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Quality Assurance Monitoring Plan

Long-Term Marine Waters Monitoring, Mooring Program

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Long-Term Marine Waters Monitoring, Mooring Program

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EAP: Environmental Assessment Program

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Abstract

The Washington State Department of Ecology (Ecology) has measured water quality monthly at 39 core stations in Puget Sound, Willapa Bay, and Grays Harbor since 1973. In 1997, Ecology installed automated sampling/monitoring stations to supplement the long-term monthly data record with more frequent measurements. High frequency measurements at fixed locations help us understand the movement of water masses and report on the frequency and duration of low-oxygen intrusions and events associated with specific water masses. The term *mooring* is used to describe automated water quality sampling stations where instrument packages are secured to structures such as docks, piers, pilings, buoys, navigational markers, or anchored to the bottom.

In 2005, Ecology's Marine Waters Monitoring (MWM) group began installing transmitters at monitoring stations to make the data available via the Internet and provide real-time access. This project is part of a national effort to develop an ocean observing system similar to the National Weather Service. Real-time or near real-time data broadcasts provide the public and scientists with current information on local marine water conditions, inter-basin water mass and energy exchange and tidal variability. Telemetry of real-time information also allows remote instrument performance checks, benefitting overall data continuity and quality.

Ecology's MWM group strategically situates moored instruments at sites in Puget Sound that are representative of larger areas, are conduits of inter-basin water mass and solute exchange, and are possible corridors for low oxygen water. Of particular interest is the characterization of water masses with low oxygen content.

This document serves as the Quality Assurance Monitoring Plan for the MWM mooring program and includes background project description, organization and schedule, quality objectives, sampling design, sampling procedures, measurement procedures, quality control, data management procedures, audits and reports, data verification and validation, and data quality assessment.

Background

The Washington State Department of Ecology (Ecology) initiated its statewide Marine Ambient Monitoring Program in 1967 (Bos et al., in press). The purpose of the program was to examine marine water quality regularly to determine existing conditions (current status) and to identify spatial and temporal trends (patterns). Many initial sampling sites were located near municipal and industrial discharges to measure effectiveness of agency regulatory programs. Over the next few decades, minor changes were made that modified the original program 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 change in monitoring strategy and consequently many monitoring stations were moved (Janzen, 1992; Bos et al., in press). This monitoring program sampled sites in Puget Sound and the coastal bays, Grays Harbor and Willapa Bay.

In 1989 at the behest of the Puget Sound Action Team, Ecology began making deeper vertical, continuous hydrographic profiles of the water column with a Conductivity, Temperature, and Depth (CTD) recorder in conjunction with other sensors (Bos et al., in press). Up until 1989, freshwater or standard methods were used to collect point samples from a few depths in the water column. Ecology's profile sampling primarily occurs monthly, during daylight, and when conditions are favorable for using a float plane.

In 1997, Ecology began using moored sensors, with automated sampling at a relatively high frequency, to improve the characterization spatial and temporal variability of the marine system. Because moored sensors produce a nearly continuous time-series data record, they are well suited toward monitoring processes, such as tidal stage, tidal transport of solutes, diurnal cycles, and detection of transient water mass intrusion. Moorings can help provide an early warning system of quickly deteriorating water quality. Moorings in the highly complex and dynamic waterbodies of Puget Sound are especially useful for improving our understanding of the temporal variability on hourly, daily, diurnal, fortnight, seasonal, and annual scales and relating observations larger scale climatic and oceanographic processes.

Current and Historic Mooring Stations (Moorings)

NOAA Moorings

In 1970, an experimental program was implemented by the Pacific Marine Environmental Lab at NOAA (Cannon, 1983). This program used unattended current meter moorings to characterize the temporal and spatial variability in the circulation and the large-scale dynamics of the Puget Sound estuarine system. These measurements were supplemented by bottle casts to measure water properties. These instruments gradually were replaced by Aanderaa current meters and were eventually equipped with temperature, conductivity, and pressure sensors. Later they were supplemented with vector-averaging current meters; salinity, temperature, and depth (STD) and CTD profilers; and nearby land-based anemometers. The current meter observations were made in the 1970s and early 1980s (Cannon, 1983).

