DEPARTMENT OF ECOLOGY
State of Washington

Quality Assurance Monitoring Plan

Marine Waters Long-Term Monitoring, Water Column Program, 2025

March 2025

Publication 25-03-101

Publication Information

Each study conducted by the Washington State Department of Ecology (Ecology) must have an approved Quality Assurance Monitoring Plan (QAMP). The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completing the study, Ecology will post the final report of the study to the Internet.

This QAMP was approved to begin work in January 2025. It was finalized and approved for publication in March 2025.

The final QAMP is available on Ecology's website at https://apps.ecology.wa.gov/publications/SummaryPages/2503101.html.

Suggested Citation
Pool, S. S., C. Krembs, and A. Fisher. 2025. Quality Assurance Monitoring Plan: Marine Waters Long-Term Monitoring, Water Column Program. Publication 25-03-101. Washington State Department of Ecology, Olympia.
https://apps.ecology.wa.gov/publications/SummaryPages/2503101.html.

Data for this project are available in Ecology's EIM Database.[1] Search Study ID: MarineWater.

The Activity Tracker Code for this study is 01-800.

Federal Clean Water Act 1996 303(d) Listings Addressed in this Study. See Section 3.3.

Contact Information

Environmental Assessment Program Publications Coordinator
Washington State Department of Ecology
P.O. Box 47600, Olympia, WA 98504-7600
Phone: 360 407-6764

Washington State Department of Ecology: https://ecology.wa.gov

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Shoreline 206-594-0000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Union Gap 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

COVER PHOTO: Marine water profiling instruments on board the research vessel *Zoea,* owned by Western Washington University, Shannon Point Marine Center. PHOTO BY CHRISTOPHER JENDREY.

[1] https://www.ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database

Quality Assurance Monitoring Plan

Marine Waters Monitoring Long-Term, Water Column Program

By S.S. Pool, C. Krembs, and A. Fisher

Published March 2025

Approved by:

Signature:	Date:
Suzan Pool, Author, Marine Monitoring Scientist, MMU, EAP	

Signature:	Date:
Alex Fisher, Author, Senior Physical Oceanographer, MMU, EAP	

Signature:	Date:
Christopher Krembs, Author, Senior Oceanographer, MMU, EAP	

Signature:	Date:
Natalie Coleman, Author's Acting Unit Supervisor, MMU, EAP	

Signature:	Date:
Julianne Ruffner, Author's Acting Section Manager, WOS, EAP	

Signature:	Date:
Robert Waldrop, Director, Manchester Environmental Laboratory	

Signature:	Date:
Christina Frans, Acting Ecology Quality Assurance Officer	

Signatures are not available on the Internet version.
EAP: Environmental Assessment Program
MMU: Marine Monitoring Unit
WOS: Western Operations Section

1.0 Table of Contents

List of Figures

List of Tables

2.0 Abstract

The Washington State Department of Ecology (Ecology) conducts several statewide monitoring programs including marine water, marine sediment, and freshwater monitoring. The Marine Waters Monitoring (MWM) program was initiated in 1967 to monitor Puget Sound and two coastal estuaries. Since then, long-term monthly water quality data have been collected at more than 86 stations. Fundamental to environmental monitoring is a strategic, well-planned, representative approach for Washington's marine waters that allows for understanding distinction between natural and human influences on marine water quality. This approach is based on high station redundancy, appropriate temporal and spatial resolution, and adequate selection of measured variables. It requires a quantitative understanding of processes acting upon water quality, from human influences to physical, biogeochemical, and ecological processes extending to oceanic and climatic boundary conditions.

The Quality Assurance Monitoring Plan (QAMP) describes Ecology's MWM program for marine water column profiles. The sampling program covers U.S. waters of the Salish Sea, including Puget Sound and the Strait of Juan de Fuca, as well as coastal bays of Grays Harbor and Willapa Bay. The plan includes a full description of the monitoring program's goals and objectives, strategies, field and laboratory procedures, data management, quality assurance and quality control, and safety guidelines. The other components of Ecology's marine monitoring program, such as ferry-based monitoring, are described in separate QAMPs. There is also an original Quality Assurance Project Plan (QAPP) for an ocean acidification study that began in fall 2018 after a pilot study was conducted in 2014 to 2015. Since then, funding has been secured and ocean acidification sampling is now part of the long-term MWM program described within this QAMP.

3.0 Background

3.1 Introduction and problem statement

Washington State Department of Ecology monitors Washington's marine water bodies in support of the federal Clean Water Act. Monitoring occurs on a regular, long-term basis to assess marine water quality. The long-term marine water monitoring program began in 1967 and initially focused on Puget Sound, Grays Harbor, and Willapa Bay surface waters and regions that were accessible with available resources, sampling equipment, and staff capabilities.

Many initial sampling stations were located near municipal and industrial discharges to measure effectiveness of agency regulatory programs. In the following decades, the MWM program implemented changes to meet growing information needs. For example, municipal and industrial discharges of oxygen-consuming wastes declined due to Ecology regulation. So, Ecology shifted its emphasis to non-point source pollution.

This shift resulted in a modified monitoring strategy and consequently, many sampling stations were moved to mid-channel or bay locations or adjusted to be collocated with preexisting stations occupied during the historical University of Washington (UW) surveys (Janzen 1992).

Additional changes gradually were incorporated as advances in sampling and sensor technologies and procedures evolved.

The MWM program worked in concert with various other efforts that contributed significantly to documenting the decline and variability in water quality in Puget Sound and Washington's coastal bays. The program expanded to sampling full water column data in 2002. The station network expanded into the Strait of Juan de Fuca in 2013. Complementary to long-term monitoring, the program also at times supported moorings in strategically important locations (discontinued due to funding). More recently, the MWM program maintains an underway ferry-based monitoring program to fill a strategic gap of water surface variability that the long-term monitoring program cannot achieve.

The focus of water column monitoring is centered primarily on quantitatively describing the status and trends of ambient water quality in context of the estuarine physical processes. Therefore, sampling occurs at representative and strategically suitable long-term monitoring stations that are visited monthly. Critical to this mission is the collection of consistent, credible, and quantitatively repetitive data over suitable scales of space and time. These data are made freely available to the public and support regional and statewide agency decision-making as well as scientific research and education.

3.2 Study area and surroundings

The MWM program study area spans three estuaries within the state: U.S. waters within the Salish Sea, Grays Harbor, and Willapa Bay. The Salish Sea is a large fjord-type estuarine ecosystem that spans territorial waters within Canada and the U.S. It extends from the northern reaches of the Strait of Georgia to the southern reaches of Puget Sound and west to the mouth of the Strait of Juan de Fuca where it connects with the Pacific Ocean (Figure 1; Freelan 2023). Puget Sound, the San Juan Islands, Bellingham Bay, and portions of the Strait of Juan de Fuca lie within the U.S. portion of the Salish Sea. Grays Harbor and Willapa Bay are two large coastal plain estuaries on the Pacific Coast of Washington State (Figure 2). Both the Salish Sea and coastal bays are influenced by a productive upwelling system situated off the coast of North America and are sensitive to hydrologic changes that occur on land.

Currently, Ecology's MWM program does not monitor nearshore and offshore waters along the Pacific Coast.

Puget Sound

Puget Sound is an ecologically and economically important and stratified, deep fjord that forms the southern branch of the Salish Sea. It is bounded by three major mountain ranges: 1) Olympic Mountains to the west, 2) Vancouver Island Ranges to the north, and 3) Cascade Range to the east. In addition, Puget Sound contains several large islands including the San Juan Islands, Whidbey Island, and Vashon Island. Puget Sound covers an area of 2,632 km^2, a volume of 168 km^3, 2,141 km of shoreline, and 303 km^2 of tideland (Burns 1985). The complex geomorphology of Puget Sound, and to a larger extent, the Salish Sea includes a variety of waterways with interconnected shallow estuaries and bays, deep glacially scoured basins and fjords, broad channels, and river deltas. Several major rivers provide seasonally varying freshwater, sediment, and nutrient inputs to Puget Sound including the Fraser, Skagit, Stillaguamish, Snohomish, Cedar, Duwamish, Puyallup, Nisqually, and Skokomish Rivers (Figure 2).

Puget Sound is bordered by both relatively undeveloped rural areas and highly developed urban and industrial regions. Developed land comprises approximately 17% of the watershed tributary to U.S. waters of the Salish Sea. It represents a combination of residential, commercial/urban, and agricultural lands or alpine areas (Herrera Environmental Consultants, Inc. 2011). Major urban centers include the cities of Bellingham, Everett, Seattle, Bremerton, Tacoma, and Olympia. These cities are predominantly situated near the mouths of large river systems and several large ports. Overall, 7 million people live within the drainage basin of the Salish Sea.

Hydrodynamic connectivity and water exchange within the Salish Sea is influenced by processes occurring on global to local scales that include climate variability (e.g., El Niño-Southern Oscillation), regional wind patterns, tides, and river discharge. Water exchange with the Pacific Ocean primarily occurs through estuarine circulation via the Strait of Juan de Fuca. Glacial sills act as constrictions to water exchange between subbasins. The sills contribute to both natural and human influenced patterns of diminished water quality by modulating material exchange within the estuary. Specifically, physical processes that occur within Admiralty Inlet, the Tacoma Narrows, northern reaches of Hood Canal, and Deception Pass play important roles in controlling water renewal within Puget Sound.

The majority of MWM program’s stations are within the major subbasins of Puget Sound (Central Basin, South Sound, Whidbey Basin, Hood Canal, and Admiralty Reach) with additional northern stations in the San Juan Islands, eastern Strait of Juan de Fuca, and Bellingham Bay (Figure 2). The study area extends about 214 km from Olympia to the Canadian Border and ranges from 10 to 40 km wide (Kennish 1998).

Grays Harbor

The Grays Harbor study area spans the tidal reaches of the Chehalis River near Aberdeen to the estuary mouth. The bay has a surface area of 150 km^2 and was formed when sea levels flooded the Chehalis River valley at the end of the last ice age which influenced its overall morphology. Grays Harbor is a shallow coastal-plain estuary, with a mean depth of 4.3 m (NOAA 1985). It has expansive sand and mud flats that are connected by a myriad of tidal channels (Hickey and Banas 2003).

The largest river flowing into the bay is the Chehalis River at the eastern end providing 80% of freshwater input to Grays Harbor. Other rivers and streams include the Hoquiam River which flows into the northern inner harbor and the Humptulips River which flows into the northern outer harbor. The mouth of the bay is 3 km wide and situated between two low peninsulas formed by ocean-built bars. Aberdeen, Hoquiam, Ocean City, and Westport are cities and towns located on or near the harbor. The watershed surrounding the bay is composed primarily of forests, interspersed with agricultural lands and residential/developed areas. Significant industries in the watershed are forestry, paper and pulp production, and sport, tribal, and commercial fisheries.

Willapa Bay

The Willapa Bay study area includes the lower part of the Willapa River at Raymond to the southern reaches near Long Island. Geologically, Willapa Bay is a submersed river valley, formed by sea level rise at the end of the last ice age and partially enclosed by the ocean-built bar of Long Beach Peninsula. The mean depth of Willapa Bay is 3.2 m and 50% of the bay is intertidal, exposing mud and sand flats. Multiple-connected channels 10 to 20 m deep compose the dominant geomorphology of the bay (Banas and Hickey 2005).

Freshwater river inputs to Willapa Bay stem primarily from the Willapa River at the northeastern corner and the Naselle River which flows into the southern part of the bay. Several lesser rivers and streams also flow into the bay. The bay is separated from the ocean by an extensive 45 km sand bar, the Long Beach Peninsula. Raymond, South Bend and Tokeland are towns situated on or close to Willapa Bay. The principal land uses of the watershed around Willapa Bay are forest, agriculture, wetlands and residential/developed lands, with forestry being the primary industry. Most of Willapa Bay is used for shellfish production.

Figure 1. Map of the Salish Sea and surrounding basin in U.S. and Canada. (Courtesy of Stefan Freelan 2023, https://www.stefanfreelan.com/salishsea).

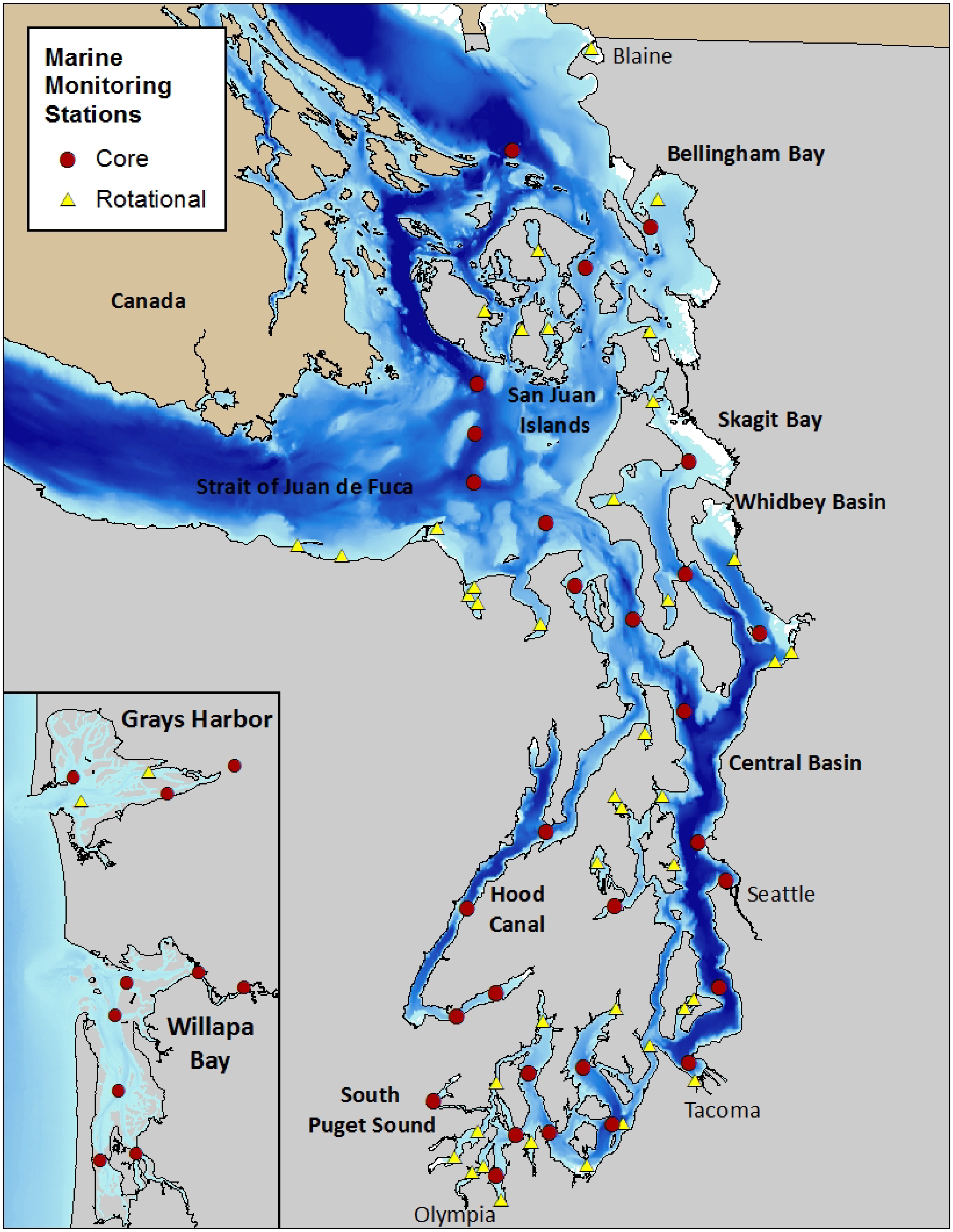

Figure 2. Map of core and rotational stations in Puget Sound, Grays Harbor, and Willapa Bay. Core stations are sampled monthly every year. Rotational stations are sampled on an as-needed basis.

3.2.1 History of study area

A thorough history of the study area, in terms of marine water monitoring, is described in a previous QAMP published in 2015 (Bos et al. 2015).

3.2.2 Summary of previous studies and existing data

A thorough history of previous studies is well documented in the QAMP published in 2015 (Bos et al. 2015). It describes the early studies in Puget Sound since it began in 1932 and the evolution to the current monitoring program. It also discusses oceanographic surveys along Washington state's Pacific Coast.

The MWM program is structured as a layered approach that integrates information over large spatial and temporal scales. This structure aids in separating regional human effects from large scale climate-driven variability. The program design therefore allows for the interpretation and communication of marine water quality within a broader context of oceanic and climatic influences. The integrated approach necessitated ongoing collaborations and coordination with federal, state, academic, and regional monitoring programs.

The program expanded from collecting monthly water column samples and profiles to include en route ferry observations and aerial documentation of surface water conditions in Puget Sound. Aerial documentation include algae blooms, river plumes, spills, and debris. This information is communicated several times a year as "Eyes Over Puget Sound" which receives 25,000 to 120,000 downloads per month on the Encyclopedia of Puget Sound[2] website.

The current focus of the MWM program is to understand core drivers of marine water conditions on water quality in Puget Sound and coastal bays. These drivers include climate, ocean boundary conditions, ecosystem resiliency, estuarine circulation (freshwater influence), and regional human nutrient enrichments. For the past three decades, Ecology has incorporated significant information from ocean, climate, and other local monitoring projects to interpret and provide increased context to marine monitoring results. A key emphasis is to differentiate between regional human impacts on water quality and large-scale consequences of climate variability on water renewal, nutrient availability and biochemical cycles including the drawdown of oxygen. Thus far, it appears that climate and ocean forces are dominant drivers of water quality in these estuaries (PSEMP 2012-2024).

Key findings have emerged over the years and are captured in peer-reviewed scientific journal publications and collaborative annual reports with the Puget Sound Ecosystem Monitoring Program (PSEMP) (Krembs 2012; PSEMP 2012-2024):

- River inputs, local winds, and Pacific Ocean water are important drivers of Puget Sound physical conditions (Newton et al. 2003; Moore et al. 2008), yet the frequency, duration, and extent of ocean water intrusions and accompanying transport processes in Puget Sound are not measured.

[2] https://www.eopugetsound.org/terms/411

- Dissolved oxygen is naturally low in upwelled Pacific Ocean water. Therefore, ocean water has naturally low dissolved oxygen when it enters Puget Sound. Under certain climate conditions, anthropogenic influences can be exacerbated through decreased circulation and water exchange. Dissolved oxygen levels can become critically low in some terminal inlets and basins such as Hood Canal and southern Puget Sound.
- Nitrogen and phosphate are seasonally and regionally variable and are influenced by many physical, biological, and human factors. Upwelled Pacific Ocean water is a major contributor of nitrate to Puget Sound while nutrients entering with freshwater and with wastewater treatment plants can be significant (Mohamedali et al. 2011). Mixing and dilution, and biological uptake additionally masks ambient nutrient concentrations. Jointly this confounds the interpretation the effects of wastewater, storm water run-off, and non-point sources. Changes in the nutrient balance and relative enrichment to a passive ocean tracer such as salt (Krembs 2012) are potentially more effective ways to understand human impacts on Puget Sound's nutrient conditions.
- Human and natural eutrophication processes can affect areas of Puget Sound and coastal bays. Reduced water circulation may amplify these effects in terminal inlets.

Marine monitoring programs are important for collecting and providing ongoing data streams for models and environmental assessments. Examples of model studies evaluated the relative contributions to low dissolved oxygen conditions in Puget Sound which were calibrated to data collected in the MWM program and focused projects (Ahmed et al. 2014; Roberts et al. 2014). The models generated the following conclusion:

> Current human sources decrease oxygen below natural conditions. Low oxygen has been measured in several portions of Puget Sound and reduced circulation may amplify these effects in closed basins.

In addition to supporting regional modeling efforts, MWM data has been used to develop data-driven indicators of ecosystem health. A vital sign of the monitoring results was developed to report regional status and trends in marine water quality in context of estuarine processes. This index, the Marine Waters Condition Index was implemented in 2012 as an indicator for the Puget Sound Partnership's dashboard indicators (Krembs 2012) and recently broken up into more specific communication tools.

Emerging concerns and understanding regarding threats to marine water quality in Washington prompt continued development of these tools to address additional topics. Concerns are multi-stressor effects (ocean acidification, marine heat waves, low dissolved oxygen, etc.) on water quality within Washington's coastal marine environment. These effects are not yet well understood, but recent expansions of monitoring efforts at Ecology and other regional programs are increasing coverage of these processes. Additional concerns relate to the sensitivity of other ecosystem components (food web, biogeochemistry, and nutrient cycling) to shifts in physical properties and boundary conditions that may result from climate change (Puget Sound Partnership 2024).

Results from Ecology's long-term MWM program are captured in multiple reports, presentations, journal articles, and conference proceedings. Water column profiles and associated discrete nutrient results are available in Network Common Data Form (netCDF) format on Ecology's Water column & sediment data[3] webpage.

Results from earlier studies such as the Eugene Collias and Research Vessel (R/V} *Barnes* surveys were converted from paper format to digital format by Skip Albertson. The Collias data set[4] is now available in Ecology's Environmental Information Management System (EIM) through the work of Melissa Peterson and Skip Albertson. Data not in EIM may be obtained by submitting a public records request at Ecology's Public Records Request Center[5]. Ecology does not have the ability to validate or verify the authenticity of these results.

3.2.3 Parameters of interest and potential sources

When the MWM program was implemented in 1967, primary contaminants of concern were industrial and municipal discharges of wastes that consumed oxygen in the water. Over time, management of industrial and municipal point-source wastes improved. Therefore, the monitoring strategy has shifted to understanding and quantifying multiple stressors to Washington's marine waters from a variety of sources. They include the Pacific Ocean, rivers, snowmelt, atmospheric, and urban and agricultural nutrient inputs. The evolving monitoring strategy also aimed at relating nutrient pollution, physical, and biogeochemical processes to impacts for the marine ecosystem.

Urbanization and population growth alter landscape use in the Salish Sea. These affect, for example, nutrient inputs from wastewater and agriculture, runoff from impervious surface, and river flows. Therefore, primary parameters of interest are those that relate to human activities, population growth, landscape change, and agency regulations. Status and trend monitoring of nutrients, turbidity, and specific pollutants indicate changes to biogeochemical processes in the marine environment. The processes include carbon cycling and organic material production that define the cornerstones of the marine food web. The MWM program does not target specific pollutants. Instead, the program monitors basic water quality properties and conventional nutrient pollutants that may indicate human or climate impacts. These are evaluated in the context of naturally varying marine water processes.

