description
Query_run_time	No	Date/Time	8	No description
Query_type	No	Text	20	No description
Remedy_date	No	Date/Time	8	No description
Remedy_desc	No	Memo	0	No description
Time_frame	No	Text	30	No description

Table B20. "tbl_QAQC"—Quality assurance and quality control methods.

Field Name	Primary?	Field Type	Field Size	Field Description
QAQC_ID	Yes	Other	16	Unique record identifier
Methods	No	Memo	0	Quality assurance and quality control methods.

Table B21. "tbl_Results"—Water quality and sonde results.

Field Name	Primary?	Field Type	Field Size	Field Description
Activity_ID	No	Other	16	No description
Bias	No	Text	12	A consistent deviation of measured values from the true value, caused by systematic errors in a procedure, as determined by applying identical procedures to a specimen of known properties.
Bias_Corrected	No	Text	1	A code (Y/N) indicating whether the confidence level has been corrected for Bias.
Char_ID	No	Other	16	No description
Data_Flag	No	Text	5	No description
Detection_Condition	No	Text	23	Result Detection Condition from STORET (Detected and Quantified, *Non-detect, *Present, *Present >QL, *Present <QL, *Not Reported)
Detection_Limit	No	Double	8	Represents the least amount of the target substance which could be detected by the instrument/analytical process employed to determine the result. Above this value the target substance is presumed to be present.
Filter	No	Text	25	For nutrient data, what type of filter was used if any.
Lower_Quant_Limit	No	Double	8	Represents the least amount of the target substance which could be quantified by the instrument/analytical process employed to determine the result. Values above the minimum and below the maximum quantitation limits are reported as valid numeric results.
Precision	No	Text	12	Estimate of the maximum possible error in the result. (e.g., Counting error in determining radiological beta particle counts.)

Table B21 (continued). "tbl_Results"—Water quality and sonde results.

Field Name	Primary?	Field Type	Field Size	Field Description
QA_Flag	No	Boolean	1	Checked if the data is flagged during QA/QC. Data should not be used for analysis.
Repl_Analysis_Num	No	Double	8	Number of replicate analyses conducted to determine the result value.
Replicate_ID	No	Text	5	For nutrient data, what is the replicate ID.
Result	No	Other	16	Result Value
Result_Comments	No	Memo	0	Result Comment or Description
Results_ID	No	Other	16	No description
Separation	No	Text	25	For nutrient data, what kind of separation method was used.
Update_TS	No	Date/Time	8	No description
Upper_Quant_Limit	No	Double	8	Represents the largest amount of the target substance which could be quantified by the instrument/analytical process employed to determine the result. Values > Min and < Max quantification limits are assumed valid values.
UserID	No	Text	100	No description
Value_Status	No	Text	1	Value Status (F=Final, P=Preliminary, etc.)
Value_Type	No	Text	10	Result Value Type (Actual, Estimated, Calculated, etc.)
Variance	No	Other	16	No description

Table B22. "tbl_Serial_Numbers"—Associated serial numbers for gear that is entered in tbl_Gear_Configurations.

Field Name	Primary?	Field Type	Field Size	Field Description
Serial_Number	Yes	Text	255	The serial number of the instrument
Gear_ID	No	Other	16	Link to tbl_Gear_Configurations

Table B23. "tbl_Sites"—Location aggregations.

Field Name	Primary?	Field Type	Field Size	Field Description
Site_ID	Yes	Other	16	Site identifier
GIS_Location_ID	No	Other	16	Link to GIS feature, equivalent to NPS_Location_ID
Park_Desc	No	Text	255	Description for a site
Park_Name	No	Text	100	Unique name or code for a site
Park_Notes	No	Memo	0	General notes on the site
Unit_Code	No	Text	4	Park, Monument or Network code
Update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
UserID	No	Text	100	Who last updated the record - automatically filled in by whoever logged on the system

Table B24. "tlu_ActivityTypes"—List of Activity Types from WQX STORET including translation from Modern STORET.