Ecology Willapa Bay Moorings

Ecology has been maintaining moored instrument stations in Willapa Bay, adjacent to Washington's outer coast, since 1997 (Figure 3). The stations were originally installed in support of an EPA-funded study titled *Spatial and Temporal Variability in Primary Productivity and Water Column Parameters in Willapa Bay, Washington*. The goal of the study was to characterize the drivers of physical properties in the marine water column, quantify river and ocean inputs to Willapa Bay and the influence of those inputs on plankton conditions in Willapa Bay. Of particular interest were the links between watershed, ocean, and estuary processes and the factors controlling primary productivity of phytoplankton.

From 2001 to 2005, the moorings were supported as part of the Olympic Region Harmful Algal Bloom (ORHAB) program. This program is a collaborative effort to (1) study where and when toxic algal blooms occur, (2) better understand the environmental conditions conducive to their formation and uptake by intertidal shellfish, and (3) investigate potential methods for reducing their impacts on human health and the environment. Data from Ecology's stations in Willapa Bay were combined with the automated collection of water and phytoplankton samples to examine the connections between coastal blooms and their potential occurrence in coastal estuaries. More information on the ORHAB program can be found at www.orhab.org. Since completion of the ORHAB project, and through summer of 2013, a single monitoring station was maintained as part of Ecology's Marine Water Column Ambient Marine Monitoring Program. The data record maintained for Willapa Bay provides baseline oceanographic conditions in Willapa Bay to other agencies, academic institutions, and partners conducting related research and monitoring in Willapa Bay.

Ecology Puget Sound Moorings

In 2005, Ecology's Environmental Assessment Program launched the Urban Harbors Monitoring Program. This program was designed to establish long-term monitoring of near shore, near bottom dissolved oxygen levels. To support this program and to demonstrate the usefulness of providing real-time water quality data, Ecology established two Puget Sound mooring stations. Both stations measure temperature, conductivity, and dissolved oxygen at near shore (6-9 meter depth at mean lower low water (MLLW)) sites within Puget Sound. To better detect water column stratification, the MMU installed near-surface units at two locations in Puget Sound.

In 2009, the continuous monitoring program began shifting focus away from urban harbors. The benefits of continuous monitoring appear to diminish once it is established that a particular harbor is prone toward hypoxia. Instead of placing our continuous monitoring stations within urban harbors, we began placing continuous monitoring stations at key points of inter-basin exchange. Ocean water intrusions may significantly influence Puget Sound's oxygen levels (Khangaonkar et al., 2012). These redeployments are designed to clarify when and to what extent low oxygen intrusion from upwelled outer coastal waters is contributing to low oxygen events in Puget Sound and coastal bays. Likewise, moorings track transport events of low oxygen water, such as Hood Canal hypoxic water into other parts of Puget Sound.

Northwest Association of Networked Ocean Observing Systems (NANOOS)

The U.S. Integrated Ocean Observing System (IOOS) provides routine, continuous data and information on coastal ocean conditions (estuaries to open coast) analogous to the National Weather Service. IOOS collects and disseminates ocean data to address a variety of societal issues, including weather and climate change, maritime safety and efficiency, natural hazards, homeland security, public health, coastal ecosystem health, and the sustainable use of ocean resources. NANOOS is the Pacific Northwest Regional Association of IOOS. Ocean-observing systems designed and operated by regional associations, such as NANOOS, are integral components of IOOS, providing data and information at the time and space scales that regional users need. IOOS is authorized by the Integrated Coastal Ocean Observing System (ICOOS) Act and is implemented through NOAA via both federal agency and regional association partners.

Since 2004, NANOOS has maintained a partnership of seven implementing institutions (University of Washington, Oregon State University, Oregon Health and Science University, Oregon Department of State Lands, Oregon Department of Geology and Mineral Industries, Boeing, and Ecology) that provide observations and data services to enable the Pacific Northwest region to access coastal information and data via the NANOOS web portal (www.nanoos.org). An important goal of NANOOS is to develop the strategies and observing assets needed to provide real-time, web-based access to observations and forecasts for Pacific Northwest estuaries, coastal ocean, and shorelines addressing the needs of regional governments, industries, non-governmental organizations, scientists, and the public.