3.2.4 Regulatory criteria or standards

The U.S. Environmental Protection Agency's (EPA) administers the Clean Water Act. The regulation requires every state to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses for protection (such as aquatic life) and criteria, usually numeric, to achieve those uses. The Clean Water Act also requires that every state conducts assessments of surface water quality every

---

[3] https://ecology.wa.gov/research-data/monitoring-assessment/puget-sound-and-marine-monitoring/water-column-data

[4] https://apps.ecology.wa.gov/eim/search/Detail/Detail.aspx?DetailType=Study&SystemProjectId=99971885

[5] https://ecologywa.govqa.us/WEBAPP/_rs/(S(1n0mpnexw0s0dnltflgbj0r1))/supporthome.aspx

two years. The assessments are submitted to EPA in two reports: 303(d), a list of impaired water bodies, and 305(b), a report of the results of the entire assessment.

Ecology conducts routine assessments on the condition of surface waters every two years, rotating between marine and freshwater systems. Washington's Water Quality Assessment reports the water quality status for water bodies in the state and identifies waters that do not meet water quality standards. This assessment meets the federal requirements for an integrated report under Sections 303(d) and 305(b) of the Clean Water Act.

All marine waters in Puget Sound and the coastal bays fall under extraordinary, excellent, or good quality designated use categories. The water quality standards associated with the various designated use categories are found in the Washington Administrative Code (WAC), WAC 173-201A[6]. These standards include numeric values for temperature, dissolved oxygen, pH, ammonium, and fecal coliform bacteria. Numeric targets vary within marine waters of Washington, as described in WAC 173-201A-210[7].

Washington's water quality assessment is guided by Ecology's Water Quality Policy 1-11[8]. This policy is used to define best environmental assessment practices, numeric criteria, and categories for designating attainment or violation of water quality standards. Data submission to Washington's water quality assessment and data use falls under the credible data policy

Marine water column variables used for EPA's water quality assessment include temperature, dissolved oxygen, and ammonium (as a toxin). Previously, the marine monitoring program included fecal coliform bacteria and pH. Fecal coliform collections were discontinued in 2013 after years of very low or infrequent occurrences in ambient surface samples. In addition, the MWM program sampling design for bacteria became obsolete and the state's Department of Health (shellfish) and Beach Environmental Assessment, Communication, and Health (BEACH; (human health effects) monitoring programs conduct bacteria monitoring using better-quality, targeted protocols. The pH data were collected from profiling sensor measurements of the entire marine water column. However, pH electrode precision and accuracy were determined to be inadequate in favor of total alkalinity and dissolved inorganic carbon data. MWM implemented a new ocean acidification monitoring program in October 2018. The MWM program discontinued pH sensor measurements in 2021.

Data collected at all core and rotational stations sampled in the MWM program are submitted for every two-year Section 303(d) assessment cycle.

[6] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A
[7] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-210
[8] https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d/Assessment-policy-1-11

4.0 Project Description

Ecology's Marine Waters Monitoring (MWM) program uses a multi-pronged monitoring strategy. The program relies on a variety of physical, chemical, and bio-optical variables to describe seasonal and regional patterns in a suite of 8 continuous sensor and 9 discretely sampled variables of the water column. Over decades, long-term patterns and trends emerge in growing data sets that relate to estuarine physical processes, climate, marine eutrophication, and the base of the food web.

The MWM program conducts monthly sampling of the water column at 37 core stations, which provide a long-term record of marine water column conditions. The program uses consistent techniques to determine long-term trends in water quality relative to established station-specific monthly baselines. Station redundancy allows for sufficient statistical representativeness of monthly conditions in complex basins. A monthly temporal resolution of monitored stations gives a representative description of seasonality. Sensors measure water quality variables over the full extent of the water column and discrete samples are collected to assess nutrient concentrations and concentrations of the organic and inorganic carbonate system.

The monthly sampling occurs year-round because certain parameters, such as chlorophyll, nutrients, and dissolved oxygen, show peak values (or highest rates of change) during the summer, whereas others (nutrient concentrations) peak during the winter. Sampling is conducted during all 12 months to ensure that seasonality and regional variation are observed on sufficient scales to support time series data analysis (MMC 1988) and modeling studies.

Data from monthly water column monitoring provide the temporal backbone of Ecology's MWM program. Its strength is the unprecedented large scale with the station network covering the U.S. portion of the Salish Sea, and coastal bays. Ecology's data are part of a spatially-nested sampling approach in collaboration with other monitoring programs with a larger regional focus and higher temporal resolution. Each program has different sensor platforms to cover the range of scales required to address marine water quality. The MWM program's water column data are supplemented by information from en route ferry-based monitoring of surface waters along predetermined transects. The program is further supplemented through opportunistic aerial photography to support outreach and public engagement.

4.1 Project goals

The purpose of the program is to provide credible, consistent, representative and continuing data records to assess and understand marine water quality in Puget Sound, Grays Harbor, and Willapa Bay through interdecadal scales. Long-term data records and appropriate data management are critical in documenting human and climatic drivers that affect regional and seasonal patterns inherent to Washingtons complex marine waterbodies. The project goals are to:

- Provide quantitative information about long-term estuarine dynamics, temporal and spatial patterns, variability, and trends relative to established baseline conditions.
- Assess the interaction of factors affecting regional estuarine processes and ecosystem functions that result from transport of water, solutes, and pollution at the confluence of oceanic and terrestrial inputs.
- Assess changes and vulnerabilities of ambient water quality in the context of local, regional, or larger-scale human, climatic, and oceanographic factors.

4.2 Project objectives

The objectives are to determine existing marine water quality and estuarine conditions and to identify spatiotemporal patterns and trends. Meeting these objectives improves understanding of Washington diverse marine waters to changing environmental and climatic factors. We strive to meet the objectives in a planned and methodical manner that incorporates advancements in technology and procedures, data management, and data quality without compromising the continuity of existing data records. Technological advances enable analyses that integrate historical data with modern, more detailed, results that expand previous findings and improve representativeness of the system as a whole. Specifically, the project objectives are to:

- Assure high quality sensor measurements, sensor performance checks and related laboratory analysis of reference samples.
- Report and communicate effectively long-term patterns and trends in our data sets including attributes such as:
    - Status, patterns, and trends of physical conditions (e.g., salinity, temperature).
    - Status patterns, and trends of biochemical properties (e.g., dissolved oxygen, nutrient concentrations and ratios).
    - Status patterns, and trends of bio-optical properties (e.g., chlorophyll fluorescence as a proxy of biomass).
    - Long-term changes to seasonal and regional variability (e.g., temperature, dissolved oxygen).
    - Inter-annual variability associated with large-scale climate and regional weather patterns.
    - Spatial patterns and temporal trends as they relate to variation to hydrological cycles on land and oceanic boundary conditions.
    - New monthly regional extremes and anomalies in context of established baselines.
    - Changes to water masses, vertical density structure, and circulation patterns.
- Contribute to the understanding of long-term changes of marine water quality in context of other environmental factors through the following activities:
    - Provide continuous data input for physical and ecological models.
    - Provide monthly observations and inform the public, management, and the Puget Sound Partnership about unexpected current conditions.

- Provide water quality information and baseline data to other Ecology programs and to state agencies, the public, managers, and private institutions.
- Coordinate findings with other PSEMP monitoring components.
- Provide data to evaluate compliance with state water quality standards under the federal Clean Water Act [303(d) list and 305(b) report].
- Identify emerging problems and inform action agendas and regulatory processes.
- Identify water masses and exchange between Salish Sea basins.
- Contribute to the overall understanding of the dynamic of natural conditions.

4.3 Information needed and sources

Following field collection, the program's monitoring data are put into a Microsoft SQL Server database for data quality control, queries, and reviews. The MWM program analyzes and interprets marine water quality data in the context of atmospheric, terrestrial, and oceanic data including those from external data sources including, but not limited to:

- U.S. Geological Survey and Environment Canada for river flow data.
- British Columbia, Canada for data on snow survey and water supply.
- National Oceanic and Atmospheric Administration branches for ocean and climate condition data, upwelling indices, Pacific Decadal Oscillation (PDO), and NE Pacific Ocean sea surface temperature.
- Scripps Institution of Oceanography for the North Pacific Gyre Oscillation Index and precipitation anomaly.
- University of Washington's Atmospheric Sciences Program for local weather information.
- The Northwest Association of Networked Ocean Observing Systems for regional marine measurements and Puget Sound metrics.
- The Ocean Observatories Initiative Coastal Endurance Array for measurements of conditions on the Washington shelf.
- Satellite remote sensing products from the National Aeronautics and Space Administration including those from Moderate Resolution Imaging Spectroradiometers (MODIS), optical hyperspectrometers [(Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)], and optical land images (Landsat).

4.4 Tasks required

The MWM program has specific tasks to achieve the overall monitoring program's strategic goals via three extensive activities: data collection, data assessment, and data management. Data collections occur year-round and monthly at 39 sampling stations (37 core stations and 2 rotational stations) as directed by the original Puget Sound monitoring plan for the water column. Data assessments of sensor data occur within a few weeks upon completion of monthly sampling. Discrete water sample analysis occurs on a time scale in accordance with laboratory turnaround times. Discrete water sample data auditing occurs typically at the end of the year with a desire to reduce the time between data analysis and auditing.

We deploy an instrument package with multiple sensors to measure the water column. The sensor variables are:

- Pressure
- Temperature
- Salinity
- Dissolved oxygen
- Turbidity
- Transmissivity
- In situ chlorophyll fluorescence
- Nitrate

An instrument package would also have oceanographic bottle samplers to collect discrete water samples from predetermined nominal depths. The discrete variables are:

- Chlorophyll *a*
- Dissolved inorganic carbon
- Total alkalinity
- Salinity
- Dissolved inorganic nutrients (NO_3, NO_2, NH_4, $SiOH_4$, PO_4)

We verify sensor performance monthly through a series of tests using an in-house laboratory bath under stable and reproducible conditions. We also have sensor manufacturers conduct annual calibrations on sensors that require routine maintenance per factory specifications. Both approaches ensure high and continued sensor performance and confidence in sensor data.

4.5 Systematic planning process

The long-term marine water monitoring plan was initially based on agency monitoring needs in the early 1970s. The plan evolved in 1989 by a regional effort to design a comprehensive ambient monitoring program for Puget Sound. More information is provided in the background section of the MWM program's 2015 Quality Assurance Monitoring Plan (QAMP; Bos et al. 2015). The monitoring priorities and strategy may change as new ecological information emerges and different questions about estuarine dynamics arise.

Every fall, the MWM program conducts annual planning that may include updates to station locations, sampling approaches, sensor selections, and data collected. These are implemented as information priorities evolve and scientific needs change. Any updates to the monitoring plan described in this QAMP will be captured in an addendum or, if significantly different, will be captured in a new QAMP.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 1 shows the responsibilities of those who will be involved in this project.

Table 1. Organization of project staff and responsibilities.

Staff[1]	Title	Responsibilities
Christopher Krembs Marine Monitoring Unit Western Operations Section Phone: 360-280-8369	Senior Oceanographer	Determines monitoring and data assessment strategy. Generates indicators of water quality conditions. Leads data review, analysis, interpretation, and reporting. Develops information products. Writes publications and presentations delivered to the agency and public
Micah Horwith Western Operations Section Phone: 360-485-5473	Ocean Acidification Senior Scientist	Coordinates ocean acidification science within Ecology. Provides recommendations to management to address ocean acidification. Oversees data compilation and analysis and reports findings.
Alex Fisher Marine Monitoring Unit Western Operations Section Phone: 360-280-6417	Senior Physical Oceanographer	Implements research on status and trend monitoring of physical processes. Synthesizes and reports on oceanic and atmospheric boundary conditions. Generates data products and analytical tools. Writes publications and presentations delivered to agency and the public.
Suzan Pool Marine Monitoring Unit Western Operations Section Phone: 360-791-8337	Marine Monitoring Scientist	Manages data workflow, processing, and QA review. Analyzes, interprets, and manages data in the EAPMW and EIM database systems. Generates analytical and QC products and develops tools. Writes reports and data summaries.
Holly Young Marine Monitoring Unit Western Operations Section Phone: 564-669-0458	Marine Waters Field Lead	Coordinates and conducts field sampling, laboratory analysis, instrument calibrations, and instrument maintenance. Records and manages field information. Conducts data QA review, analysis, and interpretation. Writes reports and data summaries
Christopher Jendrey Marine Monitoring Unit Western Operations Section Phone: 360-764-9249	Marine Waters Field Scientist	Conducts field sampling, laboratory analysis, instrument calibrations, and instrument maintenance. Records and manages field information. Conducts data QA review, analysis, audits, and interpretation. Performs and publishes EOPS aerial surveys.
Natalie Coleman Marine Monitoring Unit Western Operations Section Phone: 360-790-5152	Ocean Acidification Scientist	Provides expertise in ocean acidification parameters. Leads and assists with field sampling. Conducts ocean acidification data QA review, analysis, audits, and interpretation. Assists with sensor assessment and annual calibrations. Writes reports and data summaries.

Staff[1]	Title	Responsibilities
Emma LeValley Marine Monitoring Unit Western Operations Section	Marine Monitoring Technician	Assists with research vessel operations, field sampling, laboratory analysis, and instrument maintenance. Conducts QA review. Performs and publishes EOPS aerial surveys
Julianne Ruffner Marine Monitoring Unit Western Operations Section Phone: 360-280-4518	Unit Supervisor for the Project Manager	Provides internal review of the QAMP, approves the budget, and approves the final QAMP.
Stacy Polkowske Western Operations Section Phone: 360-464-0674	Section Manager for the Study Area	Reviews the project scope and budget, tracks progress, reviews the draft QAMP, and approves the final QAMP.
Rob Waldrop Manchester Environmental Laboratory Phone: 360-871-8801	Manchester Lab Director	Reviews and approves the final QAMP.
Christina Frans Environmental Assessment Program Phone: 360-995-2473	Acting Ecology Quality Assurance Officer	Reviews and approves the draft QAMP and the final QAMP.

[1]All staff are from EAP.
EAP: Environmental Assessment Program
EIM: Environmental Information Management System database
EOPS: Eyes over Puget Sound
QA: Quality assurance
QC: Quality control
QAMP: Quality Assurance Monitoring Plan

5.2 Special training and certifications

All personnel who conduct field activities receive training on:

- Instrument maintenance, deployments, sensor performance checks, and calibration.
- Sample collection, preservation, and handling.
- Program quality assurance and quality control (QA/QC).
- Field, chemical, and instrument safety.

Each staff is required to be familiar with this QAMP, field, and laboratory procedures described in Standard Operating Procedures (SOPs). Staff should have a college education in biology, oceanography, environmental science, and analytical chemistry and some experience with sample collection, laboratory analysis, data QA/QC, and safety.

Experienced senior technicians demonstrate field procedures to new technicians before they perform field activities. Also, the senior technician accompanies new technicians on their initial field trips to verify that they understand and follow procedures. Senior staff conduct periodic field checks to ensure consistent sampling performance among technicians. Staff and field technicians discuss field checks and implement appropriate updates or changes.

The senior technician demonstrates laboratory activities to new technicians before they run sample analyses. Training on laboratory procedures includes, but is not limited to, sample filtration, preservation, extraction, and analysis.

Field crew leader of any sampling date will be responsible for:

- Cancelling surveys should conditions warrant.
- Compliance with field and safety procedures.
- Knowledge of how to use the radio.
- Knowledge of use and location of the safety equipment.
- Sample handling and processing, including chemical safety protocols.
- Emergency procedures.

5.3 Organization chart

Not applicable – see Table 1.

5.4 Proposed project schedule

Tables 2 to 4 list key activities, due dates, and lead staff for this project and during a routine sampling year (January to December).

Table 2. Schedule for completing field and laboratory work.

Task	Due date	Lead staff
Field work completed — sample collection, instrument deployment, data retrieval	Monthly	H. Young, N. Coleman, C. Jendrey
Internal laboratory (MWL) analyses completed — chlorophyll *a*, salinity[1]	1 month post collection	H. Young, N. Coleman, C. Jendrey
External laboratory (UW-MCL) analyses completed — nutrients, salinity[2]	3 months post collection	H. Young, C. Jendrey
External laboratory (PMEL) analyses completed — total alkalinity, dissolved inorganic carbon	2 years post collection	N. Coleman
Aerial observation photos for Eyes Over Puget Sound (EOPS) survey completed	Once a month or as needed	C. Jendrey, A, Fisher, E. LeValley
Sensor assessment bath and performance tests	1 month pre collection	H. Young, N. Coleman, C. Jendrey
Factory and in-house calibrations	Annually pre collection	S. Pool, N. Coleman, C. Jendrey, H. Young

[1] Salinity samples are from the field and accompany samples for total alkalinity and dissolved inorganic carbon.
[2] Salinity samples are from internal sensor performance assessments.
MWL: Marine Waters Laboratory
PMEL: NOAA Pacific Marine Environmental Laboratory
UW-MCL: University of Washington Oceanography Department’s Marine Chemistry Laboratory

Table 3. Schedule for data entry.

Task	Due date	Lead staff
Instrument and sensor data uploads and subsequent processing and transfer to EAPMW database	Same month as collection	S. Pool, H. Young, N. Coleman
Internal laboratory data (MWL) — receipt, processing, and transfer to EAPMW database	1 month post analyses	C. Jendrey, H. Young
External laboratory data (UW-MCL, PMEL)— receipt, processing, and transfer to EAPMW database	3 months post analyses	H. Young, N. Coleman
Instrument and sensor data review and QA/QC and subsequent data adjustments in EAPMW database	1 month post collection	S. Pool, A. Fisher, H. Young, N. Coleman, M. Horwith, C. Krembs, C. Jendrey
Internal laboratory data (MWL)— review and QA/QC	2 months post analyses	C. Jendrey, S. Pool, H Young, N. Coleman, C. Krembs
External laboratory data (UW-MCL, PMEL)— review and QA/QC	4 months post analyses	A. Fisher, S. Pool, N. Coleman, M. Horwith, H. Young, C. Krembs, C. Jendrey
Post water column profiles and discrete nutrients in netCDF format on Ecology's website for large volume data users	Every January and July	S. Pool
EIM data loaded*[1]	6 months after sampling year completed	S. Pool, N. Coleman, M. Horwith
EIM QA[2]	6 months after sampling year completed	S. Pool, N. Coleman, M. Horwith
EIM complete[3]	6 months after sampling year completed	S. Pool, N. Coleman, M. Horwith

*EIM Study ID: MarineWater
EAPMW: Environmental Assessment Program's Marine Waters database
EIM: Environmental Information Management System database
MWL: Marine Waters Laboratory
netCDF: Network Common Data Form
PMEL: NOAA Pacific Marine Environmental Laboratory
QA/QC: Quality assurance and quality control
UW-MCL: University of Washington Oceanography Department's Marine Chemistry Laboratory

[1] All data entered into EIM by the lead person for this task.
[2] Data verified to be entered correctly by a different person; any data entry issues identified. Allow one month.
[3] All data entry issues identified in the previous step are fixed (usually by the original entry person); EIM Data Entry Review Form signed off and submitted to Melissa Peterson (who then enters the "EIM Completed" date into Activity Tracker). Allow one month for this step. Normally the final EIM completion date is no later than the final report publication date.

Table 4. Schedule for final report.

Task	Due date	Lead staff
Eyes Over Puget Sound (EOPS) Publication	Monthly or as needed	C. Jendrey, A. Fisher, E. LeValley
PSEMP Puget Sound Marine Waters Report	Annually in April	A. Fisher, S. Pool, C. Krembs
PSEMP Puget Sound Vital Signs Indicator for ocean acidification	Annually in April	M. Horwith
Final data products and QA/QC summarized	Annually in May	C. Krembs, A. Fisher, S. Pool
Final performance data quality objectives calculated and submitted to Office of Financial Management	Annually in July	S. Pool

PSEMP: Puget Sound Ecosystem Monitoring Program
QA/QC: quality assurance and quality control

5.5 Budget and funding

We estimated the 2025 budget for vertical profiling instruments, non-Ecology research vessels, and laboratory analyses. We assume that the annual budget for the remainder of the five-year monitoring plan will fluctuate. Table 5 shows the 2025 estimates for contract costs. Table 6 shows the 2025 estimates for laboratory analyses of discrete samples. The costs do not include ocean acidification samples (total alkalinity and dissolved inorganic carbon) for analysis by U.S. National Oceanic and Atmospheric Administration Pacific Marine Environmental Laboratory (NOAA PMEL) as a different funding source supports these samples. The budget estimates are only part of the program cost as they exclude items such as staffing, Ecology's research vessels, internal laboratory samples and supplies, and field equipment (e.g., repairs and administrative costs).

Table 5. Estimated project budget and funding for contract costs in 2025 calendar year.

Provider	Cost ($)
Sea-Bird Scientific equipment	$15,450.00
RBR Global equipment	$3,450.00
WET Labs equipment	$4,570.00
WWU Shannon Point Marine Center research vessel use	$ 21,780.00
Total	**$ 45,250.00**

WWU: Western Washington University

Table 6. Estimated external laboratory* budget details for samples in 2025 calendar year.

Parameter	Number of Samples	Number of QA Samples	Total Number of Samples	Cost per Sample	Cost Subtotal	Overhead charge (15.6 %)	Cost Total
Nutrients	1,476	192	1,668	$21.00	$35.028.00	$5,464.37	$40,492.37
Salinity	7	3	10	$22.00	$220.00	$34.32	$254.32
Totals	**1,483**	**195**	**1,678**	**$43.00**	**$35,248.00**	**$5,498.69**	**$40,746.69**

*University of Washington Oceanography Department's Marine Chemistry Laboratory

6.0 Quality Objectives

6.1 Data quality objectives

The main data quality objectives (DQOs) for this project are to (1) measure the marine water column with a profiling package of multiple sensors, (2) collect water samples from multiple depths at 37 core and 2 rotational stations, and (3) analyze water samples using internal and external laboratories. These objectives will be met by following a monthly sample collection plan which is specific for each station. The objectives may adjust for various sampling constraints (e.g., weather, instrument or vessel failures, and programming errors).