Field Name	Primary?	Field Type	Field Size	Field Description
ACTYP_UID	Yes	Long Integer	4	No description
ACTYP_CD	No	Text	70	No description
ACTYP_DESC	No	Text	255	No description
ModSTORETActivity	No	Text	70	No description
SortOrder	No	Long Integer	4	No description

Table B25. "tlu_Addresses"—Look up table of addresses. Linked to contacts in tlu_Contacts.

Field Name	Primary?	Field Type	Field Size	Field Description
Address_ID	Yes	Other	16	Unique record identifier
Address	No	Text	50	Street address
Address_created	No	Date/Time	8	Date the record was created
Address_notes	No	Memo	0	Any additional notes about the address
Address_updated	No	Date/Time	8	Date of last update to record
City	No	Text	50	City or town
Country	No	Text	50	Country
Location	No	Text	50	Location of organization
Organization	No	Text	50	Organization name
Postal_code	No	Text	50	Zip code (postal)
State_code	No	Text	50	State or Province

Table B26. "tlu_Characteristics" —User entered characteristic definitions (parameters that are measured).

Field Name	Primary?	Field Type	Field Size	Field Description
Char_ID	Yes	Other	16	Unique record identifier
Analytical_ID	No	Other	16	Link to analytical procedure
Char_Description	No	Memo	0	Describe or define more completely the characteristic definition
Char_Type	No	Text	50	What is the data type of the associated characteristic
Comp_Ind_CD	No	Text	1	Has the characteristic has been adequately defined (minimally required fields entered) for data entry
Det_Quant_Description	No	Text	255	Describe the meaning of the detection and/or quantification limits
Detection_Limit	No	Double	8	Least amount of the target substance that could be detected by the instrument or analytical process that was used to determine the result. Above this value, the target substance is presumed to be present.
Display_Name	No	Text	60	Official EPA Characteristic Display Name
Dur_Basis_Type	No	Text	10	Time period over which a measurement was made
Field_ID	No	Other	16	Link to field sampling procedure
Field_Lab	No	Text	13	Where was the characteristic was measured
Gear_ID	No	Other	16	Link to gear configuration procedures
Handling_Proc	No	Other	16	Link to transport, preserve and storage procedures
lab_id	No	Other	16	Look up to the Laboratory that processed the water sample

Table B26 (continued). "tlu_Characteristics" —User entered characteristic definitions (parameters that are measured).

Field Name	Primary?	Field Type	Field Size	Field Description
Lab_Sample_ID	No	Other	16	Link to lab sample preparation procedure
LocCharNameCode	No	Text	60	Organization's Local Name for the Characteristic Definition
Lower_Quantity_Limit	No	Double	8	Lower Quantification Limit (often referred to as the Practical Quantitation Limit - PQL) represents the smallest amount of the target substance or characteristic that could be quantified by the instrument or analytical process.
Medium	No	Text	50	Medium in which the characteristic is measured
Sample_Fraction	No	Text	50	No description
Sequence_Number	No	Single	4	Sequence number used for ordering characteristics on the results form. Characteristics are ordered in ascending order by sequence number.
ShowFilteredUnits	No	Boolean	1	Flag for whether to display all possible STORET units or filter the units based on the characteristic
Statistic_Type	No	Text	18	What type of statistic is the reported result value
Temp_Basis	No	Text	8	What is the controlled temperature at which the sample was maintained during analysis
Unit_ID	No	Other	16	Unit of Measure unique identifier
Update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event

Table B26 (continued). "tlu_Characteristics" —User entered characteristic definitions (parameters that are measured).

Field Name	Primary?	Field Type	Field Size	Field Description
Upper_Quantity_Limit	No	Double	8	Largest amount of the target substance that could be quantified by the instrument or analytical process. Values above the lower and below the upper quantification limits are reported as valid numeric results in STORET.
UserID	No	Text	8	Who last updated the record - automatically filled in by whoever logged on the system
Value_Type	No	Text	10	What type of value is the reported result
Wt_Basis_Type	No	Text	12	What is the form of the sample (or portion of the sample) that is associated with the result value

Table B27. "tlu_Contacts"—Look up table of contacts associated with the protocol.