As a funded partner, Ecology contributes to NANOOS by operating and maintaining instrument packages that collect continuous data in key estuarine locations. These data are available in real-time and time-limited archives through the NANOOS web portal (www.nanoos.org) and through the Ecology website (http://www.ecy.wa.gov/programs/eap/mar_wat/moorings.html).

Study Area

Marine Waters of Washington State

The geographical area includes the Salish Sea, Grays Harbor, and Willapa Bay. Moorings may be deployed anywhere within the study area.

The Salish Sea, Puget Sound, and Strait of Juan de Fuca

The Salish Sea extends from the north end of the Strait of Georgia and Desolation Sound to the south end of the Puget Sound and west to the mouth of the Strait of Juan de Fuca including the inland marine waters of northern Washington, USA and southern British Columbia, Canada. These separately named bodies of water form a single estuarine ecosystem. **(**Figure 1)

The Salish Sea is connected to the Pacific Ocean primarily via the Strait of Juan de Fuca (with relatively slight tidal influence from the north around Vancouver Island and through Johnstone Strait) and is contained by Vancouver Island and the Olympic Peninsula. In addition to the Gulf and San Juan Islands, the watershed contains the lower Fraser River Delta and the Puget Lowlands as well as Hood Canal, Tacoma Narrows, and Deception Pass (Freelan, 2009).