The number of results will vary depending on water depth and tide levels. The results should be representative of the southern Salish Sea and coastal bays. The sensor measurements and water sample analysis will use standard methods to obtain results that meet measurement quality objectives (MQOs) described below. The results will be analyzed against 25-year station-specific monthly baselines to describe long-term patterns, including status and trends, and to assess marine water quality. The assessments will be done in context of climate, hydrology, and ocean boundary conditions for this region.

6.2 Measurement quality objectives

Measurement quality objectives (MQOs) are to obtain data of sufficient quality, quantity and continuity so that the data can be used to evaluate the stated objectives of the monitoring program. The MQOs will be achieved through careful planning, sampling, and adherence to standard procedures.

The MWM program uses sensors to measure a broad suite of hydrographic, chemical, optical, and biological conditions at each monitoring station. The sensors are selected for their capability to profile the marine water column with high quality data, sensor response time, and sensor stability across salinity gradients to meet the MQOs. We will use sensor measurements to resolve vertical environmental gradients via sensor's response time, descending/ascending rates, and lag times for sensor variables that require a water pump. All three factors are carefully adjusted to align profiling data of multiple sensors.

An instrument package with these sensors also has oceanographic water samplers that capture water at specified depths for discrete samples. Sample collection, handling, storage, and transport prior to analysis are critical for data quality and are described in SOPs. Accredited laboratories analyze the discrete samples to meet the MQOs.

6.2.1 Targets for precision, bias, and sensitivity

The MWM program has two types of MQOs. One is for sensors on profiling instrument packages; the other is for laboratory analyses of discrete seawater samples. The precision, bias, and sensitivity for both types of MQOs are described in this section. They are also summarized in Tables 7 and 8.

Table 7. Measurement quality objectives for field sensor measurement methods (table is organized by parameter then manufacturer).

Parameter	Manufacturer	Model Name	Precision	Bias	Manufacturer Reported Range	Manufacturer Reported Accuracy	Manufacturer Reported Resolution	Lowest Value
Conductivity	RBR Global	RBR*concerto*	±0.002 mS/cm	NA	0–85 mS/cm	±0.003 mS/cm	NA	0 mS/cm
Conductivity	Sea-Bird Scientific	SBE 4	10% RSD	5% RSD	0.0–7.0 S/m	0.0003 S/m	0.00004 S/m	1 µS/cm
Density	Sea-Bird Scientific	SBE 3 and SBE 4	10% RSD	5% RSD	dependent on temperature and conductivity	dependent on temperature and conductivity	NA	0.1 sigma-t
Dissolved Oxygen	Precision Sensing (aka PreSens)	Fibox + Optode Dipping Probe (PSt3 membrane)	NA	0.45 mg/L at 7.62 mg/L	0–45 mg/L	±0.4% O_2 at 20.9% O_2	NA	0.015 mg/L
Dissolved Oxygen	RBR Global	RBR*concerto*	±10 µM	NA	0–500 µM	±8 µM	NA	0 µM
Dissolved Oxygen	RBR Global	RBR*duet* T.ODO *fast*	±10 µM	NA	0–500 µM	±8 µM	NA	0 µM
Dissolved Oxygen	Sea-Bird Scientific	SBE 43	5% RSD	5% RSD	0–120% of saturation	2% of saturation	NA	0.05 mg/L
Fluorescence	Sea-Bird Scientific (formerly WET Labs, Inc.)	ECO-FLNTURT	10% RSD	5% RSD	0–50 µg chl/L	0.025 µg chl/L	NA	0.1 µg chl/L
Light Transmission	Sea-Bird Scientific (formerly WET Labs, Inc.)	C-Star	10% RSD	5% RSD	0–100%	99% R^2	NA	0.01%
Nitrate	Sea-Bird Scientific (formerly Satlantic, Inc.)	SUNA V2	2.4 µM	15% RSD	0.5–2000 µM	0.028 mg N/L (2 µM)	NA	2.4 µM

Parameter	Manufacturer	Model Name	Precision	Bias	Manufacturer Reported Range	Manufacturer Reported Accuracy	Manufacturer Reported Resolution	Lowest Value
Pressure	RBR Global	RBR*concerto*	0.25 dbar	NA	0–500 dbar	0.25 dbar	NA	0 dbar
Pressure	Sea-Bird Scientific	integrated in SBE 25*plus*	5% RSD	1% RSD	0–500 m	0.1% of full scale range	0.002% of full scale range	0.1 dbar
Temperature	RBR Global	RBR*concerto*	±0.005°C	NA	-5–35°C	±0.002°C	NA	-5°C
Temperature	RBR Global	RBR*duet* T.ODO *fast*	±0.005°C	NA	-5–35°C	±0.002°C	NA	-5°C
Temperature	Sea-Bird Scientific	SBE 3	0.025°C	0.05°C	-5.0–35°C	0.001°C	0.0003°C	0.01°C
Turbidity	Sea-Bird Scientific (formerly WET Labs, Inc.)	ECO-FLNTURT	10% RSD	5% RSD	0–25 NTU	0.01 NTU	NA	0.1 NTU

NA: not available
RSD: relative standard deviation

Table 8. Measurement quality objectives for laboratory analysis of seawater samples (table is ordered by parameter).

Parameter	Laboratory	Laboratory Duplicate (RPD)	Field Replicate (RPD or RSD)	Matrix Spike Duplicate (RPD)	Laboratory Control Standard (% Recovery)	Matrix Spike (% Recovery)	Internal Standard Recovery (%)	RL	MDL or Lowest Concentrations of Interest
Chlorophyll *a*	MWL	NA	10%	NA	NA	NA	NA	NA	0.025 µg/L
Dissolved inorganic ammonium	UW-MCL	NA	10%	NA	NA	NA	NA	NA	0.03 uM, 0.0006 mg/L
Dissolved inorganic carbon	PMEL	NA	< 0.5%	NA	0.25%	NA	NA	NA	±0.1% µmol/kg
Dissolved inorganic nitrate	UW-MCL	NA	10%	NA	NA	NA	NA	NA	0.14 uM, 0.0028 mg/L
Dissolved inorganic nitrite	UW-MCL	NA	10%	NA	NA	NA	NA	NA	0.03 uM, 0.0003 mg/L
Dissolved inorganic orthophosphate	UW-MCL	NA	10%	NA	NA	NA	NA	NA	0.03uM, 0.0006 mg/L
Dissolved inorganic silicate	UW-MCL	NA	10%	NA	NA	NA	NA	NA	0.34 uM, 0.0113 mg/L
Salinity	MWL	NA	5%	NA	NA	NA	NA	NA	0.05 PSU
Salinity	UW-MCL	NA	5%	NA	NA	NA	NA	NA	0.002 PSU
Total alkalinity	PMEL	NA	< 0.5%	NA	0.25%	NA	NA	NA	±0.1% µmol/kg

MDL: method detection limit
MWL: Ecology's Marine Waters Laboratory
NA: not applicable
PMEL: NOAA Pacific Marine Environmental Laboratory
RL: reporting limit
RPD: relative percent difference
RSD: relative standard deviation
UW-MCL: University of Washington Oceanography Department's Marine Chemistry Laboratory

6.2.1.1 Precision

Precision is a measure of variability among replicate measurements due to random error. The Marine Waters Monitoring (MWM) program will evaluate precision through field replicates of discrete samples, routine sensor calibrations, and monthly in-house sensor performance assessments.

Precision of sensors will be assessed through monthly sensor performance checks in Ecology's Marine Waters Laboratory (MWL) laboratory-controlled seawater tank. Also, routine manufacturer calibrations provide information on electronic drift that may affect precision. Targets for acceptable precision in a single sensor's series of measurements are listed in Table 8.

Precision of laboratory analyses will be evaluated through field and laboratory replicates. Field staff will collect a minimum of one set of replicates for each sample type during every field sampling event. Laboratories will also analyze laboratory replicates, matrix spikes, and standards per analytical methods. Targets for acceptable precision between replicates, in terms of relative percent difference (RPD) or relative standard deviation (RSD), are listed in Table 9.

6.2.1.2 Bias

Bias is the difference between the sample mean and the true value. This will be evaluated for field instruments and discrete samples.

Bias of field instruments is established through a few methods. Monthly sensor performance checks in the MWL laboratory-controlled seawater tank. Annual instrument calibrations provide information on sensor performance that may affect bias. Independent samples are collected and analyzed to verify sensor performance. Targets for acceptable bias in a single sensor's series of measurements are listed in Table 8.

Bias of discrete field samples will be addressed through laboratory blanks and check standards.

6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance. It is commonly described as a detection limit. Sensitivity of marine water column data are reported as lowest value detectable for a given method. The lowest values of interest for sensors and discrete parameters are listed in Tables 8 and 9, respectively.

6.2.2 Targets for comparability, representativeness, and completeness

6.2.2.1 Comparability

It is important that data collected and analyzed by different technicians or monitoring groups are comparable over time. To ensure comparability, we use the same methods and procedures whenever possible throughout the MWM program. MWM technicians operate with primary and backup responsibilities. Redundancy in training and crosschecks within the team foster a work environment that focuses on high data quality correctly input and uploaded into the data management system. Regular field and laboratory audits of technicians are conducted to ensure individuals are consistent with each other in their technical proficiency and practices.

All protocols used by MWM are based on the most current, standard, internationally accepted seawater methods (Grasshoff et al. 1999; PSEP 1991; PSEP 1997). All procedures are reviewed every 2-3 years and updated to include improvements and necessary modifications. These standardized procedures support comparability between other studies and long-term monitoring programs. They also provide a baseline of marine water column profiles to compare with current and incoming data.

Standard seawater methods and Standard Operating Procedures (SOPs) include the following list (full citations are in the References section):

Sampling methods

- Puget Sound Estuary Program (PSEP) (1991) for "Recommended Guidelines for Measuring Conventional Marine Water-Column Variables in Puget Sound."
- PSEP (1997) for "Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissue in Puget Sound."
- Young et al. (2023b) for Ecology's SOP EAP025 on seawater sampling.
- Glisson (2024) for Ecology's SOP EAP070 to minimize the spread of invasive species.

Laboratory methods

- Coleman (2022a) for Ecology's SOP EAP028 on reagent preparation.
- Coleman (2022b) for Ecology's SOP EAP053 on analyzing salinity samples collected in the field.
- Young and Jendrey (2023) for Ecology's SOP EAP026 on analyzing discrete samples for chlorophyll *a* pigments.
- Standardized methods for specific laboratory analytes itemized in Section 9.0 on laboratory procedures.

Sensor methods

- Young et al. (2023a) for Ecology's SOP EAP086 on conducting monthly sensor performance assessments in laboratory-controlled conditions.
- Field sensor manuals, application notes, and technical notes from sensor manufacturers for sensor deployments, maintenance, and calibrations.
- Data processing methods of field sensors following manufacturers' recommendations.

MWM staff also compares inter-laboratory nutrient standards of different monitoring partners, such as King County Department of Natural Resources. Standard protocols are followed for generating laboratory control samples and for conducting laboratory analyses. An inter-laboratory comparison would include seawater nutrient standards are prepared in replicate by MWL once or twice a year, for comparative analyses by UW-MCL and another laboratory. An inter-laboratory comparison would be similar to one conducted in collaboration with King County Department of Natural Resources (King County 2014). This same inter-lab comparison could be extended to other partners or laboratories to validate and verify results.

6.2.2.2 Representativeness

Samples and measurements will be representative of conditions, seasonal cycles, and spatial and temporal variations in the study area's marine water environment. Natural spatial and temporal variability may contribute greatly to overall variability in the parameter value.

Monthly sample collections and measurements will capture a wide variety of seasonal conditions. These will be spread by at least three weeks between consecutive visits to the same region. Sampling surveys are conducted over several separate days during a month, with no set date or condition imposed.

Data collection will span the full water column at 39 designated stations, which are strategically located near the middle of inlets or passages to reflect basin-scale water quality. These locations are not intended to represent conditions near a specific wastewater or river discharge.

6.2.2.3 Completeness

Completeness is a measure of the amount of valid data needed to be obtained from a measurement system to meet study objectives. The completeness objective for this study is that 95% of all collected data meet measurement quality objectives. There is no attainment objective established given the safety considerations specific to marine water sampling. We make all efforts possible to complete all sampling every month to avoid gaps in the data record.

6.3 Acceptance criteria for quality of existing data

The MWM program has data on the marine water column from 1973 to present. Data quality from 1973 to 1998 vary, depending on the type of quality assurance (QA) required, data collection and analytical methods, field sensor technology, sampling logistics, and degree of documentation. These are documented in Janzen (1992), Newton et al. (1997), Newton et al. (1998), and Newton et al. (2002). Data quality from 1999 to 2024 follows consistent methods, quality control (QC), and data management as described in the previous two QAMPs by Bos et al. (2015) and Keyzers et al. (2021) and in related QAMP addenda. Newly generated data are accepted for use after initial data processing and QA/QC activities confirm that instrument operations, laboratory analyses, and field information collection were performed without error or failure.

6.4 Model quality objectives

NA

7.0 Study Design

7.1 Study boundaries

The study boundaries are marine water areas of Puget Sound from Olympia to the Canadian border, Grays Harbor, and Willapa Bay. The boundaries within the study area are described in Section 3.2. Figure 2 depicts the study boundaries along with the sampling stations.

7.2 Field data collection

7.2.1 Sampling locations and frequency

Station locations were determined by integrating three existing and recommended station networks:

- Existing Ecology stations.
- Stations recommended in 1988 by the Puget Sound Water Quality Authority – Monitoring Management Committee (MMC 1988).
- Historical stations surveyed by Collias (1970) during the 1950s and 1960s.

The Marine Water Monitoring (MWM) program has a list of historical stations and data context to consider for future renewed sampling. Additional data from these stations collected on a rotational basis or as part of specific projects could be used for additional trend analyses. Where possible, recommendations for stations from the MWM program's clients are incorporated into the sampling strategy to report on localized conditions supporting specific projects. Currently, Ecology has active and inactive stations at 166 locations.

The MWM program has three groups of stations. The first group is designated as core stations (n = 39) that are monitored monthly throughout a sampling year (Table 9). Stations in this group feed the former vital sign adopted by the Puget Sound Partnership, the Marine Water Condition Index (MWCI). The second group is designated as rotational stations (n = 49) that were typically rotated every few years when stations were sampled by float plane (Table 10). Recent shifts to collect data by boat as a cost-saving measure has limited the use of rotational stations. The third group is designated as historical stations (n = 62) that are no longer monitored for various reasons such as restricted areas and unsafe conditions. We selected 37 core and 2 rotational stations to monitor the marine water column in sampling year 2025 (Table 11). Figure 3 shows the locations of these stations. As monitoring needs change, stations may be added or removed from the station list.

Table 9. Core stations, descriptions, marine region, maximum depths, water resource inventory area (WRIA), and coordinates.

Station	Description	Marine Region	Maximum depth (m)	WRIA	Latitude Decimal Degrees	Longitude Decimal Degrees
ADM001	Admiralty Inlet off Bush Point	Admiralty Inlet	148	6	48.0300	-122.6167
ADM002	Admiralty Inlet north of Quimper Peninsula	Admiralty Inlet	82	17	48.1875	-122.8417
ADM003	Admiralty Inlet south of Whidbey Island	Admiralty Inlet	210	15	47.8792	-122.4818
BLL009	Bellingham Bay near Point Frances	Strait of Georgia	20	1	48.6867	-122.5983
BUD005	Budd Inlet near Olympia Shoals	South Basin	15	13	47.0917	-122.9167
CMB003	Commencement Bay in center and off Browns Point	Main Basin	150	10	47.2900	-122.4483
CRR001	Carr Inlet off Green Point	South Basin	95	15	47.2767	-122.7083
CSE001	Case Inlet off southern Heron Island	South Basin	58	15	47.2650	-122.8433
DNA001	Dana Passage south of Brisco Point	South Basin	40	13	47.1617	-122.8700
EAP001	East Passage southwest of Three Tree Point	Main Basin	213	9	47.4167	-122.3800
ELB015	Elliott Bay east of Duwamish Head	Main Basin	82	9	47.5967	-122.3683
GOR001	Gordon Point north of Ketron Island	South Basin	168	15	47.1833	-122.6333
GRG002	Georgia Strait north of Patos Island	Strait of Georgia	190	2	48.8083	-122.9533
GYS008	Grays Harbor midway down South Channel	Grays Harbor	6	22	46.9383	-123.9117
GYS016	Grays Harbor off Damon Point	Grays Harbor	11	22	46.9533	-124.0917
HCB003	Hood Canal near Eldon	Hood Canal Basin	144	15	47.5383	-123.0083
HCB004	Hood Canal east of Great Bend near Sisters Point	Hood Canal Basin	55	14	47.3567	-123.0233
HCB007	Hood Canal in Lynch Cove	Hood Canal Basin	21	14	47.3983	-122.9283
HCB008	Hood Canal off King Spit outside Navy zone	Hood Canal Basin	76	15	47.7533	-122.7450
HCB009	Hood Canal east of Hazel Point and south of Bangor	Hood Canal Basin	111	15	47.6883	-122.7500
HCB010	Hood Canal north of Seabeck and south of Bangor	Hood Canal Basin	100	15	47.6670	-122.8200

Station	Description	Marine Region	Maximum depth (m)	WRIA	Latitude Decimal Degrees	Longitude Decimal Degrees
NSQ002	Nisqually Reach west of Devils Head	South Basin	101	13	47.1683	-122.7867
OAK004	Oakland Bay in midbay and north of Eagle Point	South Basin	19	14	47.2133	-123.0767
PSB003	Puget Sound Main Basin off West Point	Main Basin	67	8	47.6600	-122.4417
PSS019	Possession Sound near Gedney Island	Whidbey Basin	101	7	48.0117	-122.3000
PTH005	Port Townsend Harbor northwest of Walan Point	Admiralty Inlet	26	17	48.0833	-122.7633
RSR837	Rosario Strait south of Peapod Rocks	Strait of Georgia	56	2	48.6165	-122.7630
SAR003	Saratoga Passage north of East Point	Whidbey Basin	149	6	48.1083	-122.4900
SIN001	Sinclair Inlet near Naval Shipyard	Main Basin	16	15	47.5500	-122.6417
SJF000	Strait of Juan de Fuca south of San Juan Island	Strait of Juan de Fuca	180	2	48.4167	-123.0250
SJF001	Strait of Juan de Fuca southeast of Hein Bank	Strait of Juan de Fuca	160	2	48.3333	-123.0250
SJF002	Strait of Juan de Fuca southwest of East Bank	Strait of Juan de Fuca	145	18	48.2500	-123.0250
SKG003	Skagit Bay near Strawberry Point	Whidbey Basin	24	6	48.2967	-122.4883
WPA003	Willapa Bay at mouth of Johnson Slough	Willapa Bay	10	24	46.7050	-123.8367
WPA004	Willapa Bay near Toke Point	Willapa Bay	14	24	46.6867	-123.9717
WPA006	Willapa Bay in Nahcotta Channel near Oysterville	Willapa Bay	21	24	46.5450	-123.9783
WPA007	Willapa Bay south of Jenson Point on Long Island	Willapa Bay	14	24	46.4533	-124.0083
WPA008	Willapa Bay north of Naselle River mouth	Willapa Bay	14	24	46.4637	-123.9392
WPA113	Willapa Bay west of Bay Center Channel	Willapa Bay	11	24	46.6440	-123.9930

Table 10. Rotational stations, descriptions, marine region, maximum depths, water resource inventory area (WRIA), and coordinates.