Field Name	Primary?	Field Type	Field Size	Field Description
Contact_ID	Yes	Text	50	Unique record identifier consisting of the last name, underscore, and first name of contact.
Contact_created	No	Text	50	Date the contact record was created
Contact_is_active	No	Boolean	1	Is the contact currently associated with the protocol
Contact_location	No	Text	255	Contact's work locations
Contact_notes	No	Memo	0	Notes about contact
Contact_updated	No	Date/Time	8	Date the contact record was updated
Email	No	Text	50	The email address of contact
Fax	No	Text	25	Fax number

Table B27 (continued). "tlu_Contacts"—Look up table of contacts associated with the protocol.

Field Name	Primary?	Field Type	Field Size	Field Description
First_name	No	Text	20	First name of contact
Home_voice	No	Text	25	Home phone number
Last_name	No	Text	24	Last name of contact
Middle_init	No	Text	1	Middle initial of contact
Mobile_voice	No	Text	25	Mobile phone number
Organization	No	Text	50	The organization the contact is associated with
Position_title	No	Text	50	Position title of contact
Work_voice	No	Text	25	Work phone number

Table B28. "tlu_Geospatial"—Abbreviated geospatial table from STORET 10/10/2006 (Methods and Datums).

Field Name	Primary?	Field Type	Field Size	Field Description
Category	No	Text	10	Geospatial category: Vertical or Horizontal
Description	No	Text	255	Description of the Geospatial method or datum
Subcategory	No	Text	6	Geospatial subcategory: Method or Datum

Table B29. "tlu_Permitted_Values"—Non-STORET table containing permitted values for some of the STORET input fields in NPSTORET.

Field Name	Primary?	Field Type	Field Size	Field Description
Field_Name	No	Text	50	Name of the field for permitted values
Field_Value	No	Text	50	Permitted values for designated field
Sort_Order	No	Integer	2	Sort order

Table B30. "tlu_Primary_Type"—Look up table for water body types. Abbreviated version of NPSTORET table.

Field Name	Primary?	Field Type	Field Size	Field Description
Primary_Type	No	Text	50	Water body type

Table B31. "tlu_Sample_Type"—Look up table for sample type. Abbreviated version of NPSTORET table.

Field Name	Primary?	Field Type	Field Size	Field Description
Sample_Type	No	Text	50	Water quality sample type
Sort_Order	No	Long Integer	4	Sort order

Table B32. "tlu_Unit_of_Measurement"—Look up table of units of measure from STORET 10/10/2006 (Units of Measure—Added and populated 'DISPLAY_NAME' field).

Field Name	Primary?	Field Type	Field Size	Field Description
Description_Text	No	Text	50	Description of unit of measure
Display_Name	No	Text	10	Display name
Short_Form_Name	No	Text	10	Abbreviated unit of measure
Unit_ID	No	Other	16	Unique record identifier
UOM_Type	No	Text	5	Unit of measure type

Table B33. "tlu_Wind"—Look up table for the wind codes based on the Beaufort Scale.

Field Name	Primary?	Field Type	Field Size	Field Description
Value	Yes	Double	8	Numeric value for wind speed
Description	No	Text	100	Definition of wind speed

Table B34. "xref_Activity_QAQC"—Cross-reference table between activities and quality assurance and quality control.

Field Name	Primary?	Field Type	Field Size	Field Description
Activity_ID	No	Other	16	M. Link to tbl_Activity
QAQC_ID	No	Other	16	M. Link to tbl_QAQC

Table B35. "xref_Contact_Address"—Cross-reference table between contacts and addresses.

Field Name	Primary?	Field Type	Field Size	Field Description
Address_ID	No	Other	16	Link to tlu_Address
Address_type	No	Text	50	Address type: physical address, mailing address, or mailing and physical address
Contact_address_notes	No	Text	250	Contact address notes
Contact_ID	No	Text	50	Link to tlu_Contacts

Table B36. "xref_Event_Contacts"—Cross-reference table between events and contacts.

Field Name	Primary?	Field Type	Field Size	Field Description
Contact_ID	No	Text	50	Link to tlu_Contacts
Contact_Role	No	Text	50	The contact's role in the protocol
Event_ID	No	Other	16	Link to tbl_Events

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 963/190231, September 2013

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

EXPERIENCE YOUR AMERICA™