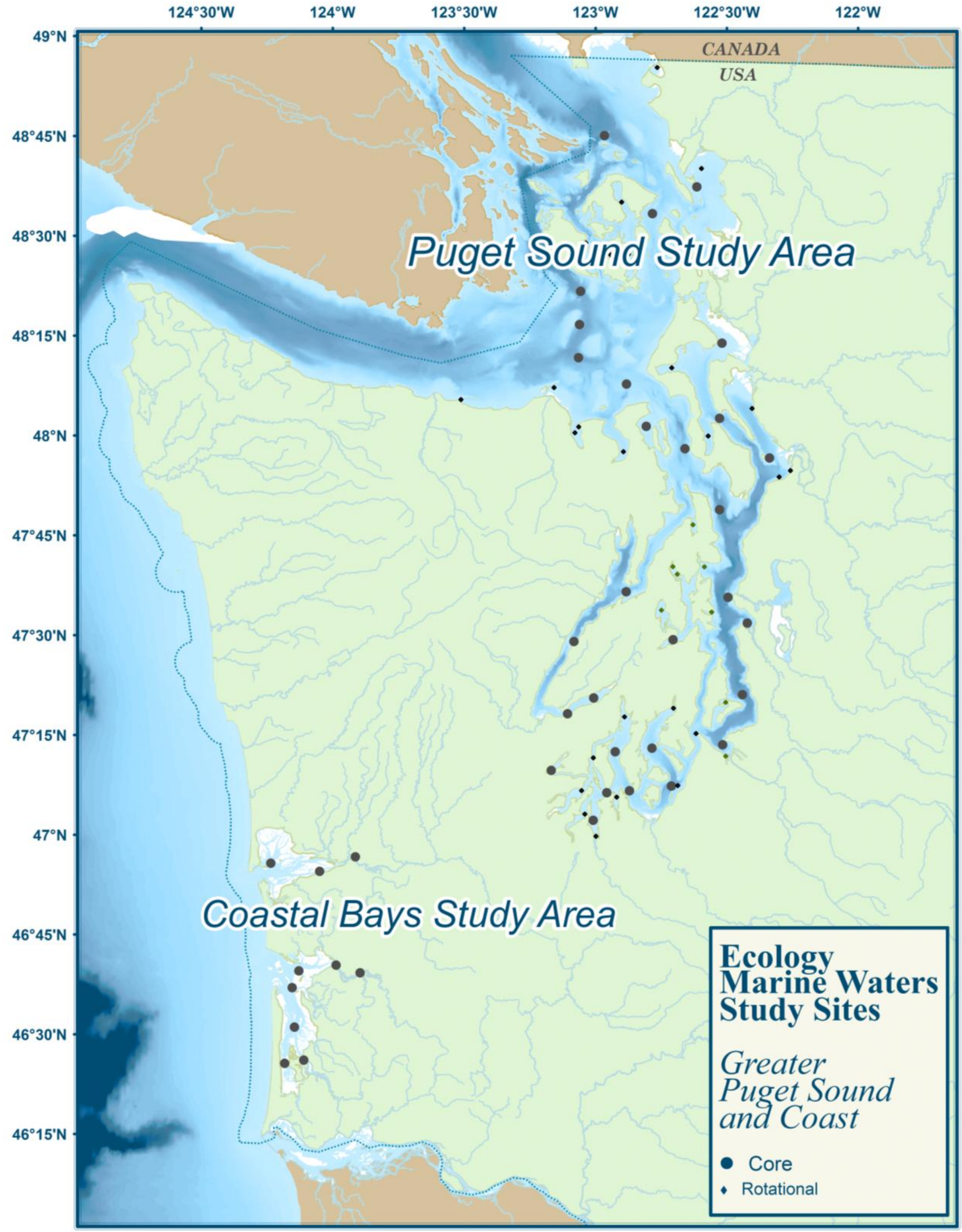

Figure 1. Map of Salish Sea.

Courtesy of Stephen Freelan, Western Washington University, 2009.

The geomorphology of the area includes a variety of landforms with interconnected shallow estuaries and bays, deep glacially scoured basins and fjords, and broad channels and river mouths. It is bounded by three major mountain ranges: the Olympics to the west, the mountains of Vancouver Island to the north, and the Cascade Range to the east. A regional depression extends from British Columbia to Oregon and includes the Puget lowlands between the Olympic and Cascade Mountains. The Puget Sound region of the Salish Sea is the flooded area of these lowlands (Burns, 1985).

The Puget Sound study area defined by the MWM Program encompasses marine basins, channels, and embayments in northwest Washington from the U.S./Canada border to the southern-most inlets near Olympia and Shelton. It includes Puget Sound proper, Whidbey Basin, Hood Canal, and portions of Admiralty Inlet, the San Juan Islands, and the eastern portion of the Strait of Juan de Fuca **(**Figure 1). The study area from the Washington/Canada border to Budd Inlet in southern Puget Sound extends for about 200 km and ranges in width from 10 to 40 km (Kennish, 1998).

Puget Sound Basins

The Strait of Juan de Fuca connects to the Strait of Georgia via Haro Strait on the west side of San Juan Islands and via Rosario Strait on the east of this island group. Boundary Bay, Bellingham Bay, and Padilla Bay all border the Straits to the east. Guemes Channel, which separates these bays from the Strait of Juan de Fuca, is now the location of a mooring deployment. South of this junction, Puget Sound is connected to the Strait of Juan de Fuca primarily via Admiralty Inlet. This region is referred to as the San Juan/North Sound region by the MWM program. Puget Sound is also connected less significantly to the eastern straits via Deception Pass at the north end of Whidbey Island and through Swinomish Slough which connects Skagit and Padilla Bays. The Puget Sound study area is further sub-divided bathymetrically into 4 basins, where each basin is a depression and separated from the others by a barrier (sill) or less drastic shoaling of the seafloor.

The entrance to the Main Basin of Puget Sound is constricted by a sill (75 m depth) at Admiralty Inlet, and this basin includes both Admiralty Inlet and the Central Basin. We now deploy a mooring at the Admiralty sill. Whidbey Basin connects to the Main Basin to the east and is considered an appendage to the Main Basin, as there is no true sill defining this basin. At this time, we deploy a mooring at the border between Whidbey Basin and the Main Basin. Both Whidbey and Central Basins are defined by deep passages, river deltas, mudflats, tidelands and island shorelines. South Puget Sound is separated from the Central Basin by a sill and constricted passage called Tacoma Narrows. We hope to establish a mooring station at this location in the future.