Station	Description	Marine Region	Maximum depth (m)	Watershed WRIA	Latitude Decimal Degrees	Longitude Decimal Degrees
BLL011	Bellingham Bay off Nooksack River	Strait of Georgia	23	1	48.7333	-122.5833
BLL040	Bellingham Bay east of Chuckanut Rock	Strait of Georgia	21	1	48.6840	-122.5382
BML001	Burley-Minter Lagoon	South Basin	14	15	47.3783	-122.6333
BUD002	Budd Inlet at south end of Olympia Port Dock	South Basin	12	13	47.0517	-122.9050
CMB006	Commencement Bay at mouth of Thea Foss Waterway	Main Basin	39	10	47.2617	-122.4367
CSE002	Case Inlet off Rocky Point	South Basin	23	14	47.3533	-122.8133
DIS001	Discovery Bay near Mill Point	Strait of Juan de Fuca	42	17	48.0183	-122.8467
DRA002	Drayton Harbor	Strait of Georgia	12	1	48.9833	-122.7617
DUN001	Dungeness Bay	Strait of Juan de Fuca	19	18	48.1733	-123.1133
DYE004	Dyes Inlet northeast of Chico Bay	Main Basin	38	15	47.6233	-122.6883
EAG001	Eagle Harbor	Main Basin	20	15	47.6217	-122.5217
EAS001	East Sound off Rosario Point	Strait of Georgia	33	2	48.6433	-122.8817
ELD001	Eld Inlet near Flapjack Point	South Basin	16	13	47.1067	-122.9483
ELD002	Eld Inlet south Flapjack Point	South Basin	10	13	47.0967	-122.9750
FID001	Fidalgo Bay east of Anacortes	Strait of Georgia	12	3	48.5133	-122.5933
FRI001	Friday Harbor west of Brown Island	Strait of Georgia	19	2	48.5383	-123.0117
FSH001	Fisherman Bay at Lopez Island	Strait of Georgia	5	2	48.5100	-122.9167
GYS004	Grays Harbor on Chehalis River	Grays Harbor	20	22	46.9783	-123.7833
GYS009	Grays Harbor in Moon Island Reach	Grays Harbor	15	22	46.9650	-123.9483
GYS015	Grays Harbor north of Whitcomb Flats	Grays Harbor	15	22	46.9233	-124.0750
HCB002	Hood Canal near Pulali Point in Dabob Bay	Hood Canal Basin	50	17	47.7462	-122.8485
HCB013	Hood Canal south of Hood Canal Floating Bridge	Hood Canal Basin	87	15	47.8376	-122.6290
HLM001	Holmes Harbor east of Honeymoon Bay	Whidbey Basin	54	6	48.0633	-122.5317
HND001	Henderson Inlet off Cliff Point	South Basin	23	13	47.1517	-122.8333

Station	Description	Marine Region	Maximum depth (m)	Watershed WRIA	Latitude Decimal Degrees	Longitude Decimal Degrees
JDF005	Sequim Bay east of Pitship Point	Strait of Juan de Fuca	39	17	48.0617	-123.0300
JDF007	Sequim Bay northwest of Goose Point	Strait of Juan de Fuca	17	17	48.0483	-123.0083
LOP001	Lopez Sound between Lopez and Decatur Islands	Strait of Georgia	15	2	48.5133	-122.8500
NRR001	Tacoma Narrows near Point Defiance	South Basin	60	12	47.3167	-122.5483
NSQ001	Nisqually Reach near Nisqually River Delta	South Basin	29	15	47.1133	-122.6967
OCH014	Port Orchard south of Point Bolin	Main Basin	20	15	47.6733	-122.5933
PAH003	Port Angeles Harbor near head of Ediz Hook	Strait of Juan de Fuca	19	18	48.1350	-123.4600
PAH008	Port Angeles Harbor near Morse Creek	Strait of Juan de Fuca	19	18	48.1217	-123.3500
PCK001	Pickering Passage near Harstine Island	South Basin	22	14	47.2483	-122.9233
PGA001	Port Gamble	Hood Canal Basin	22	15	47.8400	-122.5800
PMA001	Port Madison south of Buoy 65	Main Basin	51	15	47.7350	-122.5333
PNN001	Penn Cove near Penn Cove Park, Whidbey Island	Whidbey Basin	31	6	48.2317	-122.6750
POD006	Port Orchard in Liberty Bay and off Virginia Point	Main Basin	16	15	47.7150	-122.6333
POD007	Port Orchard in Liberty Bay and off Poulsbo	Main Basin	6	15	47.7333	-122.6500
PSS008	Possession Sound off Point Gardner in East Waterway	Whidbey Basin	37	7	47.9815	-122.2235
PSS010	Possession Sound near Darlington	Whidbey Basin	99	7	47.9650	-122.2630
QMH001	Quartermaster Harbor south of Burton	Main Basin	21	15	47.3800	-122.4650
QMH002	Quartermaster Harbor off Kingsbury Beach	Main Basin	11	10	47.3967	-122.4417
SEQ002	Sequim Bay in northern part of bay	Strait of Juan de Fuca	26	17	48.0767	-123.0167
SKG001	Skagit Bay near Hope Island	Whidbey Basin	29	6	48.3967	-122.5800
STL001	Puget Sound off Steilacoom west of Chambers Bay	South Basin	122	15	47.1850	-122.6100
SUZ001	Port Susan west of Kayak Point	Whidbey Basin	107	5	48.1350	-122.3700
TOT001	Totten Inlet south of Windy Point	South Basin	31	14	47.1650	-122.9633
TOT002	Totten Inlet near Deepwater Point	South Basin	12	14	47.1217	-123.0200
WPA001	Willapa Bay in Willapa River off Raymond	Willapa Bay	11	24	46.6883	-123.7483

Table 11. Marine water column monitoring stations selected for sampling in 2025.

Marine Region	Station	Description	County	WRIA	Maximum Depth (m)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
Grays Harbor	GYS008	Grays Harbor midway down South Channel	Grays Harbor	22	6	46.9383	-123.9117
Grays Harbor	GYS016	Grays Harbor off Damon Point	Grays Harbor	22	11	46.9533	-124.0917
Willapa Bay	WPA003	Willapa Bay at mouth of Johnson Slough	Pacific	24	10	46.7050	-123.8367
Willapa Bay	WPA004	Willapa Bay near Toke Point	Pacific	24	14	46.6867	-123.9717
Willapa Bay	WPA006	Willapa Bay in Nahcotta Channel near Oysterville	Pacific	24	21	46.5450	-123.9783
Willapa Bay	WPA007	Willapa Bay south of Jenson Point on Long Island	Pacific	24	14	46.4533	-124.0083
Willapa Bay	WPA008	Willapa Bay north of Naselle River mouth	Pacific	24	14	46.4637	-123.9392
Willapa Bay	WPA113	Willapa Bay west of Bay Center Channel	Pacific	24	11	46.6440	-123.9930
Strait of Georgia	BLL009	Bellingham Bay near Point Frances	Whatcom	1	16	48.6867	-122.5983
Strait of Georgia	BLL040	Bellingham Bay east of Chuckanut Rock	Whatcom	2	26	48.6840	-122.5382
Strait of Georgia	GRG002	Georgia Strait north of Patos Island	San Juan	2	190	48.8083	-122.9533
Strait of Georgia	RSR837	Rosario Strait south of Peapod Rocks	San Juan	2	56	48.6165	-122.7630
Strait of Juan de Fuca	SJF000	Strait of Juan de Fuca south of San Juan Island	San Juan	2	180	48.4167	-123.0250
Strait of Juan de Fuca	SJF001	Strait of Juan de Fuca southeast of Hein Bank	San Juan	2	160	48.3333	-123.0250
Strait of Juan de Fuca	SJF002	Strait of Juan de Fuca southwest of East Bank	San Juan	2	145	48.2500	-123.0250
Admiralty Inlet	ADM001	Admiralty Inlet off Bush Point	Island	6	148	48.0300	-122.6167
Admiralty Inlet	ADM002	Admiralty Inlet north of Quimper Peninsula	Jefferson	17	82	48.1875	-122.8417
Admiralty Inlet	ADM003	Admiralty Inlet south of Whidbey Island	Kitsap	15	210	47.8792	-122.4818
Admiralty Inlet	PTH005	Port Townsend Harbor northwest of Walan Point	Jefferson	17	26	48.0833	-122.7633
Whidbey Basin	PSS019	Possession Sound near Gedney Island	Snohomish	7	101	48.0117	-122.3000

Marine Region	Station	Description	County	WRIA	Maximum Depth (m)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
Whidbey Basin	SAR003	Saratoga Passage north of East Point	Island	6	149	48.1083	-122.4900
Whidbey Basin	SKG003	Skagit Bay near Strawberry Point	Island	6	24	48.2967	-122.4883
Hood Canal Basin	HCB003	Hood Canal near Eldon	Mason	14	144	47.5383	-123.0083
Hood Canal Basin	HCB004	Hood Canal east of Great Bend near Sisters Point	Mason	14	55	47.3567	-123.0233
Hood Canal Basin	HCB007	Hood Canal in Lynch Cove	Mason	14	21	47.3983	-122.9283
Hood Canal Basin	HCB010	Hood Canal north of Seabeck and south of Bangor	Kitsap	15	100	47.6670	-122.8200
Main Basin	CMB003	Commencement Bay in center and off Browns Point	Pierce	10	150	47.2900	-122.4483
Main Basin	EAP001	East Passage southwest of Three Tree Point	King	9	213	47.4167	-122.3800
Main Basin	ELB015	Elliott Bay east of Duwamish Head	King	9	82	47.5967	-122.3683
Main Basin	OCH014	Port Orchard south of Point Bolin	Kitsap	15	20	47.6733	-122.5933
Main Basin	PSB003	Puget Sound Main Basin off West Point	King	8	40	47.6600	-122.4417
Main Basin	SIN001	Sinclair Inlet near Naval Shipyard	Kitsap	15	16	47.5500	-122.6417
South Basin	BUD005	Budd Inlet near Olympia Shoals	Thurston	13	15	47.0917	-122.9167
South Basin	CRR001	Carr Inlet off Green Point	Pierce	15	95	47.2767	-122.7083
South Basin	CSE001	Case Inlet off southern Heron Island	Pierce	15	55	47.2650	-122.8433
South Basin	DNA001	Dana Passage south of Brisco Point	Thurston	13	40	47.1617	-122.8700
South Basin	GOR001	Gordon Point north of Ketron Island	Pierce	15	168	47.1833	-122.6333
South Basin	NSQ002	Nisqually Reach west of Devils Head	Pierce	13	100	47.1683	-122.7867
South Basin	OAK004	Oakland Bay in mid-bay and north of Eagle Point	Mason	14	19	47.2133	-123.0767

WRIA: Water Resource Inventory Area

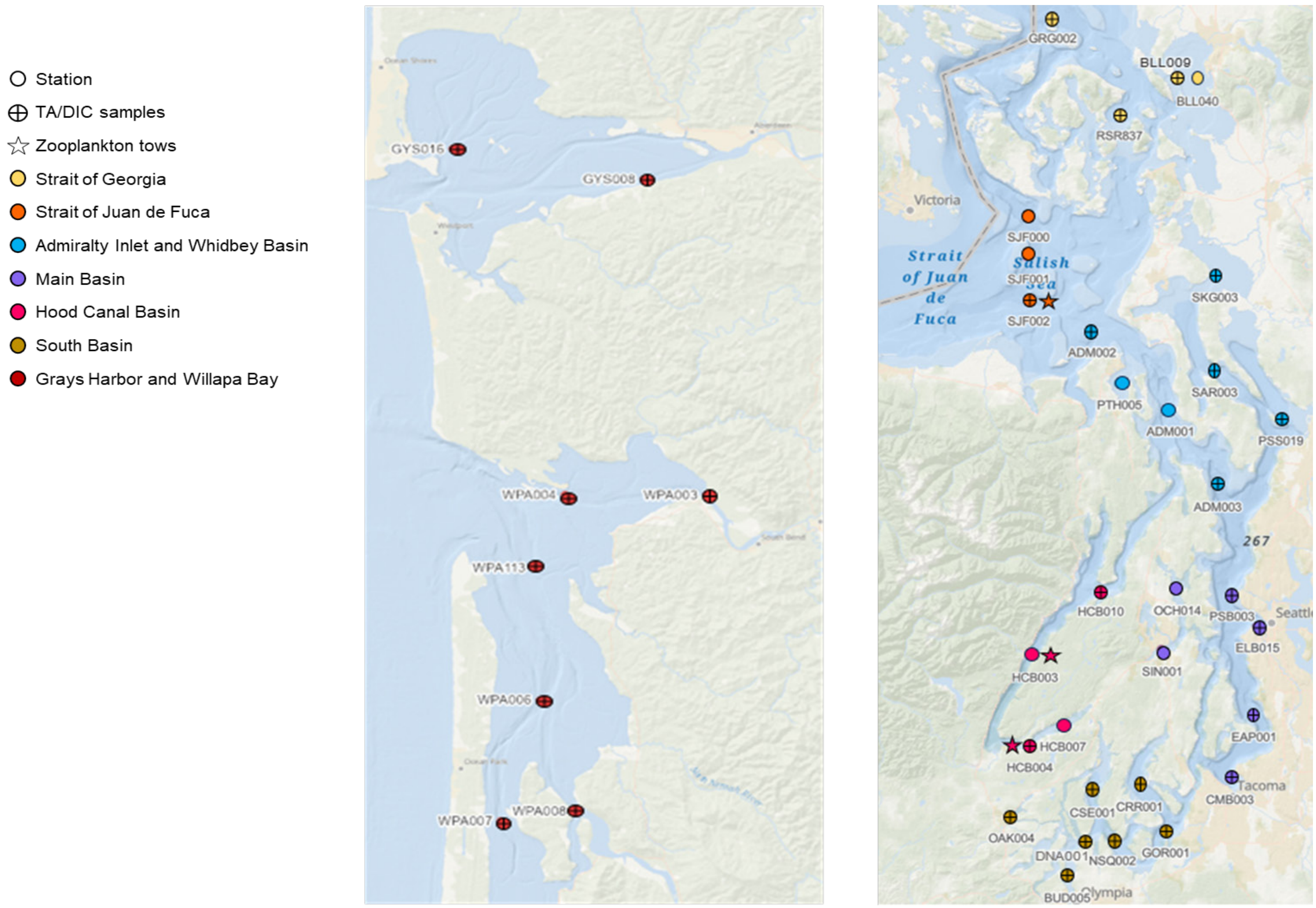

Figure 3. Map of marine water column stations to sample in 2025. Map legend is on the left. Map panel on left shows stations in Grays Harbor (north) and Willapa Bay (south). Map panel on right shows stations in Puget Sound.

7.2.2 Field parameters and laboratory analytes to be measured

We plan to collect multiple parameters through field observations, sensor measurements, and seawater samples. Field observations will consist of weather and sea conditions. An instrument package of multiple sensors will measure a broad suite of hydrographic, chemical, optical, and biological conditions in the water column at each station. The instrument package will also have Niskin water samplers to collect discrete seawater samples from targeted depths on upcasts. Table 12 lists parameters that we plan to collect.

Table 12. Parameter type, parameters, and nominal depths for the Marine Water Monitoring Program to collect.

Parameter type	Parameter	Depth (m)
Observations	Weather and sea conditions	NA
Sensor	Conductivity (to calculate density and salinity)	0 to NB
Sensor	Temperature	0 to NB
Sensor	Pressure (to calculate depth)	0 to NB
Sensor	Dissolved oxygen	0 to NB
Sensor	Nitrate	0 to NB
Sensor	Light transmission	0 to NB
Sensor	Beam attenuation	0 to NB
Sensor	Turbidity	0 to NB
Sensor	Fluorescence	0 to NB
Discrete sample	Chlorophyll *a* and pheophytin	0, 10, 30
Discrete sample	Dissolved inorganic nitrate	0, 10, 30, [1]80, [1]140, 10mAB, NB
Discrete sample	Dissolved inorganic nitrite	0, 10, 30, [1]80, [1]140, 10mAB, NB
Discrete sample	Dissolved inorganic ammonium	0, 10, 30, [1]80, [1]140, 10mAB, NB
Discrete sample	Dissolved inorganic orthophosphate	0, 10, 30, [1]80, [1]140, 10mAB, NB
Discrete sample	Dissolved inorganic silicate	0, 10, 30, [1]80, [1]140, 10mAB, NB
Discrete sample	Total alkalinity	0, 30, 10mAB
Discrete sample	Dissolved inorganic carbon	0, 30, 10mAB
Discrete sample	Salinity	0, 30, 10mAB

[1] 80- and 140-m samples are collected only at three stations in the Strait of Juan de Fuca.
NA: not applicable
NB: near bottom
10mAB: 10 m above bottom

We added a deepwater target depth for total alkalinity and dissolved inorganic carbon and their concurrent salinity and nutrient samples. We will collect samples from 10 m above bottom to evaluate deepwater ocean acidification conditions in 2025.

We decided to pause sampling for particulate organic carbon, total organic carbon, particulate nitrogen, and total nitrogen. We will analyze data on and related to these four parameters. Our findings will contribute to a decision on whether and where to resume collecting them.

New parameters are added to the sampling program based on advances in monitoring and gain insight into hydrography, food webs or biogeochemical processes.

7.3 Modeling and analysis design

Sensor and seawater sample data are used by Ecology's Modeling and TMDL Unit to support Salish Sea Model applications. Acceptance criteria for quality of data are described in the Ecology's Quality Assurance Project Plan for Salish Sea Model Applications (McCarthy et al. 2018)

7.3.1 Analytical framework

NA

7.3.2 Model setup and data needs

NA

7.4 Assumptions underlying design

An inherent design assumption of monthly ambient sampling is that the data are representative of broader environmental conditions; however, monthly measurements are snapshots of conditions and may not fully capture the range of conditions nor unique events.

Though we take steps to assure representativeness, data users must be careful not to overstate these measurements. A single profile cannot ascertain cross-channel, surface, or temporal variability. This is especially the case for measurements taken when values change rapidly with the tide, on the diurnal period, or during events such as storms, weather events, or high or low river flows.

7.5 Possible challenges and contingencies

As new ecological information emerges and different questions arise, the monitoring priorities and strategy will change. Station locations, monitoring methods, and collected data are updated as information priorities evolve and scientific needs change. Any updates will be captured in future addenda to this monitoring plan or, if significantly different, will be captured in a new Quality Assurance Monitoring Plan.

7.5.1 Logistical problems

There is no attainment objective established given the safety considerations specific to marine water sampling. We make all possible efforts to complete all sampling every month to avoid gaps in the data record. Even with the best planning, challenges are bound to arise when working outside and dealing with weather and tides, changes in staffing, and sampling platform or sensor issues. To mitigate these issues, we:

- Schedule multiple field back-up dates.
- Train multiple staff on field procedures.
- Have back-up sampling platform options.
- Maintain interchangeable sets of auxiliary equipment, ensure equipment are well maintained, and thoroughly check functionality before starting fieldwork.
- Conduct regular assessments of all procedures and equipment to ensure all are performing correctly.

7.5.2 Practical constraints

We will not conduct field operations under adverse or unsafe conditions for safety reasons. A research vessel (boat) allows us to collect data under a broader tolerance of weather and sea conditions than a floatplane does. Field operations by boats are limited by high winds and fog. Therefore, we plan to closely track the weather and have a flexible field schedule. They will ensure data collection continues throughout the year.

We will suspend data collection in areas where access is denied or operations. Mainly, these are restricted areas with prohibited access by federal agencies such as the U.S. Coast Guard, Federal Aviation Administration, or Department of Defense. Furthermore, we will determine if another station outside restricted areas is feasible for field operations and data collection.

Budget constraints may cancel or curtail data collection and assessment through staff reductions or limited availability of resources. Examples of resources are equipment and supplies, laboratory analyses, or calibration and maintenance services. Equipment that declines in quality can fail to generate data that meet quality standards.

Sample analyses are dependent on timely transfer of water samples to laboratories and on functioning laboratory instruments. Careful planning of sample intake and transfers minimizes holding times between receivals and analyses. However, laboratories' staffing changes and instrument failures can occur. We will mitigate instrument failures by investigating alternate laboratories to run analyses in interim or by ceasing sample collection until instrument is repaired or replaced.

Any circumstance that interferes with data collection and quality will be noted and discussed in reports and data summaries.

7.5.3 Schedule limitations

Every effort is made to sample every station every month, but the schedule can be disrupted by unfavorable weather conditions, equipment failures, limited staffing, or unavailable research vessels. Whenever possible, field work is rescheduled until completed. The following activities will help mitigate unforeseen schedule limitations:

- Prepare and implement annual schedule to provide adequate time for:
    - QAMP review and approval, including any annual addendum.
    - Obtaining any necessary sampling permits.
    - Planning on sufficient internal laboratory supplies such as sample bottles, chemical reagents, and instruments.
    - Annual laboratory accreditation for MWL.
    - Confirming laboratory capacity at MEL and external laboratories for sample transfers, preservations, analysis, and reports.
- Schedule field activities on back-up dates.
- Schedule one of the back-up sampling platform options.

8.0 Field Procedures

8.1 Invasive species evaluation

We use research vessels with little to no opportunity for contact with invasive species. Therefore, we have low risk of transporting invasive species between water bodies. Any aquatic vegetation on boat trailers and instrument packages will be removed before departing boat launches. Furthermore, field staff make every effort to minimize the spread of aquatic organisms by following protocols set in "Standard Operating Procedures to Minimize the Spread of Invasive Species," Ecology's SOP No. EAP070 (Glisson 2024).

8.2 Measurement and sampling procedures

Marine Waters Monitoring (MWM) staff follow relevant SOPs that outline the measurement and sampling procedures (Table 13).

Table 13. Relevant standard operating procedures (SOPs) for data collection.

Field or Laboratory Activity	Relevant SOP
Collection of seawater samples	EAP025 (Young et al. 2023b)
Preparation of reagents for sample preservation and analysis	EAP028 (Coleman 2022a)
Marine water salinity sample analysis	EAP053 (Coleman 2022b)
Analysis of chlorophyll samples	EAP026 (Young and Jendrey 2023)
Assessment of sensor performance in laboratory-controlled conditions	EAP086 (Young et al. 2023a)

Sampling will occur within a 500-m radius of station's target coordinates. This is the recommended procedure found in the original Puget Sound Estuary Program (PSEP) protocols and is the preferred method for long-term monitoring (PSEP 1998).

Sampling platforms

MWM staff will sample aboard research vessels operated by Ecology and Western Washington University Shannon Point Marine Center. Research vessels make it possible to collect more water samples and support collaborations than sampling by a float plane allows. Vessels can also handle more inclement weather, such as fog and bigger waves, than a float plane can. Yet, vessels limit the flexibility to collect data from rotational stations because of transit times, sea conditions, and logistics. Each vessel has a winch to lower and retrieve instruments and water sampling equipment.

Each sampling platform will have:

- Required U.S. Coast Guard approved personal flotation devices (PFDs).
- Emergency equipment [e.g., lifeboats, flares, first aid kits, automated external defibrillator (AED), fire extinguisher].
- Ship-to-shore radio equipment with very high frequency (VHF) waves to communicate with other vessels for safety.

- Global Positioning System (GPS) to attain station position per target coordinates.
- Electronics to check station depths, monitor tidal height, and record sampling time.
- Meteorological instruments to measure wind variables.

Tidal information will come from multiple sources such as Nobeltec® Tides and Currents software, U.S. National Oceanic and Atmospheric Administration (NOAA), and the Canadian Hydrographic Service (CHS).

Sensor measurements

We will use a profiling package of multiple sensors to measure hydrographic conditions at each station. The package includes sensors that will measure conductivity (density and salinity), temperature, depth (pressure), dissolved oxygen, nitrate and nitrite, in situ chlorophyll fluorescence, turbidity, and light transmission (beam attenuation). The package will have 4.0-L Niskin samplers to collect discrete water samples at target depths. The sensors and Niskin samplers will be mounted on a water sampling frame to form an oceanographic rosette. Each Niskin sampler has its end caps cocked into an open position before each cast. During a cast, the sampling frame's firing arms are triggered to release the end caps to close the Niskin samplers at target depths. This effectively captures water for filling sample bottles. With this package, we can:

- Measure the water column at a sampling rate of 16 Hz to optimize resolution for 0.5-m depth intervals from near the water surface to near bottom.
- Reduce errors because of rapid sampling rate and steep parameter gradients (e.g., rapid changes in temperature).
- Conduct either real-time or autonomous deployments at a rate no faster than 0.5 m/s.
- Capture water at target depths with Niskin samplers to collect water for discrete samples.
- Attach an oxygen optode as a reference check alongside a dissolved oxygen membrane sensor (SBE 43) during each cast.
- Have a set of replicate sensors in storage.
- Swap or replace sensors that exhibit issues or damage with newly calibrated, operational sensors.

In addition, we plan to use a smaller conductivity-temperature-depth (CTD) package integrated with an optical dissolved oxygen sensor for coastal bay stations. This package is intended for sampling in shallow areas and, therefore, less discrete water samples to collect. This package does not have capability to connect a Niskin water sampler. To compensate, we will deploy a Niskin sampler alongside the CTD to measure the water column as closely as possible to capture the water. We plan to run a six-month side-by-side comparison of the profiling package and smaller CTD package to confirm that the latter package meets expectations.

All profiles will be measured from the water surface to near bottom. The instruments record measurements internally which field staff will upload for subsequent data processing. Upon return to Ecology, staff will copy the instrument data to a secure network server.

In addition, we take pressure sensor measurements to determine the daily atmospheric pressure offset. Pressure measurements are recorded before lowering and after raising the instrument package in the water. These measurements are then used to calculate the pressure offset. This offset is also used during data processing to generate the most accurate readings of in-water pressure.

Table 7 itemizes sensors that we plan to use. These sensors are specially manufactured for oceanographic measurements at resolutions that MWM staff desire to meet measurement quality objectives.

All deployments of CTD and auxiliary sensors follow manufacturer operating and maintenance manuals. MWM technicians regularly review manuals and technical notes from manufacturers to stay up to date on improvements and changes to sensor operation methods.

During each station attempt, MWM field staff collect complete vertical profiles of the water column and collect water at target depths.

Monthly sensor assessments verify that sensors are performing as expected. They provide an early detection of potential issues of one or more sensors. If a sensor's performance is questionable, we replace it with an equivalent sensor and reassess before field deployment. In addition, we qualify the questionable sensor's measurements. Specific routines and information for sensor performance checks can be found in SOP EAP086 (Young et al. 2023a).

Discrete sample collection

MWM staff will follow SOP EAP025 to collect seawater samples for a suite of analytes. Seawater sampling methods are derived from standard international oceanographic sampling methods published by the Intergovernmental Oceanographic Commission (IOC 1994). Collection of water samples varies from station to station. Parameters to collect are dependent on several factors such as depth, collaborations, budget, historical precedent, and strategic importance.

The monthly plan for collecting seawater samples is in Table 14. Table 8 lists parameters that laboratories will analyze the seawater samples for.

We plan to use the same Niskin water sampler to collect water for dissolved inorganic nutrient samples and chlorophyll *a* samples. We will also collect triplicates for these parameters, but they will not be from the same station because the volume of the Niskin water sampler does not provide enough water to fill triplicates for both nutrient and chlorophyll *a* samples. Instead, the triplicates will be collected from separate stations.

Dissolved inorganic nutrient triplicates test field precision. A test of true laboratory precision requires more water volume than is available to generate a split sample in the laboratory. Currently, UW-MCL does not offer this service.

Chlorophyll *a* triplicates will be evaluated to test if they fall outside of established limits (i.e., relative standard deviation). If they do, the reviewer flags triplicate data. Any laboratory measurement problem that cannot be resolved for a specific sample is given an appropriate data quality flag.

Dissolved inorganic carbon is sensitive to headspace equilibration, so each individual sample must come from separate unopened Niskin water samplers. Therefore, field replicates are collected from the same depth but different Niskin samplers for dissolved inorganic carbon and total alkalinity. We will also collect concurrent salinity and nutrient samples. These parameters support ocean acidification monitoring.

Table 14. Monthly discrete sampling plan for each marine region and station.

The table lists marine regions, stations, and parameters to collect at specified nominal depths (m): 0, 10, 30, 80, 140, 10 m above bottom (10mAB), or near bottom (NB). Multiple entries of nominal depths indicate field replicates to collect. The table also shows the number of samples for each region and parameter and the monthly totals of stations and samples per parameter.

Marine Region	Station	Nutrients	Chlorophyll	TA/DIC	Salinity	Zooplankton
Grays Harbor	GYS008	0	0	0	0	NC
Grays Harbor	GYS016	0, 10	0, 10	0	0	NC
Willapa Bay	WPA004	0, 10	0, 10	0	0	NC
Willapa Bay	WPA113	0, 10	0, 10	0	0	NC
Willapa Bay	WPA006	0, 10	0, 10	0	0	NC
Willapa Bay	WPA007	0, 10	0, 10	0	0	NC
Willapa Bay	WPA008	0, 10	0, 10	0	0	NC
Willapa Bay	WPA003	0	0	0	0	NC
Coastal Bays Totals	**8**	**14**	**14**	**8**	**8**	**0**
Hood Canal Basin	HCB007	0, 10, NB	0, 10	NC	NC	NC
Hood Canal Basin	HCB004	0, 10, 30, 10mAB	0, 10, 30	0, 30, 30, 10mAB	0, 30, 30, 10mAB	Complete profile vertical tow
Hood Canal Basin	HCB003	0, 10, 10, 10, 30	0, 10, 30	NC	NC	Complete profile vertical tow
Hood Canal Basin	HCB010	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB	0, 30, 10mAB	NC
Hood Canal Basin Totals	**4**	**16**	**11**	**7**	**7**	**2**
South Basin	BUD005	0, 10, NB	0, 10	0	0	NC
South Basin	DNA001	0, 10, 30	0, 10, 30	0, 30, 30	0, 30, 30	NC
South Basin	NCQ002	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB	0, 30, 10mAB	NC
South Basin	GOR001	0, 10, 30	0, 10, 30	NC	NC	NC
South Basin	CRR001	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB	0, 30, 10mAB	NC
South Basin	CSE001	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB, 10mAB	0, 30, 10mAB	NC
South Basin	OAK004	0, 10, 10, 10	0, 10	0	0	NC
South Basin Totals	**7**	**25**	**19**	**14**	**13**	**0**
Main Basin	OCH014	0, 10, NB	NC	NC	NC	NC
Main Basin	PSB003	0, 10, 30	0, 10, 30	0, 30	0, 30	NC
Main Basin	SIN001	0, 10, NB	0, 10	NC	NC	NC

Marine Region	Station	Nutrients	Chlorophyll	TA/DIC	Salinity	Zooplankton
Main Basin	ELB015	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB	0, 30, 10mAB	NC
Main Basin	EAP001	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB	0, 30, 10mAB	NC
Main Basin	CMB003	0, 10, 30, 10mAB	0, 0, 0, 10, 30	0, 30, 10mAB, 10mAB	0, 30, 10mAB	NC
Main Basin Totals	**6**	**21**	**16**	**12**	**11**	**0**
Strait of Georgia	BLL009	0, 10	0, 10	0	0	NC
Strait of Georgia	BLL040	0, 10, NB	NC	NC	NC	NC
Strait of Georgia	RSR837	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB	0, 30, 10mAB	NC
Strait of Georgia	GRG002	0, 10, 30, 10mAB	0, 10, 30	0, 30, 30, 10mAB	0, 30, 30, 10mAB	NC
Strait of Georgia Totals	**4**	**13**	**8**	**8**	**8**	**0**
Juan de Fuca Strait	SJF000	0, 30, 80, 140	0, 30	NC	NC	NC
Juan de Fuca Strait	SJF001	0, 30, 80, 140	0, 0, 0, 30	NC	NC	NC
Juan de Fuca Strait	SJF002	0, 30, 80, 140, 10mAB	0, 30	0, 30, 10mAB	0,30, 10mAB	40 m to 0 m and 120 m to 80 m
Juan de Fuca Strait Totals	**3**	**13**	**8**	**3**	**3**	**2**
Admiralty Inlet	PTH005	0, 10, 10, 10, NB	0, 10	NC	NC	NC
Admiralty Inlet	ADM001	0, 10, 30	0, 10, 30	NC	NC	NC
Admiralty Inlet	ADM002	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB	0, 30, 10mAB	NC
Admiralty Inlet	ADM003	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB	0, 30, 10mAB	NC
Admiralty Inlet Totals	**4**	**16**	**11**	**6**	**6**	**0**
Whidbey Basin	SKG003	0, 10, NB	0, 10	0	0	NC
Whidbey Basin	SAR003	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB, 10mAB	0, 30, 10mAB	NC
Whidbey Basin	PSS019	0, 10, 30, 10mAB	0, 10, 30	0, 30, 10mAB	0, 30, 10mAB	NC
Whidbey Basin Totals	**3**	**11**	**8**	**8**	**7**	**0**
Monthly Totals	**39**	**129**	**95**	**66**	**63**	**4**

10mAB: 10 m above bottom
NB: near bottom
NC: not collecting
TA/DIC: total alkalinity and dissolved inorganic carbon

Field Observations, Weather, and Conditions

Field technicians will make observations and record weather and related conditions that are useful for interpreting data and related water conditions. Furthermore, they play an important role in high quality data interpretation and assessment of monitoring results. These observations and conditions include:

- Water color.
- Debris.
- Sightings of fronts, eddies and other surface current features.
- Evidence of river discharge.
- Plankton blooms and presence of algal mats.
- Sea surface conditions and wave and swell height.
- Tidal activity, if apparent.
- Wind speed and direction.
- Cloud cover (%) and cloud type.
- Presence of direct sunlight.
- Mammal sightings.
- General weather condition (overcast, cool, rainy, foggy, sunny, warm).

Many of these observations are subjective, depending on the experience and background of the observer. Technicians and volunteers use standardized guides whenever possible to make observations. Exceptions to this may include wind speed and direction, which can be determined by meteorological instruments aboard the sampling platform.

Critical field data such as correct sampling location (latitude and longitude) are best managed while sampling, so technicians are trained to recognize landmarks and proper location and check these before sampling. Time of deploying the instrument package is recorded using field laptops. Laptop time accuracy is routinely verified. Tide and current information are added after sampling.

8.3 Containers, preservation methods, holding times

Table 15 presents containers, preservation methods, and holding times for each sample bottle.

Table 15. Sample containers, preservation, and holding times.

Parameter	Matrix	Minimum Quantity Required	Container	Preservative	Holding Time
Dissolved inorganic nutrients (nitrate, nitrite, silicate, orthophosphate, and ammonium)	Water	40 mL	60 mL narrow-mouthed seawater aged polyethylene	Store on ice in the field. Freeze upon arrival at the laboratory.	3 months
Chlorophyll *a*	Water	65 mL	65 mL narrow-mouthed polyethylene	Store on ice in the field. Filter immediately upon arrival at laboratory and freeze in 90% acetone.	4 weeks
Total alkalinity and dissolved inorganic carbon	Water	500 mL	500 mL borosilicate glass bottle	Preserve sample with 200 µL super-saturated $HgCl_2$. Apply Apiezon® L grease to stopper, insert & twist to remove all air. Store in cool (~4°C), dark conditions.	6 months
Salinity	Water	100 mL	125 mL, brown wide-mouth seawater aged polyethylene	None	6 months

8.4 Equipment decontamination

MWM staff make all efforts to avoid sampling in waters that contain high levels of contaminants, such as oil spills or toxic substances. If contact is suspected, staff follow all recommended protocols from instrument manufacturers for cleaning and, if needed, re-calibrating sensors. If non-sensor sampling equipment may be contaminated, staff follow Ecology's SOP EAP090, "Decontamination of Sampling Equipment for Use in Collecting Toxic Chemical Samples when cleaning equipment" (Friese 2020).

8.5 Sample identifier (ID)

All sample bottles are labeled with unique sample numbers. These numbers are reconciled with the marine water database that contains information on station, date, depth, and parameter(s). They are further reconciled with logs of internal laboratory analysis and with chain of custody forms for MEL and external laboratories.

8.6 Chain of custody

Chain of custody ensures that samples are accounted for throughout the process from field collections to laboratory analyses, including data reports. Field staff will deliver chain of custody information that has:

- Sample identification number.
- Sample counts.
- Station, date, depth, bottle number, and parameter.
- Name of person holding or delivering samples.
- Parameter(s) to analyze.

Chain-of-custody procedures manage sample counts, handle schedules, and track analysis. When samples are ready for delivery, external laboratories are contacted to schedule delivery. Advance notice is given so that transfer is successful, and samples are kept in optimal storage conditions at all times during transport and transfer.

Upon sample delivery, laboratory personnel log and assign a laboratory identification number to each sample. Each laboratory sample number must correspond to station, sample date, and depth. When analytical results are received from laboratories, chain of custody forms are reconciled with data to ensure complete delivery and correct invoicing for all results. MWM staff will research and investigate any discrepancies in coordination with the laboratory(s) until the problem is resolved.

8.7 Field log requirements

MWM technicians use rugged tablets and/or laptops as electronic field logging devices. The MWM program has in-house applications to create sampling routes, record survey information, and upload them into a SQL Server database on a secured network server. Technicians will record:

- Sampling route name.
- Station.
- Coordinates.
- Vessel operator’s name.
- Field crew names.
- Vessel name.
- Laptop.
- Date.
- Time.
- Weather and environmental conditions.
- Field observations.
- Samples collected, including parameter, Niskin sampler number, and target depths.
- Sample bottle numbers.
- Instrument package’s information such as:
    - Serial number of internal data logger (e.g., SBE 25*plus*).

    - Cast start time.
    - Replicate cast number.
- Comments.

In addition, any changes or deviations from the sampling plan or unusual circumstances that might affect interpretation of results are recorded.

A paper log is brought along on every survey to use as a backup if the electronic form or device should fail. Digital copies of the field and sample logs are stored for future reference on a shared, secure, frequently backed up network server.

Field notebooks will contain backup paper logs, maps, checklists, station and sampling plans, SOPs, technical notes, a weather dictionary, and safety and contact information. They are resources needed for a field survey, including pre- and post-field procedures.

Technicians will take photos to document unusual and important events observed during field work.

8.8 Other activities

Annual boat safety training

Boat safety training will occur annually on one or more of Ecology's research vessels that are used for marine water monitoring. Vessel operators are licensed as captains and will provide the annual training.

Sensor maintenance

All sensors will undergo regular maintenance and annual sensor calibrations. At end of a sampling day, the instrument package will be rinsed with freshwater and flushed where appropriate with deionized distilled water. The package will also be inspected for secure connections of communication cables and tubing. Any sensors needing repair will be replaced with a functional sensor and the faulty sensor will be sent to the manufacturer for repair and re-calibration.

Notifications

Notifications will be sent to MWM staff and MEL to schedule transport of seawater samples and data processing. After sampling, MWM technicians will notify external laboratories when to expect arrival of samples they analyze.

Zooplankton sampling

We will continue to collect zooplankton samples for the Salish Sea Marine Survival Project (SSMSP) at one of the Strait of Juan de Fuca stations, SJF002, along with two vertical net tows for zooplankton at Hood Canal stations HCB003 and HCB004. For more information on SSMSP, see the "Pacific Salmon Foundation's Salish Sea Marine Survival Project — 2017 – 2018 Research Plan" (PSF 2016).

9.0 Laboratory Procedures

9.1 Lab procedures table

Seawater nutrient and salinity (from sensor performance assessments) sample analyses are conducted by the University of Washington Marine Chemistry Laboratory (UW-MCL). Salinity (from the field) and chlorophyll *a* samples are analyzed by Ecology's Marine Waters Laboratory (MWL). Total alkalinity and dissolved inorganic carbon sample analyses are conducted by the U.S. National Oceanic Atmospheric Administration Pacific Marine Environmental Laboratory (NOAA PMEL). More details on laboratory procedures are described in the "Manchester Laboratory Users Manual" (MEL 2016) and in recommended Puget Sound Estuary Program (PSEP) protocols (PSEP 1991; PSEP 1997). Table 16 lists the specific methods for each analyte.

Table 16. Laboratory measurement methods.

Analyte	Sample Matrix	Expected Range of Results	Detection Limit or Reporting Limit	Limit Type	Analytical (Instrumental) Method
Total alkalinity	Water	500–2180 µmol/kg	±0.1% µmol/kg	RL	Dickson et al., 2007 (SOP 3b)
Dissolved inorganic carbon	Water	550–2180 µmol/kg	±0.1% µmol/kg	RL	Dickson et al., 2007 (SOP 2)
Dissolved inorganic nitrate	Water	0.00–40.00 µM	0.18 µM, 0.0025 mg/L	DL	EPA 353.4; IOC, 1994
Dissolved inorganic nitrite	Water	0.00–2.00 µM	0.01 µM, 0.0001 mg/L	DL	EPA 353.4; IOC, 1994
Dissolved inorganic ammonium	Water	0.00–10.00 µM	0.09 µM, 0.0013 mg/L	DL	EPA 349
Dissolved inorganic orthophosphate	Water	0.00–4.00 µM	0.03 µM, 0.0009 mg/L	DL	EPA 365.5; IOC, 1994
Dissolved inorganic silicate	Water	0.00–200.00 µM	0.45 µM, 0.013 mg/L	DL	EPA 366; IOC, 1994
Chlorophyll *a*	Water	0.00–200.00 µg/L	0.01 mg/L	RL	EPA 445.0
Salinity	Water	0.00–36.00 PSU	0.002 PSU	RL	IOC, 1994
Salinity	Water	0.05–39.00 PSU	0.05 PSU	RL	Coleman (2022b)

DL: detection limit
RL: reporting limit

9.2 Sample preparation method(s)

Sample preparation methods follow SOPs in Table 13 and analytical methods, including filtration and preservation, in Table 15. No special sample preparation is needed for the water samples. Each laboratory that does the sample analysis also takes care of any necessary bottle preparation. Multiple streams of bottles are delivered to our lab monthly, which are then sorted for the specific routes.

9.3 Special method requirements

NA

9.4 Laboratories accredited for methods

All laboratories conducting analyses for the Marine Waters Monitoring (MWM) program are accredited through Ecology's Laboratory Accreditation Program. Each laboratory was selected to analyze discrete seawater samples and meet measurement quality objectives. All laboratories are accredited by Ecology through its Laboratory Accreditation Unit.

- University of Washington Oceanography Department's Marine Chemistry Laboratory (UW-MCL) analyzes nutrient and salinity samples. Salinity samples are from controlled saltwater baths used for sensor performance assessments.
- MWM program's field technicians analyze chlorophyll *a* samples in Ecology's Marine Waters Laboratory (MWL).
- U.S. National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory (PMEL) analyzes dissolved inorganic carbon and total alkalinity.

The analytical techniques employed at PMEL for analysis of dissolved inorganic carbon (DIC) and total alkalinity (TA) in seawater and the future applications of any modified analytical techniques for DIC and TA less than 1,500 µmol/kg in estuarine waters of the Salish Sea are relatively novel. For these and other reasons, Ecology has an existing Laboratory Accreditation Waiver on file for DIC and TA analyses (Gonski et al. 2019).

10.0 Quality Control Procedures

Quality control (QC) procedures used during field sampling and laboratory analyses provide data for determining the accuracy and precision of the monitoring results. All sensors, laboratory equipment, and instruments are subjected to routine and strict performance tests. In addition, they undergo recommended maintenance and calibration procedures. Many of these quality control procedures can also be found in detail in the Puget Sound Estuary Program (PSEP) Protocols (1997).

The monitoring program's quality control procedures consist of three parts. A summary of procedures for each part is:

1. Discrete water samples — Evaluate and control analytical precision and bias through use of laboratory check standards, replicates, and blanks.
2. Continuous vertical sensor profiles — Collect water samples to verify sensor performance. Also assess sensor performance in Ecology's Marine Waters Laboratory (MWL) using a saltwater bath under controlled conditions.
3. Field observations — Record and standardize site-specific observations of weather and general conditions. Use pre-designated, standardized data types, data units, and lists of pre-defined, descriptive terms.

Specific activities are performed to test and ensure high quality data for different data types. In addition, sensor technology changes which then update steps in the QC process for sensor measurements. The details of activities are documented in Ecology's SOP No. EAP088 "Standard Operating Procedure for Marine Waters Data Quality Assurance and Quality Control" and summarized in this QAMP (Bos 2022). This SOP is updated every three years.

10.1 Table of field and laboratory quality control

Table 17 presents number of field and laboratory replicates, blanks, and standards for each discrete parameter.

Table 17. Quality control samples, types, and frequency.

Parameter	Field Blanks	Field Replicates	Laboratory Check Standards	Laboratory Method Blanks	Analytical Duplicates	Laboratory Matrix Spikes
Dissolved inorganic nutrients	2/sampling day	3 at 3 stations/ month	2–3	2/sampling day	NA	NA
Chlorophyll *a*	2/sampling day	3 at 2 stations/ month	4 total: 2 high, 2 low	2/sampling day	NA	NA
Total alkalinity	NA	2 at 6 stations/ month	1 at each end of analytical run	NA	At discretion of analyst	NA
Dissolved inorganic carbon	NA	2 at 6 stations/ month	1 at each end of analytical run	NA	NA	NA
Salinity (field samples)	NA	2 at 3 stations/ month	NA	NA	NA	NA

NA: Not applicable

Discrete water samples QC

All laboratory results are reviewed and assessed using QA/QC procedures. This includes confirming field log information, chain-of-custody tracking, analytical results from laboratories, and uploads/entries into the Environmental Assessment Program Marine Waters (EAPMW) database. Through data analysis, analytical results will be checked for:

- Data being within expected ranges.
- Data gaps or missing expected results.
- Spurious values that are negative or have unreasonable magnitude.
- Data outliers outside expected data pattern, whether too high or too low.
- Climatological fit that is within historical data ranges and patterns.
- Reasonable fit with proximal results at neighboring station, day, or depth.
- Seasonality in that data reflect seasonal processes or effects.
- Logical relationships in which fractions of related variables make sense (e.g., relate total nitrogen and dissolved nitrogen).

These checks are performed through statistical and graphical analyses.

Field replicates

Replicate samples help determine field and sampling variability. One station from each survey of 10 sites is sampled to conduct a quantitative determination of homogeneity of conditions, along with precision and bias of sampling methods. Parameters to be replicated include nutrients, chlorophyll *a*, total alkalinity, dissolved inorganic carbon, and salinity.

Laboratory replicates

Total variation in laboratory samples is assessed by collecting replicate samples from the same Niskin sampling bottle for all parameters at 5% or more of sites. These replicates are used to assess whether the data quality objectives for precision were met. If the objectives were not met, the data are qualified. In addition, each laboratory that analyzes field samples routinely performs replicate sample analyses using sample splits within laboratory batches for quality control purposes. The difference between field and laboratory variability is a measure of the sample field variability.

Laboratory control standards

For testing laboratory performance and analyst proficiency, check standards or laboratory control samples of known concentrations are included with every sample batch. Recovery percentage is calculated from these results and therefore can be used as a measure of analytical accuracy and bias. If the results fall outside of established limits, data associated with the batch is flagged by the reviewer. Any measurement problem that cannot be resolved is given a data quality flag.

Laboratory blanks

Blanks are prepared and analyzed in each laboratory to determine if samples could be contaminated during processing and analysis. Blanks are generally run before and after each batch of samples and compared to established acceptance limits. Blank results are reported by each lab and are included with each data set. Blank results are evaluated by the marine waters monitoring group and receive final approval from the monitoring coordinator or senior oceanographer.

A positive blank can indicate laboratory contamination. Blanks are important to measure, especially to determine the accuracy of low-level samples near the detection limits. Blank responses are used to determine method detection limits (MDLs) and, in some cases, to apply data quality flags to sample batches. Table 17 lists the QA/QC samples used to perform quality assessment of laboratory procedures and data results.

Dissolved inorganic nutrients

UW-MCL analyzes dissolved inorganic nutrient samples with two types of checks that we provide. We obtain low nutrient seawater (LNSW), a standard reference material, from Ocean Scientific International, Ltd. (OSIL). This LNSW can be used as both a method check and standard check. Two bottles from every set of 64 are filled with OSIL LNSW as a method blank. At the end of each field day, field staff fills an empty nutrient sample bottle with OSIL LNSW as a standard check. The standard check replicates the standard field collection method. Nutrient samples are analyzed by UW-MCL. This lab runs a standard check and a blank check at the beginning and end of each sample analysis run.

Chlorophyll *a*

MWL analyzes chlorophyll *a* samples. For each field run, we make a filtered seawater blank and a method blank using deionized water before and after filtration of the samples. The seawater blank serves as a check on reagents. The method blank serves as a check on laboratory analysis.

Total alkalinity, dissolved inorganic carbon, and salinity

NOAA PMEL analyzes dissolved inorganic carbon and total alkalinity samples. The laboratory uses Certified Reference Materials (CRMs) provided by A.G. Dickson of Scripps Institution of Oceanography (SIO) to calibrate analyzers (Dickson et al. 2003). The dissolved inorganic carbon, total alkalinity, and salinity (from the field) values of the CRMs are measured and certified during preparation at SIO prior to distribution and use (Dickson et al. 2007). Recovery percentage is calculated from these results and therefore can be used as a measure of analytical accuracy and bias. If the results fall outside of established limits, data associated with the batch are flagged by the reviewer as estimates. Any measurement problem that cannot be resolved is given a data quality flag.

Sensor profiles QC

All field sensor measurements are subjected to the following tests:

- Data are within expected ranges.
- Syntax of data output are in proper format and magnitude.
- Gaps and missing data are addressed.
- Flat lined data are abnormally uniform given environmental condition and/or context.
- Sensor signal output have accurate length, number, lines, or characters.
- Sensor signal exhibits the proper rate of change given environmental conditions or context.
- Spurious results are negative or of unreasonable magnitude.
- Outliers (spikes) are outside the expected data pattern, either too high or too low.
- Climatological fit that is within historical data ranges and patterns.
- Multi-variant coherence with related parameters collected or measured at the same time or depth.
- Reasonable fit with proximal results at neighboring station, day, or depth.
- Seasonality in that data reflect seasonal processes or effects.
- Logical relationships in which fractions of related variables make sense.

Manufacturer calibrations

Sensor manufacturers calibrate field sensors annually, or sooner if a sensor needs repair. With each calibration, the manufacturer generates a new set of calibration coefficients. Also, the manufacturer reports on drift and loss of sensitivity relative to the previous calibration. The most recent calibration coefficients are applied to the data during processing prior to storage in the database. We check these calibration coefficients for electronic drift that confirms or questions sensor performance.

Sensor performance assessments

The Marine Waters Monitoring (MWM) program implemented multiple levels of testing sensors before, during, and after deployment. The tests check sensor performance and operation to determine if measurement procedures are functioning as expected and generating high quality data. Technicians routinely collect a variety of quality control samples and conduct a variety of evaluations to test whether quality objectives are being met in the field and in laboratories.

MWM staff conducts monthly sensor assessments in a controlled seawater bath where environmental effects from currents, advection, and weather are minimal. These assessments verify that the following sensors perform as expected: nitrate, transmissometer, conductivity, temperature, and dissolved oxygen. The laboratory and field sensors are run side-by-side in the bath. This paired sample approach generates a data volume adequate for more statistically robust comparisons of sensors. The monthly sensor assessments determine the precision, stability, and electrical drift of sensors prior to field use. Specific routines and information for sensor performance checks can be found in Ecology's SOP EAP086 "Marine Waters Sensor Performance Assessment – Lab Procedures" (Young et al. 2023a).

These sensor performance tests of instruments are conducted and compared to expected value ranges determined by constant, sensor-specific performance testing and to published specifications. Technicians test instrument packages under controlled conditions prior to any field survey to ensure proper operations. Additional checks of sensor performance are:

- **Nitrate sensor** – Deionized water blanks and known nitrate standard are used for frequent checks of the nitrate sensors following the manufacturer's guidelines.
- **Transmissometer** – Light and dark blanks in air are used to check the transmissometer.
- **Dissolved oxygen senso**r – Sensor measurements in bath assessments fall within 2% of the expected value (i.e., the paired bath measurement values of the assessed instrument are 98-102% of the reference instrument measurements). The instrument-to-instrument comparison ratio is confirmed by replicate measurements and an independent oxygen optode (e.g., PreSens optode). The sensor should fall within 5% of the expected result.
- **Pressure sensor** – Sensor measurements in bath assessments are:
  - Near expected pressure values, given the depth of the bath water, and
  - Continuous and stable, and
  - Comparable with the reference sensor held at the same depth within the bath.
- **Conductivity sensor** – Salinity values come from converting conductivity sensor measurements to salinity. Replicate sensor measurements in saltwater bath assessments fall within a difference of <0.2%. In addition, salinity samples from the bath are collected as sensor verification samples. UW-MCL analyzes these salinity samples. The laboratory checks them against seawater before and after analysis.
- **Temperature sensor** – Replicate sensor measurements in bath assessments fall within a difference of <0.2% between referenced sensor and assessed sensor.

Any sensor that does not pass performance checks is not deployed and is removed from the instrument pool for additional diagnostics. Any sensor malfunction is immediately recognized through sensor performance readings. Problem detection is verified in the field using plotting tools, then data collection is suspended. Once the problem is resolved and the sensor repaired or replaced, data collection can resume.

Sensor verification samples

Independent field samples are collected to compare with sensors to identify possible sensor malfunction or drift. Reference samples for chlorophyll fluorescence are collected during each sampling run. Reference samples are also used to adjust data as appropriate (Bos 2022).

Seawater samples are collected at stations where there is little to no vessel drift to minimize effects of rapidly changing horizontal water masses. Chlorophyll *a* samples are collected from 0, 10, and 30 m below water surface to capture a variety of levels typically observed in the upper water column where light is present (euphotic zone). If sensor values differ substantially from the analyzed water samples, then sensor data are "flagged" until differences are resolved.

Historically, the MWM program have been collecting discrete chlorophyll samples from 80 and 140 m at three stations in the eastern area of the Juan de Fuca Strait (SJF000, SJF001, and SJF002) until end of 2024. The program also collected samples from 80 m at a station in Admiralty Inlet north of Quimper Peninsula (ADM002) in 2019. Typically, phytoplankton, and thus, chlorophyll pigments, occurs in the euphotic zone in the upper water layer. The sampling depths of 80 m and deeper are below the euphotic zone and have chlorophyll concentrations that are often below detectable levels.

Therefore, we have decided to discontinue collecting and analyzing discrete chlorophyll samples from 80 and 140 m. This decision will optimize our resources and work efficiency. We discontinued collecting chlorophyll samples from 140 m in 2020 and will discontinue collecting them from 80 m in 2025. We will continue to collect discrete chlorophyll samples at other depths and stations within our station network. Data from these samples will cover the full range of chlorophyll *a* concentrations to adjust measurements of in situ fluorescence.

We no longer collect dissolved oxygen (DO) Winklers from the field or laboratory-controlled saltwater bath assessments (Krembs and Pool 2025). The MWM program had previously collected Winklers to verify performance of DO sensors. Instead of Winklers, we will have an independent oxygen optode attached to the instrument package near the SBE 43 Clark cell membrane oxygen sensor. Then, we will run data comparisons between the two sensors to confirm measurement validity.

Sensor profile replicates

Local currents and mixing within the water column affect the fate and transport of an individual water parcel being sampled. Additionally, platform drift due to currents and wind may alias horizontal variability within a specific location into vertical variation with depth. As such, replicate casts collected one after another provide a measure of field variability in space and time rather than a test of instrument precision and accuracy. For this reason, the MWM program uses independent, in-situ sample collection and lab testing to perform QA of sensor performance.

Field observations QC

Field observation records will have standardized options to select from for variables such as cloud cover, sea conditions, and instrument information. Field entries will be done through applications designed and built in-house. The applications aid in determining which variables are required (e.g., on-station coordinates) or optional (e.g., comments) and in standardizing values.

10.2 Corrective action processes

QC results may indicate problems with data over the course of the project. Staff and external lab analysts will follow prescribed procedures to resolve the problems. Options for corrective action may include:

- Retrieving missing information.
- Re-calibrating analytical instruments or sensors.
- Re-analyzing samples (must be done within holding time requirements).
- Modifying the analytical procedures.
- Collecting additional samples or taking additional field measurements.
- Qualifying results using QC codes.

11.0 Data Management Procedures

Data and information management are critical to maintaining an efficient, organized, long-term monitoring system capable of generating high quality, up-to-date, and informative products for managers and scientists. Data must pass all QA/QC tests before analysis, reporting, and distribution to the public. The Marine Waters Monitoring (MWM) program has invested considerable resources in maintaining and updating data processing and storage structures to facilitate distribution of data and products. There are several levels of information management required in this system.

- Field, laboratory, and sensor data management (database of final data results which pass QA/QC).
- Document management (lists, SOPs, procedures, logs, forms).
- Original data file management (raw sensor and laboratory results).
- Analytical and QA/QC information management (summary statistics, calibration information, equations, and other analysis information).
- Reports, observations, and other products (analytical results, graphs, photos, video).

The MWM program has a Microsoft SQL Server database named EAPMW to store data on:

- Field logs.
- Weather and water conditions.
- Discrete sample collections.
- Sensor profile attempts.
- Analytical results and their data qualifiers.
- Sensor profile measurements and their data qualifiers.
- Sensor information and their calibration coefficients.
- Sensor adjustment factors and calculations (dissolved oxygen, fluorescence, and nitrate).
- MWL instrument information and calibrations.
- Station information including names, descriptions, coordinates, and depths.
- Baseline of sensor data from 1999 to 2023 (25 years) to compare incoming data with historical trends.

At this time, the EAPMW database stores data from 1999 to present. Data from 1973 to 1998 remain in other formats (e.g., Microsoft Excel, Microsoft Access) until they can be transferred to the EAPMW database.

Figure 4 shows the overall organization of the data workflow and products generated by the MWM program. At many levels, it is essential for information and products to be thoughtfully organized for efficient and reliable output.

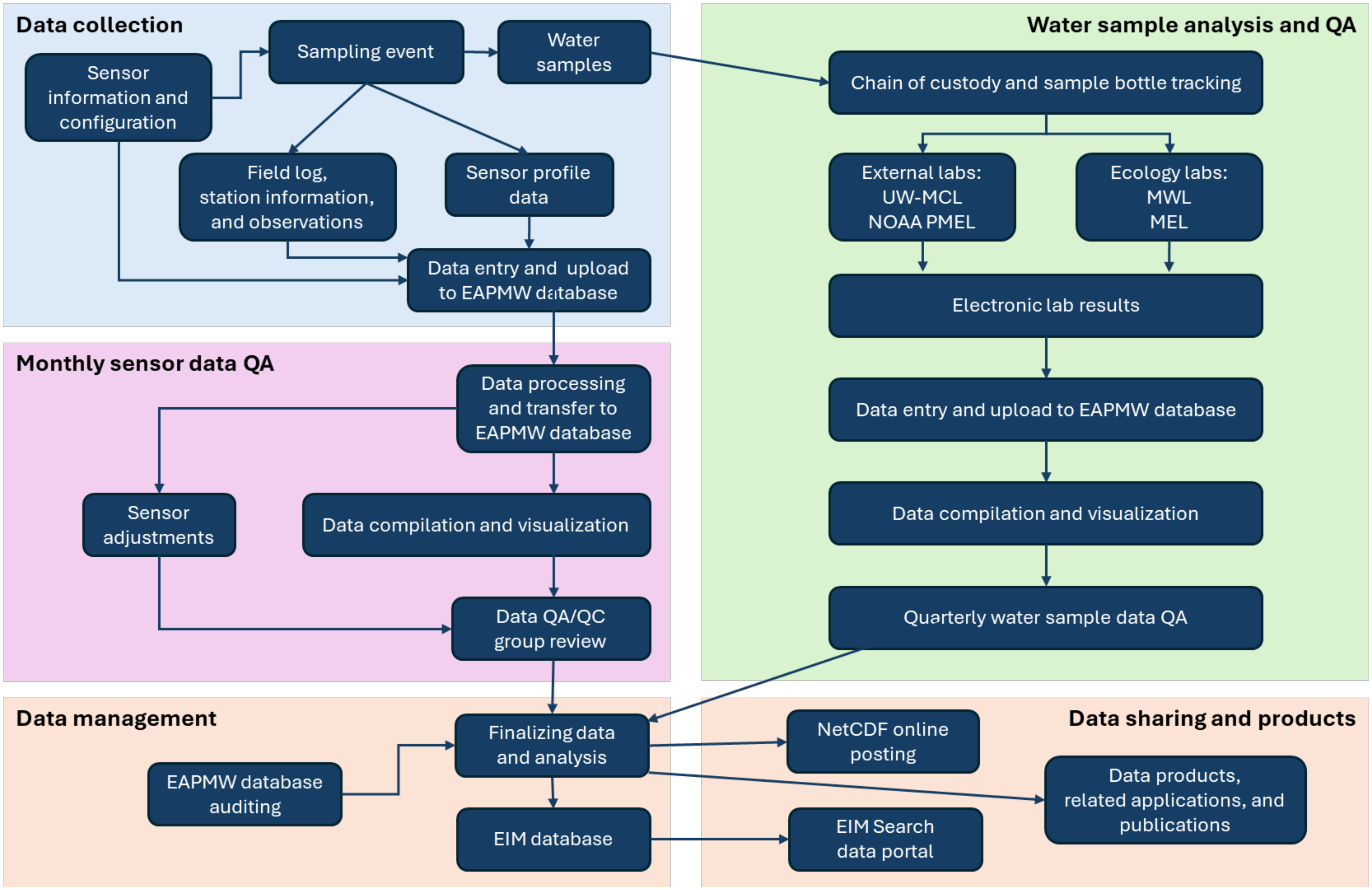

Figure 4. Data workflow and products in Marine Waters Monitoring Program.

11.1 Data recording and reporting requirements

The Environmental Information Management (EIM) System uses a field name called "StudyID" which represents identifiers (IDs) of numerous studies to connect data sets to projects that generate them. The MWM program has four EIM StudyIDs, and these are in Table 18.

Table 18. EIM Study IDs

EIM Study ID	Associated data
MarineWater	Reviewed and finalized data from 1999 to present
MarineWater-P	Provisional data undergoing review; transfer to MarineWater study ID upon completion
MarineWater1973-1989	Historical monitoring data grouped together based on primary methods used for collection and analyses.
MarineWater1989-1998	Historical monitoring data grouped together based on primary methods used for collection and analyses.

Field logs and observations

Field technicians record field data and observations into digital forms on electronic devices. As a backup to the electronic field log, a blank, printed version is brought along on every sampling event and used if the field tablet or laptop fails. They record data during sampling events and at every station, including those that are rejected. In addition, they record collections of discrete samples, and these records aid in maintaining chain-of-custody requirements from field to laboratories.

Upon return from the field, a second technician reviews field logs, electronic or printed, for correctness and completeness and then uploads data to the EAPMW database. If errors are found, the technician confirms with the original sampling team and then corrects as possible. All entries are independently verified for accuracy by another individual on the project team.

Sensor profiles

Sensor profiling data processing and management involves many procedures and calculations. These procedures follow established national standards and manufacturers' recommendations, including calculation of derived variables and adjustments of certain sensors (currently dissolved oxygen, optical fluorometer, and nitrate sensor). The processing routines incorporate standard oceanographic methods (IOC 1994). The MWM program updates and improves data processing procedures as sensor and computer technology evolves.

At a descriptive level, MWM staff:

1. Upload sensor profiling data onto electronic devices (i.e., field laptops) immediately after collection.
2. Name raw (unprocessed) data files with field date and station name.
3. Transfer data files to a secure network drive when staff return from the field.
4. Use in-house software applications and manufacturer software to process the data and transfer them to the EAPMW database.

Discrete seawater samples

Collections of discrete seawater samples are recorded onto field logs as previously described. These records are uploaded to and stored in the EAPMW database. They are then used to track samples from collections through receival of analytical results.

11.2 Laboratory data package requirements

External laboratories (UW-MCL and NOAA PMEL) typically send reports and analytical results as files attached to email. The results are reconciled and reviewed for completeness. This includes ensuring that we have results for each discrete sample and requested parameter. Any discrepancies are discussed with the laboratories or contractors for amendment. Once data have been reviewed and verified, MWM staff enter final data, including reason for any discrepancies, into the EAPMW database.

Ecology's MWL enter laboratory results for chlorophyll *a* and field salinity samples into the EAPMW database.

Ecology's MEL submits and stores analytical results in the Laboratory Information Management System (LIMS). This system is accessible through EIM from which designated MWM staff can download results. MEL follows procedures outlined in their users' manual (MEL 2016) for data review and reporting. Laboratory results are checked for missing and improbable data. MWM staff check for missing data using "Laboratory Analysis Requested" forms as a reference.

All digital raw data files are stored unchanged on a secure network server.

All analytical results include:

- Raw data results for all parameters measured at each station in electronic format.
- Replicate sample results.
- A case narrative or report with methods used, any problems with the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers.
- All associated QC results. This includes:
    - field and analytical (laboratory) control replicates,
    - laboratory control (check) samples,
    - reference materials or standards, and
    - method blanks.
- Any qualification of the results.

11.3 Electronic transfer requirements

Electronic data files are stored on a secure, network server after verification is complete and data are uploaded to the EAPMW database. MWM staff will enter and/or upload field logs, observations, sample collections, sensor measurements, and analytical results in the EAPMW database through in-house applications.

In addition, MWM staff will provide marine water column profiles and discrete nutrient results in a Network Common Data Form (netCDF). The data range from 1999 to present. The netCDF format makes data accessible on multiple computer platforms and with various software such as R, Python, and MATLAB. We chose to provide netCDF files so that large-volume data users such as regional Puget Sound modelers can access the marine water column data that we collect. The netCDF files are posted on Ecology's website at: https://ecology.wa.gov/research-data/monitoring-assessment/puget-sound-and-marine-monitoring/water-column-data. They will be updated every January and July.

11.4 EIM/STORET data upload procedures

The EAPMW database is under development to transfer data Ecology's EIM database upon completion of data quality control and quality assessment. We also need to develop a synchronization process to update EIM with edits and additions from EAPMW. All data that pass QA/QC are finalized and stored in EAPMW and then in EIM for subsequent transfer to the EPA Water Quality eXchange (WQX) database.

Marine water column data in EIM are available through two ways.

1. Monitoring Program Automation (MPA) in EIM through monitoring program ID "MarineAmbient": https://apps.ecology.wa.gov/eim/search/SMP/MarineAmbientSearch.aspx?StudyMonitoringProgramUserId=MarineAmbient&StudyMonitoringProgramUserIdSearchType=Equals
2. Main EIM Search page using one or more study IDs listed in Table 19: https://apps.ecology.wa.gov/eim/search/Default.aspx.

11.5 Model information management

NA

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

Field staff may be audited at any time by the appropriate Marine Waters Monitoring (MWM) staff to ensure that field work and instrument operations are being completed according to this QAMP, any published QAMP amendment, and any published Ecology SOPs. This would consist of observing and correcting any sampling technique inconsistent with those provided in this QAMP. Experienced MWM staff will conduct field training sessions and consistency reviews before and/or during each field season. Field consistency reviews are not true audits, but instead serve to improve field work consistency, improve adherence to SOPs, provide a forum for sharing innovations, and strengthen Ecology's data QA program.

Ecology's Laboratory Accreditation Unit (LAU) conducts on-site audits and accreditation for laboratories in accordance with WAC-173-50-080.

Data audits are conducted monthly on sensor and laboratory data after they have been processed and uploaded to the EAPMW database. Annual audits are conducted for every sampling year after data have been finalized. These audits occur four to six months after the sampling year is completed.

To audit laboratory data, we track, reconcile, and monitor the status of samples delivered to all laboratories for analyses and track any problems that arise. After the sampling year, we will conduct several audits to assess overall attainment, identify missing or erroneous results, and summarize overall completeness.

We audit sensor data results from initial collection through processing and review to finalization. We monitor counts by month and station at multiple points in the workflow. We look for missing, duplicate, or irregular data results. A final step is to audit our EAPMW database and the agency EIM database after loading data. This tracking to determine "conservation of data points" makes sure all data have been flagged appropriately and no data are overlooked, duplicated, or lost.

12.2 Responsible personnel

Personnel responsible for audits are:

- Field – experienced MWM staff.
- Laboratory – LAU staff.
- Data – responsible personnel and their data auditing tasks are in Table 19.

MWM staff will track the status of samples being analyzed by all laboratories, being particularly alert to any significant QC problems as they arise.

Table 19. Personnel responsible for data audits and quality assurance.

Marine Monitoring Staff	Title	Responsibilities
Christopher Krembs	Senior Oceanographer	Audits of historical sensor and lab data sets. Monthly participation in CTD data reviews, including nitrate sensor data. Monthly data statistical analysis of bath sensor assessment. Leads routine data finalization work and special data QC and management projects.
Micah Horwith	Ocean Acidification Senior Scientist	Leads data statistical analysis, QA/QC, and audits of the TA, DIC, and salinity data. Monthly review of the TA, DIC, and dissolved oxygen field and laboratory data. Leads routine ocean acidification data finalization.
Alex Fisher	Senior Physical Oceanographer	Generates monthly review products of water masses and temperature-salinity trends. Conducts monthly review of CTD temperature, salinity, and density data. Rotating data duties to run monthly audits at all stages of QC. Conducts variety of audits on an as-needed basis. Leads routine data finalization work and special data QC and management projects.
Suzan Pool	Marine Monitoring Scientist	Business lead for marine waters data management with EAP Information Technology group. Conducts monthly review of CTD nitrate sensor data. Rotating data duties to run monthly audits at all stages of QC. Conducts routine, historical, and current data audits. Leads routine data finalization work and special data QC and management projects.
Holly Young	Marine Waters Field Lead	Monthly review of the CTD fluorescence data. Leads the monthly tracking, reconciliation, QA/QC, and audits of field and laboratory data. Supports variety of audits on an as-needed basis.
Christopher Jendrey	Marine Waters Field Scientist	Monthly review of the CTD transmissometer and turbidity data. Monthly tracking, reconciliation, QA/QC, and audits of field and laboratory data. Supports variety of audits on an as-needed basis.
Natalie Coleman	Ocean Acidification Scientist	Leads the tracking, reconciliation, QA/QC, and audits of TA, DIC, and salinity data and other field and laboratory data. Monthly review of the TA, DIC, and dissolved oxygen field and laboratory data. Supports variety of audits on an as-needed basis.
Emma LeValley	Marine Monitoring Technician	Monthly review of CTD transmissometer and turbidity data. Supports monthly tracking, reconciliation, QA/QC, and audits of field and laboratory data. Supports variety of audits on an as-needed basis.

CTD: conductivity-temperature-depth sensor profiles
DIC: Dissolved inorganic carbon
EAP: Environmental Assessment Program
QA/QC: Quality assurance and quality control
TA: Total alkalinity

12.3 Frequency and distribution of reports

The MWM program generates a variety of data summaries and reports for the public, scientists and engineers, Ecology management, and external agencies. Ad hoc reports and presentations are generated for regional and national conferences and meetings, and by request of management and other public entities, as resources allow.

Routine products are:

- Annual Puget Sound Ecosystem Management Program (PSEMP) marine water report.
- Eyes Over Puget Sound
- Condition reports
- Marine Water Condition Index (MWCI)
- Water Quality Assessment (WQA) submission
- Washington State Office of Financial Management (OFM) performance measures

Related applications to the data are:

- Planning and review
- Data and technical requests
- Presentations at conferences and workshops

Monthly data summaries are reported in an online report titled “Eyes Over Puget Sound” (EOPS), approximately six to 12 times per year. Every effort is made to release this report within a week after conducting an EOPS aerial photographic survey.

Marine water quality conditions are considered a key indicator of Puget Sound ecosystem health so the MWM group reports changes in water quality conditions using the Marine Water Condition Index (MWCI), updated annually. The MWCI takes advantage of the long-term de-seasonalized dataset generated by the MWM program and uses monthly core station data to provide updates. The Puget Sound Partnership (PSP) has adopted Ecology’s MWCI as one of its dashboard indicators. Ecology evaluates the MWCI for coastal bays as well as Puget Sound, using the same methodology.

The MWM group contributes several monitoring products to the annual Puget Sound Marine Waters Overview report. This report is a product of the PSEMP’s Marine Waters Workgroup. The objective of this report is to collate and distribute physical, chemical, and biological information obtained from various marine monitoring and observing programs in Puget Sound. The report can be found at the PSEMP website.

12.4 Responsibility for reports

The MWM program has an extensive information on historical data. An intensive team approach is required to analyze and interpret this wealth of information. The senior oceanographer leads reporting on status and trends on various products and presentation of results. Members of the MWM program assist in reports and presentations.

13.0 Data Verification

Data verification and review is conducted by the Marine Waters Monitoring (MWM) group by examining all field and laboratory-generated data to ensure:

- Specified methods and protocols were followed.
- Data are consistent, correct, and complete, with no errors or omissions.
- Data specified in the Sampling Process Design section were obtained.
- Results for QC samples as specified in the Measurement Quality Objectives and Quality Control sections accompanying the sample results.
- Established criteria for QC results were met.
- Data qualifiers are properly assigned.

To assure accurate entry of data into the database, the designated MWM staff (typically data manager) checks 10% of all values against the source data. If errors are found, an additional 10% of values are checked. This process continues until no errors are found or all values have been verified or corrected.

The designated MWM staff (typically senior oceanographer or data manager) checks 10% of the annual, finalized data in Ecology databases and available via the Internet against the source data. If errors are found, an additional 10% of values are checked and the process continues in this way until no errors are found or all values have been verified or corrected.

13.1 Field data verification, requirements, and responsibilities

The lead technician and all crew members are responsible for carrying out field procedures on station positioning, sample collection, and sensor deployments. Additionally, technicians systematically review all field documents (such as field logs, chain-of-custody sheets, and sample labels) to ensure data entries are consistent, correct, and complete, with no errors or omissions. A second staff person always checks the work of the staff person who primarily collected or generated data results.

13.2 Laboratory data verification

MWL technicians will verify data entries into EAPMW by checking that all samples and analytes are accounted for. One technician will check data entries of another technician who primarily collected or generated analytical results.

MWM staff will verify and review all data received from MEL and external laboratories. The verification process will follow specified criteria.

- Field logs.
- Calibration records.
- Sample analytical results.
- Laboratory QA/QC analytical results.

Staff will verify sample and data disposition by conducting continual tracking and reconciliation procedures. Particular attention is paid to any significant QC problems that may arise. Any discrepancies are discussed with the laboratories or contractors for amendment. Once data have been reviewed and verified, MWM staff enter final QC information into the EAPMW database.

13.3 Validation requirements, if necessary

NA

13.4 Model quality assessment

NA

13.4.1 Calibration and validation

NA

13.4.1.1 Precision

NA

13.4.1.2 Bias

NA

13.4.1.3 Representativeness

NA

13.4.1.4 Qualitative assessment

NA

13.4.2 Analysis of sensitivity and uncertainty

NA

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

Data quality assessments follow current and available oceanographic data QA/QC standards and must keep pace with oceanographic monitoring and sensor technologies as they continue to evolve. Different types of data require unique data review techniques. The Marine Waters Monitoring (MWM) program has three types of data: sensor, discrete sample analyses, and field observations.

A strong QA program is a major pre-requisite for establishing QC standards for field sensor data collection. There is a national consensus among a broad group of oceanographers and marine scientists. This consensus is that good QC requires good QA, and good QA requires good scientists, engineers, and technicians. An effective QA effort continuously strives to ensure that end data products are of high value and to prove they are free of error (U.S. IOOS, 2018).

Data qualifiers

Following quality assessment, all data are given a three number quality description (QC code) and released for public use or removed from the data set.

1. The first flag communicates whether the sample passes (2) or fails (1). A pass flag will keep the data moving to the next step of QC. A fail flag will identify data as invalid. Data will have a zero or none code until they are reviewed (Table 20).
2. The second flag communicates the reason behind the flags. For example, a one means the sensor performance failed (Table 21).
3. The third flag communicates where in the data review process the sample is. A two indicates the data has been reviewed and flags have been applied, but that the data have not yet been finalized (Table 22).

In the end, a data point with no issues would be flagged as 2_0_3.

Table 20. Data quality values and their definitions and descriptions.

Data Quality Value	Definition	Description
0	None	Data quality not yet determined
1	Fail	Data fails QC, unacceptable
2	Pass	Data passes QC, acceptable

Table 21. Data quality flags and their definitions, descriptions, and applicability to sensor and/or laboratory data.

Data Quality Flag	Applicable to Sensor Data	Applicable to Laboratory Data	Definition	Description
0	Yes	Yes	No specification	No specific reason given for pass or fail.
1	Yes	No	Sensor or equipment performance	Inconsistent instrument performance.
2	Yes	No	Procedure modification	Data collection method modified from standard procedures.
3	Yes	No	Method limitation	Method limitation.
4	Yes	No	Outlier	Discontinuous or unexpected single result.
5	Yes	No	Data behavior	Unexpected or unlikely continuous data pattern.
6	Yes	No	Out of range	Data exceeds engineering range specified for instrument, valid range for datatype, range based on climatology or range that calculation should allow.
7	Yes	No	Estimate or missing information	Result is an estimate or is missing underlying source or related information needed for validation.
8	Yes	No	Non-survey	Result, such as sensor equilibration data, collected during operations, but not considered to be an ambient measurement.
9	Yes	No	Calculated	Data generated by calculation from other measurements.
D	No	Yes	RPD or %RSD between field replicates greater than acceptable specified limits	"D" represents difference or deviation. Relative percent difference (RPD) or percent relative standard deviation (%RSD) between field replicates greater than acceptable limits. RPD is calculated between two replicates. %RSD is calculated between three or more replicates.
JB	No	Yes	Blank contamination	Analyte found in blank.
JE	No	Yes	Calibration exceedance	Reported result is an estimate because it exceeds the calibration range.
JH	No	Yes	Holding time exceedance	Analyzed past recommended holding time; recommended holding conditions not met.
J	No	Yes	Estimate	Analyte was positively identified. The reported result is an estimate.

Data Quality Flag	Applicable to Sensor Data	Applicable to Laboratory Data	Definition	Description
JM	No	Yes	Method modification	Analysis or data collection method modified from routine practices.
M	No	Yes	Missing result	Sample collected but lost in transit or during analysis
R	No	Yes	Rejected	The sample results were rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
U	No	Yes	Undetected	The analyte was not detected at or above the reported sample quantitation limit.
UJ	No	Yes	Analyte not detected at or above the reported estimate	The analyte was not detected at or above the reported estimate.

Table 22. Data quality assessment level numbers and their definitions and descriptions.

Data Quality Assessment	Definition	Description
0	None	No quality control done
1	Preliminary	Automated processing done and initial value generated
2	Reviewed	Manually reviewed; data flags applied
3	Final	Review is final

Monthly reviews

MWM staff meet monthly to perform a group review of all raw and processed sensor data. Each group review examines station-specific profiling data plots, statistical summaries, and environmental boundary conditions. Staff members individually review various data sets, documenting problems and applying data qualifiers as necessary. All flagged data are presented, reviewed, and discussed in group reviews. Data are flagged in the EAPMW database through an established set of data qualifiers, including those that pass data.

Sampling year reviews

Once the sampling year is complete, all reviewed data are re-assessed in the context of the annual summary and then finalized after data verification, QA, and QC procedures are complete. The final data review happens quarterly or bi-annually as workloads allow.

This final level of checks uses historical data to create a statistical envelope on which the current data are plotted. As the year goes on, the graphs are updated and then the seasonal trend provides more context for determining whether the data will either be accepted,

accepted with qualification, or rejected. If MQOs were not met, the MWM group will discuss whether corrective actions can be taken or whether the data will be rejected.

Sensor profiles

Sensor profiling data move on in the QA process after they went through the preliminary level of quality assessment (pre-processed data). Every sensor variable is reviewed on a monthly basis using interquartile range (IQR) plots and historical data. The IQR plots currently uses data from 1999 to the previous sampling year, also known as a moving baseline. We are in the process of improving this method by using a fixed 25-year statistical baseline that takes in the full range of data from 1999 to 2023. After group review, the sensor data are assigned three quality description values which communicate the result of the data quality assessment.

Discrete sample results

Discrete sample results for a sampling year are assessed by comparing them against historical envelopes. This comparison entails plotting the sampling year's analytical results against the full temporal range of available data from first collection through previous year's collections. In addition, we evaluate QC results of laboratory standards and blanks as part of assessing analytical results of discrete samples. All data are finalized upon review of a sampling year against historical envelopes.

A general practice for data management is that results or concentrations between the method detection limit (MDL) and the reporting limit (RL) are reported as detected but not quantified. This is because the potential exists to misuse or misinterpret low-level data which has relatively large uncertainty and can bias data interpretations. Statistical evaluations of data with high uncertainties can lead to erroneous conclusions, especially if the sample populations are limited in size or have high percentages of non-detects.

For the MWM program, analytical results or concentrations between the MDL and RL are quantified and annotated with a J qualifier (estimated concentration; see Table 22). This qualification indicates a higher level of uncertainty in the quantitative value.

Sample results that are considered detected are those quantified at concentrations at least three times greater than the corresponding results in the method blank and in the field blank samples.

Sample results that are not at least three times greater than the corresponding results in the field or reagent blank samples are qualified with a JB qualifier. This flag indicates that a result was positively identified but an estimate due to contamination of the field or reagent blank.

14.2 Treatment of non-detects

Sample results that are not at least three times greater than the corresponding results in the method blank are qualified with a U flag to indicate "not detected" (see Table 22).

Laboratories flag non-detected analytical results with a U or UJ qualifier and report non-detect data with a value of the analyte's RL or MDL, depending on the analytical method. The use of RL or MDL as discrete values can overestimate analytes that may be present at concentrations below the detection threshold of laboratory instruments and methods (e.g., ammonium). In other words, the potential exists to misuse and misinterpret low-level data that have high quantitative uncertainty. For example, these values may artificially increase the trend of such analytes in analysis. Therefore, we use a random number between zero and MDL to prevent data loss and artificial skewness. This random number can change upon each calculation updates to status and trend analysis.

14.3 Data analysis and presentation methods

The MWM program evaluates trends for the year 1999 and beyond, when field collection and laboratory methods were standardized against standard oceanographic procedures. Consistent methods and protocols allow for the assessment of long-term status and trends for measurements collected since 1999.

The MWM program uses a variety of software to compile, query, and analyze data. Some of the software that we use in addition to Microsoft Office software suite are:

- MathWorks MATLAB.
- R Statistical Software (R Core Team, 2024) and RStudio Desktop (Posit Team 2024).
- Python programming language.
- Microsoft SQL Server Management Studio.
- Golden Software Surfer.

We use data in the EAPMW database to query and perform QA/QC assessments of marine water column profiles and associated discrete water samples. Every month, the vertical profiles are plotted in standardized templates, including vertical profile plots, in statistical context of historical data ranges. And, discrete laboratory results are plotted in standardized graphics to evaluate them, some of which can be compared with sensor data.

Monthly sensor profiles are evaluated using interquartile ranges. These ranges are calculated by using historical results for each station and each depth of a specified month. An example of interquartile plots of sensor profiles is shown in Figure 5. Data significantly higher or lower than the historical ranges are automatically flagged and reviewed. Reports on monthly anomalies in water properties through the entire station network are then generated for data quality assurance reviews. To determine significant trends, data sets are de-seasonalized using station-specific historical monthly data based on the data from 1999 to the present.

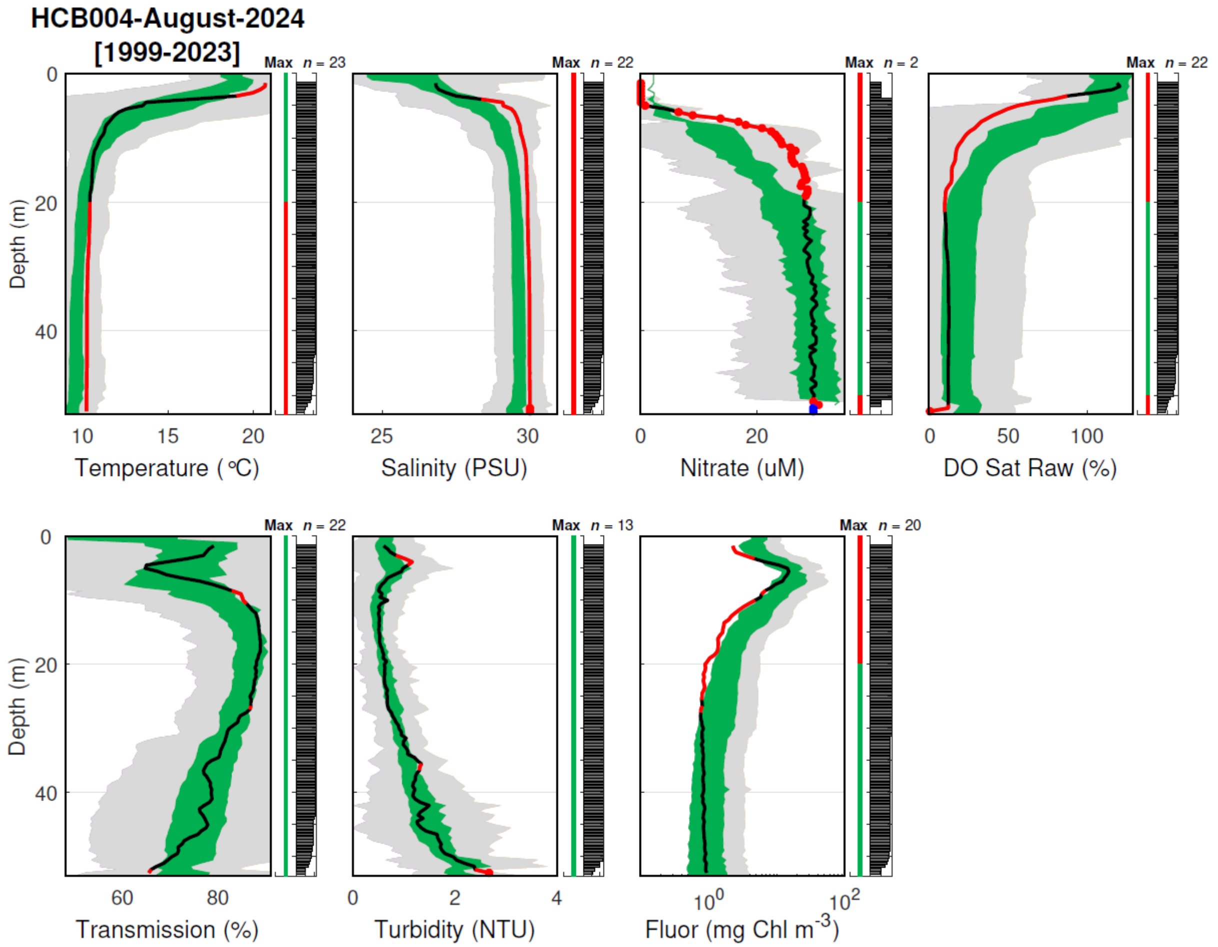

Figure 5. Station-specific monthly marine water column profiles plotted in the context of interquartile ranges of historical results.

Heat maps are useful in that they provide a visual display of data trends as a summary. MWM staff use heat maps to describe the volume of data and to communicate long-term monitoring results.

Further analysis to detect significant changes in water quality is performed via mathematical and other statistical analyses of the data. Non-parametric tests of the data are predominantly used to further interpret oceanographic influences and processes. Non-parametric analysis was specifically chosen because water quality parameters collected at random do not display a normal frequency distribution. The dataset may include some of the following attributes which must be considered when conducting statistical analysis:

- Missing data.
- Values near or below laboratory detection limits.
- Weather events that may cause anomalous values.
- Laboratory method changes.
- Field sampling and data collection method changes.
- Personnel changes.
- Equipment malfunctions.

The MWM program also reports status and trends of data to various entities or groups, including but not limited to:

- PSEMP Marine Waters Annual Reports
- PSEMP Marine Waters Condition Reports
- PSEMP Vital Signs Indicator for ocean acidification
- Marine Waters Condition Index
- Regional oceanographic and estuarine science conferences (e.g., Salish Sea Ecosystem Conference)
- Eyes Over Puget Sound

Presentations are given verbally or through scientific posters.

14.4 Sampling design evaluation

The sampling design is effective for continuity of a long-term data set. The sample design is evaluated based on the success of station attainment, and data collection to inform MWM's strategy for tracking status and trends of water quality in Puget Sound, Grays Harbor, and Willapa Bay. If meaningful conclusions can be drawn from the data, the sample design will be considered effective.

14.5 Documentation of assessment

Documentation of data assessment contains information about QA/QC qualifiers, data audits, sensor performance, significant QA issues, and recommended solutions. Data qualifiers are applied to sensor and laboratory parameter in the EAPMW database. A metadata document provides information on stations, deployed sensors, sensor and analytical methods, date ranges, and data qualifiers.

15.0 References

Ahmed, A., G. Pelletier, M. Roberts, and A. Kolosseus, 2014. South Puget Sound Dissolved Oxygen Study: Water Quality Model Calibration and Scenarios. Publication No. 14-03-004. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/1403004.html.

Banas, N. S., and B. M. Hickey. 2005. Mapping exchange and residence time in a model of Willapa Bay, Washington, a branching, macrotidal estuary. Journal of Geophysical Research, 110(C11011): 1–20. https://doi.org/10.1029/2005JC002950.

Bos, J. 2022. Standard Operating Procedure EAP088, Version 1.1: Marine Waters Data Quality Assurance and Quality Control. Publication No. 23-03-233. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/2303233.html. (Recertified 2022.)

Bos, J., N. Coleman, M. Horwith, E. Rauschl, S. Albertson, J. Ruffner, and C. Krembs. 2022. Addendum 1 to Quality Assurance Project Plan: Long-Term Marine Waters Monitoring, Water Column Program. Publication No. 22-03-103. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/2203103.html.

Bos, J., M. Keyzers, L. Hermanson, C. Krembs, and S. Albertson. 2015. Quality Assurance Monitoring Plan: Long-Term Marine Waters Monitoring, Water Column Program. Publication No. 15-03-101. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/1503101.html.

Burns, R. E., 1985. The shape and form of Puget Sound. Washington Sea Grant. 100 pp.

Coleman, N. 2022a. Standard Operating Procedure EAP028, Version 2.5: Reagent Preparation. Publication No. 22-03-220. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/2203220.html. (Recertified 2022.)

Coleman, N. 2022b. Standard Operating Procedure EAP053, Version 1.0: Marine Water Salinity Sample Analysis. Publication No. 22-03-201. WA State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/documents/2203201.pdf.

Collias, E. E., 1970. Index to physical and chemical oceanographic data of Puget Sound and its approaches, 1932-1966. University of Washington, Department of Oceanography, Special Report No. 43, Division of Marine Resources, Washington State Sea Grant Program, Publication No. WSG 70-4 and Washington State Department of Natural Resources Aquatic Land Management Series Publication No. DNR-ALMS 1. https://repository.library.noaa.gov/view/noaa/39763/noaa_39763_DS1.pdf.

Dickson, A. G., J. D. Afghan, G. C. Anderson. 2003. Reference materials for oceanic CO2 analysis: A method for the certification of total alkalinity. Marine Chemistry, 80(2-3): 185–197.

Dickson, A. G., C. L. Sabine, and J. R. Christian. 2007. Guide to best practices for ocean CO_2 measurements. North Pacific Marine Science Organization.

Freelan, S. 2023. Salish Sea & Surrounding Basin. https://www.stefanfreelan.com/salishsea.

Friese, M. 2020. Standard Operating Procedure EAP090, Version 1.2: Decontaminating Field Equipment for Sampling Toxics in the Environment. Publication No. 21-03-202. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/2103202.html. (Recertified 2020.)

Glisson, W.J. 2024. Standard Operating Procedure EAP070, Version 2.4: Minimize the Spread of Invasive Species. Publication No. 23-03-225. WA State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/2403204.html. (Recertified 2024.)

Gonski, S., C. Krembs, and G. Pelletier. 2019. Quality Assurance Project Plan: Ocean Acidification Monitoring at Ecology's Greater Puget Sound Stations. Publication No. 19-03-102. Washington State Departent of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/SummaryPages/1903102.html.

Grasshoff, K., M. Ehrhardt, and K. Kremling. 1999. Methods of seawater analysis. 3rd. ref. ed. Verlag Chemie GmbH, Weinheim. 600 pp.

Herrera Environmental Consultants, Inc., 2011. Toxics in Surface Runoff to Puget Sound: Phase 3 Data and Load Estimates. Washington State Department of Ecology, Olympia, WA. Publication No. 11-03-010. https://apps.ecology.wa.gov/publications/publications/1103010.pdf

Hickey, B. M. and N. S. Banas. 2003. Oceanography of the U.S. Pacific Northwest coastal ocean and estuaries with application to coastal ecology. Estuaries, 26(4B): 1010–1031.

IOC [Intergovernmental Oceanographic Commission]. 1994 Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements. Paris, France, UNESCO-IOC, 170pp. (Intergovernmental Oceanographic Commission Manuals and Guides: 29), (JGOFS Report; 19). DOI: https://doi.org/10.25607/OBP-1409

Janzen, C. D. 1992. Marine Water Column Ambient Monitoring Plan: Final Report. Publication No. 92-23. Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/SummaryPages/9223.html.

Kennish, M. J. 1998. Pollution Impacts on Marine Biotic Communities. CRC Press, Boca Raton, FL. 310 pp.

Keyzers, M., J. Bos, and S. Albertson. 2021. Quality Assurance Monitoring Plan: Long-Term Marine Waters Monitoring, Water Column Program. Publication No. 21-03-108. Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/SummaryPages/2103108.html.

King County. 2014. Interim Report on An Inter-Laboratory Nutrient Comparison Study Between the King County Environmental Laboratory and University of Washington Marine Chemistry Laboratory. Prepared by Scott Mickelson, King County Water and Land Resources Division, Seattle, Washington; and Julia Bos, Washington State Department of Ecology Marine Monitoring Unit, Olympia, WA.

Krembs, C. 2012. Marine Water Condition Index. Washington State Department of Ecology, Olympia, WA. Publication No. 12-03-013. https://fortress.wa.gov/ecy/publications/SummaryPages/1203013.html.

Krembs, C. and S. Pool. 2025. (In publication). Technical Memorandum: Quantitative evaluation of historic dissolved oxygen sensor SBE 43 adjustments using Winkler reference samples and justification for future sole use of oxygen optode sensors. Washington State Department of Ecology, Olympia, WA.

McCarthy, S., C. Figueroa-Kaminsky, and A. Ahmed. 2018. Quality Assurance Project Plan: Salish Sea Model Applications. Publication No. 18-03-111. Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/SummaryPages/1803111.html.

MEL. 2016. Manchester Environmental Laboratory *Lab Users Manual*, Tenth Edition. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

MMC [Monitoring Management Committee]. 1988. Puget Sound Ambient Monitoring Program: Final Report. Puget Sound Water Quality Authority, Olympia, WA. https://www.eopugetsound.org/sites/default/files/features/resources/PugetSoundCommResearch1988Optimized.pdf.

Mohamedali, T., M. Roberts, B. Sackmann, and A. Kolosseus. 2011. Puget Sound Dissolved Oxygen Model - Nutrient Load Summary for 1999-2008. Washington State Department of Ecology, Olympia, WA. Publication No. 11-03-057. https://fortress.wa.gov/ecy/publications/summarypages/1103057.html.

Moore, S. K., N. J. Mantua, J. P., Kellogg, and J. A. Newton. 2008. Local and large-scale climate forcing of Puget Sound oceanographic properties on seasonal to interdecadal timescales. Limnology and Oceanography, 53(5): 1746-1758. https://doi.org/10.4319/lo.2008.53.5.1746.

Newton, J. A., S. L. Albertson, K. Nakata, and C. Clishe. 1998. Washington State Marine Water Quality in 1996 and 1997. Publication No. 98-338. Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/SummaryPages/98338.html.

Newton, J. A., S. L. Albertson, and A. L. Thomson. 1997. Washington State Marine Water Quality in 1994 and 1995. Publication No. 97-316. Washington State Department of Ecology, Olympia. WA. https://apps.ecology.wa.gov/publications/SummaryPages/97316.html.

Newton, J. A., S. L. Albertson, K. Van Voorhis, C. Maloy, and E. Siegel. 2002. Washington State Marine Water Quality, 1998 through 2000. Publication No. 02-03-056. Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/SummaryPages/0203056.html.

Newton, J. A., E. Siegel, E. and S. L. Albertson. 2003. Oceanographic changes in Puget Sound and the Strait of Juan de Fuca during the 2000–01 drought. Canadian Water Resources Journal/Revue canadienne des ressources hydriques. 28(4): 715-728. https://doi.org/10.4296/cwrj2804715.

NOAA [U.S. National Oceanic and Atmospheric Administration]. 1985. National Estuarine Inventory Data Atlas. Strategic Assessment Branch, Ocean Assessments Division, Office of Oceanography and Marine Assessment, National Ocean Service, Rockville, MD.

Posit Team. 2024. RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. http://www.posit.co.

PSEMP [Puget Sound Ecosystem Monitoring Program] Marine Waters Workgroup. 2024. Puget Sound marine waters: 2023 overview. J. Apple, R. Wold, K. Stark, J. Bos, S. Yang, J. Selleck, N. Burnett, A. Marquez, L. Loehr, J. Rice, S. Kantor, C. Krembs, and J. Newton (Eds). https://pspwa.box.com/shared/static/vn146azam00pf1xr2lig4gouy98rwf75.pdf.

PSEMP Marine Waters Workgroup. 2023. Puget Sound marine waters: 2022 overview. J. Apple, R. Wold, K. Stark, J. Bos, S. Yang, J. Selleck, N. Burnett, F. Perez, G. Ferrara, A. Marquez, S. K. Moore, S. Kantor, C. Krembs, G. Hannach, and J. Newton (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2022. Puget Sound marine waters: 2021 overview. J. Apple, R. Wold, K. Stark, J. Bos, P. Williams, N. Hamel, S. Yang, J. Selleck, S. K. Moore, J. Rice, S. Kantor, C. Krembs, G. Hannach, and J. Newton (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2021. Puget Sound marine waters: 2020 overview., J. Apple, R. Wold, K. Stark, J. Bos, P. Williams, N. Hamel, S. Yang, J. Selleck, S. K. Moore, J. Rice, S. Kantor, C. Krembs, G. Hannach, and J. Newton (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2020. Puget Sound marine waters: 2019 overview. J. Apple, R. Wold, K. Stark, J. Bos, P. Williams, N. Hamel, S. Yang, J. Selleck, S. Moore, J. Rice, S. Kantor, C. Krembs, G. Hannach, and J. Newton (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2019. Puget Sound marine waters: 2018 overview. S. Moore, R. Wold, B. Curry, K. Stark, J. Bos, P. Williams, N. Hamel, J. Apple, S. Kim, A. Brown, C. Krembs, and J. Newton (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2018. Puget Sound marine waters: 2017 overview. S. K. Moore, R. Wold, K. Stark, J. Bos, P. Williams, N. Hamel, S. Kim, A. Brown, C. Krembs, and J. Newton (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2017. Puget Sound marine waters: 2016 overview. S. K. Moore, R. Wold, K. Stark, J. Bos, P. Williams, N. Hamel, A. Edwards, C. Krembs, and J. Newton (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2016. Puget Sound marine waters: 2015 overview. S. K. Moore, R. Wold, K. Stark, J. Bos, P. Williams, K. Dzinbal, C. Krembs, and J. Newton (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2015. Puget Sound marine waters: 2014 overview. S. K. Moore, K. Stark, J. Bos, P. Williams, J. Newton, and K. Dzinbal (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2014. Puget Sound marine waters: 2013 overview. S. K. Moore, K. Stark, J. Bos, P. Williams, J. Newton, and K. Dzinbal (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2013. Puget Sound marine waters: 2012 overview. S. K. Moore, K. Stark, J. Bos, P. Williams, J. Newton, and K. Dzinbal (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEMP Marine Waters Workgroup. 2012. Puget Sound marine waters: 2011 overview. S. K. Moore, R. Runcie, K. Stark, J. Newton, and K. Dzinbal (Eds). https://pspwa.app.box.com/s/hferayhcyzwvcxrao8uohnxjbvjxhpxt.

PSEP [Puget Sound Estuary Program]. 1991. Recommended Guidelines for Measuring Conventional Marine Water-Column Variables in Puget Sound. Prepared for U.S. Environmental Protection Agency (U.S. EPA), Region 10, Office of Puget Sound, Seattle, WA and Puget Sound Water Quality Authority, Olympia, WA.

PSEP. 1997. Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissue in Puget Sound. Prepared for U.S. EPA, Region 10, and Puget Sound Water Quality Authority, Olympia, WA.

PSEP. 1998. Recommended Guidelines for Station Positioning in Puget Sound. Prepared for U.S. EPA, Region 10, and Puget Sound Water Quality Authority, Olympia, WA.

PSF [Pacific Salmon Foundation]. 2016. Salish Sea Marine Survival Project — 2017–2018 Research Plan. PSF, 300-1682 West 7th Ave., Vancouver, BC, Canada V6J 4S6. https://marinesurvival.wpengine.com/wp-content/uploads/Strait-of-Georgia-Marine-Survival-Research-Plan-2017-2018.pdf.

Puget Sound Partnership. 2024. State of the Sound Report 2023. Puget Sound Partnership, Olympia, WA. https://www.psp.wa.gov/sos.php.

R Core Team. 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Roberts, M., T. Mohamedali, B. Sackmann, T. Khangaonkar, and W. Long, 2014. Puget Sound and the Straits Dissolved Oxygen Assessments: Impacts of Current and Future Human Nitrogen Sources and Climate Change through 2070. Publication No. 14-03-007. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/summarypages/1403007.html.

U.S. IOOS [U.S. Integrated Ocean Observing System], 2018. Manual for Real-Time Quality Control of Dissolved Oxygen Observations: A Guide to Quality Control and Quality Assurance for Dissolved Oxygen Observations in Coastal Oceans. 53 pp. https://cdn.ioos.noaa.gov/attachments/2018/08/QARTOD_DOSecondUpdate_final.pdf.

Young, H. and C. Jendrey. 2023. Standard Operating Procedure EAP026, Version 4.1: Chlorophyll a Analysis. Publication No. 23-03-231. (In Publication). Washington State Department of Ecology, Olympia. (Recertified 2023.)

Young, H., N. Coleman, S. Pool, and C. Krembs. 2023a. Standard Operating Procedure EAP086, Version 4.0: Marine Waters Sensor Performance Assessment — Lab Procedures. (In Publication). Washington State Department of Ecology, Olympia. (Recertified 2023.)

Young, H., C. Jendrey, and N. Coleman. 2023b. Standard Operating Procedure EAP025, Version 4.0: Seawater Sampling. Publication No. 23-03-207. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/2303207.html. (Recertified 2023.)

16.0 Appendices

Appendix A. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Ambient: Background or away from point sources of contamination. Surrounding environmental condition.

Anthropogenic: Human-caused.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Diurnal: Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed during a calendar day, and which typically recur every calendar day (e.g., diurnal temperature rises during the day and falls during the night).

Eutrophic: Nutrient rich and high in productivity resulting from human activities such as fertilizer runoff and leaky septic systems.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Source of pollution that discharges at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Reach: A specific portion or segment of a stream.

Sediment: Soil and organic matter that is covered with water (for example, river or lake bottom).

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of WA State.

Turbidity: A measure of water clarity. High turbidity can have a negative impact on aquatic life.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act, requiring Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

Acronyms and Abbreviations

AED	Automated external defibrillator
BEACH	Beach Environmental Assessment, Communication, and Health
CHS	Canadian Hydrographic Service
CRM	Certified Reference Materials
CTD	Conductivity-temperature-depth sensor
DO	Dissolved Oxygen (see Glossary above)
DIC	Dissolved inorganic carbon
DL	Detection limit
DQO	Data quality objective
e.g.	For example
EAPMW	Environmental Assessment Program Marine Waters (name of database)
Ecology	Washington State Department of Ecology
ENSO	El Niño-Southern Oscillation
EOPS	Eyes Over Puget Sound
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
GPS	Global Positioning System
i.e.	In other words

ID	Identifier
IQR	Interquartile range
LIMS	Laboratory Information Management System
LNSW	Low nutrient seawater
MDL	Method detection limit
MMC	Monitoring Management Committee
MQO	Measurement quality objective
MWCI	Marine Water Condition Index
MWL	Ecology's Marine Waters Laboratory
MWM	Marine Waters Monitoring
MPA	Monitoring program automation
NC	Not collecting
netCDF	Network Common Data Form
NOAA	U.S. National Oceanic and Atmospheric Administration
OFM	Office of Financial Management
OSIL	Ocean Scientific International, Ltd.
PFD	Personal flotation devices
PMEL	NOAA Pacific Marine Environmental Laboratory
PSEMP	Puget Sound Ecosystem Monitoring Program
PSEP	Puget Sound Estuary Program
PSF	Pacific Salmon Foundation
PSP	Puget Sound Partnership
QA	Quality assurance
QAMP	Quality assurance monitoring plan
QAPP	Quality assurance project plan
QC	Quality control
R/V	Research vessel
RL	Reporting limit
RPD	Relative percent difference
RSD	Relative standard deviation
SBE	Sea-Bird Electronics, Inc. (now known as Sea-Bird Scientific, Inc.)
SOP	Standard operating procedures
SQL	Structure Query Language
SSMSP	Salish Sea Marine Survival Project
TA	Total alkalinity
TA/DIC	Total alkalinity and dissolved inorganic carbon
USGS	United States Geological Survey
UW	University of Washington
UW-MCL	UW Oceanography Department Marine Chemistry Laboratory
VHF	Very high frequency range of radio frequency electromagnetic waves
WAC	Washington Administrative Code
WQA	Water Quality Assessment
WQX	U.S. EPA Water Quality eXchange data portal
WRIA	Water Resource Inventory Area
WWU	Western Washington University

Units of Measurement

°C	degrees centigrade
dbar	decibar, a unit of pressure
Hz	hertz
kg	kilograms, a unit of mass equal to 1,000 grams
km	kilometer, a unit of length equal to 1,000 meters
km^2	kilometer squared, a unit of area
km^3	kilometer cubed, a unit of volume
m	meter
mL	milliliter
mg/L	milligrams per liter (parts per million)
N/L	nitrogen per liter
NTU	nephelometric turbidity units
mS/cm	milliSiemens per centimeter, a unit of conductivity
PSU	Practical Salinity Units
R^2	R squared, a statistical measure of variance
sigma-t	density expressed as kg/m^3 - 1000
S/m	Siemens per meter, a unit of conductivity
µg/L	micrograms per liter (parts per billion)
µM	micromolar (a chemistry unit)
µmol/kg	micromole per kilogram
µS/cm	microSiemens per centimeter, a unit of conductivity

Quality Assurance Glossary

Accreditation: A certification process for laboratories, designed to evaluate and document a lab's ability to perform analytical methods and produce acceptable data. For Ecology, it is "Formal recognition by (Ecology)…that an environmental laboratory is capable of producing accurate analytical data." [WAC 173-50-040] (Kammin, 2010)

Accuracy: The degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms *precision* and *bias* be used to convey the information associated with the term *accuracy* (USGS, 1998).

Analyte: An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e.g., fecal coliform, Klebsiella (Kammin, 2010).

Bias: The difference between the sample mean and the true value. Bias usually describes a systematic difference reproducible over time and is characteristic of both the measurement system and the analyte(s) being measured. Bias is a commonly used data quality indicator (DQI) (Kammin, 2010; Ecology, 2004).

Blank: A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process (USGS, 1998).

Calibration: The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured (Ecology, 2004).

Check standard: A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards but should be referred to by their actual designator, e.g., CRM, LCS (Kammin, 2010; Ecology, 2004).

Comparability: The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator (USEPA, 1997).

Completeness: The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator (USEPA, 1997).

Continuing Calibration Verification Standard (CCV): A quality control (QC) sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run (Kammin, 2010).

Control chart: A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system (Kammin, 2010; Ecology 2004).

Control limits: Statistical warning and action limits calculated based on control charts. Warning limits are generally set at +/- 2 standard deviations from the mean, action limits at +/- 3 standard deviations from the mean (Kammin, 2010).

Data integrity: A qualitative DQI that evaluates the extent to which a data set contains data that is misrepresented, falsified, or deliberately misleading (Kammin, 2010).

Data quality indicators (DQI): Commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity (USEPA, 2006).

Data quality objectives (DQO): Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions (USEPA, 2006).

Data set: A grouping of samples organized by date, time, analyte, etc. (Kammin, 2010).

Data validation: An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment and objective criteria, to determine whether the MQOs for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability, and integrity, as these criteria relate to the usability of the data set. Ecology considers four key criteria to determine if data validation has occurred. These are:

- Use of raw or instrument data for evaluation.
- Use of third-party assessors.
- Data set is complex.
- Use of EPA Functional Guidelines or equivalent for review.

Examples of data types commonly validated would be:

- Gas Chromatography (GC).
- Gas Chromatography-Mass Spectrometry (GC-MS).
- Inductively Coupled Plasma (ICP).

The end result of a formal validation process is a determination of usability that assigns qualifiers to indicate usability status for every measurement result. These qualifiers include:

- No qualifier – data are usable for intended purposes.
- J (or a J variant) – data are estimated, may be usable, may be biased high or low.
- REJ – data are rejected, cannot be used for intended purposes.
  (Kammin, 2010; Ecology, 2004).

Data verification: Examination of a data set for errors or omissions, and assessment of the Data Quality Indicators related to that data set for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a data set (Ecology, 2004).

Detection limit (limit of detection)**:** The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero (Ecology, 2004).

Duplicate samples: Two samples taken from and representative of the same population, and carried through and steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis (USEPA, 1997).

Field blank: A blank used to obtain information on contamination introduced during sample collection, storage, and transport (Ecology, 2004).

Initial Calibration Verification Standard (ICV): A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples (Kammin, 2010).

Laboratory Control Sample (LCS): A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples (USEPA, 1997).

Matrix spike: A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias due to interference or matrix effects (Ecology, 2004).

Measurement Quality Objectives (MQOs)**:** Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness (USEPA, 2006).

Measurement result: A value obtained by performing the procedure described in a method (Ecology, 2004).

Method: A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed (EPA, 1997).

Method blank: A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples (Ecology, 2004; Kammin, 2010).

Method Detection Limit (MDL): This definition for detection was first formally advanced in 40CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero (Federal Register, October 26, 1984).

Percent Relative Standard Deviation (%RSD): A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$\%RSD = (100 * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples (Kammin, 2010).

Parameter: A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all parameters (Kammin, 2010; Ecology, 2004).

Population: The hypothetical set of all possible observations of the type being investigated (Ecology, 2004).

Precision: The extent of random variability among replicate measurements of the same property; a data quality indicator (USGS, 1998).

Quality assurance (QA): A set of activities designed to establish and document the reliability and usability of measurement data (Kammin, 2010).

Quality Assurance Project Plan (QAPP): A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives (Kammin, 2010; Ecology, 2004).

Quality control (QC): The routine application of measurement and statistical procedures to assess the accuracy of measurement data (Ecology, 2004).

Relative Percent Difference (RPD): RPD is commonly used to evaluate precision. The following formula is used:

[Abs(a-b)/((a + b)/2)] * 100

> where “Abs()” is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples (Ecology, 2004).

Replicate samples: Two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled (USGS, 1998).

Representativeness: The degree to which a sample reflects the population from which it is taken; a data quality indicator (USGS, 1998).

Sample (field): A portion of a population (environmental entity) that is measured and assumed to represent the entire population (USGS, 1998).

Sample (statistical): A finite part or subset of a statistical population (USEPA, 1997).

Sensitivity: In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit (Ecology, 2004).

Spiked blank: A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method (USEPA, 1997).

Spiked sample: A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method’s recovery efficiency (USEPA, 1997).

Split sample: A discrete sample subdivided into portions, usually duplicates (Kammin, 2010).

Standard Operating Procedure (SOP): A document which describes in detail a reproducible and repeatable organized activity (Kammin, 2010).

Surrogate: For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis (Kammin, 2010).

Systematic planning: A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning (USEPA, 2006).

References for QA Glossary

Ecology, 2004. Guidance for the Preparation of Quality Assurance Project Plans for Environmental Studies. Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/SummaryPages/0403030.html.

Kammin, B., 2010. Definition developed or extensively edited by William Kammin, 2010. Washington State Department of Ecology, Olympia, WA.

USEPA, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4. https://www.epa.gov/sites/default/files/2015-06/documents/g4-final.pdf.

USGS, 1998. Principles and Practices for Quality Assurance and Quality Control. Open-File Report 98-636. U.S. Geological Survey. https://pubs.usgs.gov/of/1998/ofr98-636/pdf/ofr98636.pdf.