The South Puget Sound basin, consisting of deep passages, many islands and multiple finger inlets, has the most shoreline of any of the basins. Hood Canal is the smallest of the Puget Sound basins, and connects to the west side of the Main Basin at Admiralty Inlet. It has limited tidelands, bays, coves and mudflats compared to the other basins. South of the entrance to Hood Canal lies a shallow sill, constricting exchange between Hood Canal and the Main Basin (Burns, 1985).

Puget Sound has depths up to 300 m, while depth over the sills ranges from 44 m at the Narrows to 75 m at Admiralty Inlet. It has an area of 2632 km^2, a volume of 168 km^3, 2141 km of shoreline and 303 km^2 of tideland (Burns, 1985).

Circulation in Puget Sound is driven by a complex mix of freshwater inputs, tides, and winds. Puget Sound has been characterized as a two-layered estuarine system with marine waters entering at the sill in Admiralty Inlet from the Strait of Juan de Fuca at depths of 100 to 200 m and freshwater entering from a number of large streams and rivers. Major rivers entering Puget Sound include the Skagit, Stillaguamish, Snohomish, Cedar, Duwamish, Puyallup, and Nisqually (Figure 1). The Skagit, Stillaguamish, and Snohomish rivers account for more than 75% of the freshwater input into the Sound. The Fraser River in British Columbia is the largest freshwater source in the Salish Sea region and directly influences the San Juan Island and eastern Straits area.

Up to two-thirds of the freshwater outflow in Puget Sound is downwelled upon reaching Admiralty Inlet, mixed with deep ocean water and recirculated in the Sound (Ebbesmeyer et al., 1984). Residence time for water in the Central basin can be 160 days, and up to 290 days in isolated inlets and restricted deep basins in Hood Canal and southern Puget Sound (Khangaonkar et al., 2012).

Puget Sound is bordered by both relatively undeveloped rural areas and highly developed urban and industrial areas. Overall, 7 million people live within the drainage basin of the Salish Sea Salish Sea including the cities of Vancouver, Seattle, Tacoma, Everett, Bellingham, Victoria, Bremerton, Olympia , Nanaimo, Port Angeles, and Port Townsend (Freelan, 2009).

The Coastal Bays Study Area

The study area covered by the coastal portion of the Marine Water Column Monitoring Program includes the two largest estuaries on the outer Washington Coast, Grays Harbor and Willapa Bay (Figure 1). Currently, our study area does not include nearshore and offshore waters along the Pacific coast due to resource constraints and difficulties in sampling these environments.

Grays Harbor

The Grays Harbor study area includes the lower portion of the Chehalis River at Aberdeen out to the mouth of Grays Harbor. 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. Grays Harbor is a shallow estuary, with a mean depth of 4.3 m (National Oceanic and Atmospheric Administration, 1985). It is composed of connected channels surrounded by sand and mud flats.

The largest river flowing into the bay is the Chehalis River at the eastern end, providing 80% of all freshwater input to Grays Harbor. Many lesser rivers and streams flow into the bay, including the Hoquiam River which flows into the northern inner harbor at the town of Hoquiam and the Humptulips River which flows into the outer Harbor at North Bay. The mouth of the bay, which opens to the Pacific Ocean, is just three km wide and is situated between two low peninsulas formed by ocean-built bars. The watershed surrounding the bay is composed primarily of forests, interspersed with agricultural lands and residential/developed areas. Overall, the human population of Grays Harbor County, including the cities and towns of Aberdeen, Hoquiam, Ocean City, and Westport, is nearly 72,000. All live on or near the harbor (U.S. Census, 2013). 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 and out to the mouth connecting to the Pacific Ocean. Willapa Bay is the second largest estuary on the U.S. west coast at 240 km^2. Like Grays Harbor, it is also a drowned 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. Fifty percent of the bay is intertidal, with mud and sand flats surrounding multiple-connected channels 10 to 20 m deep composing the dominant geomorphology of the bay (Banas et al., 2007).

Freshwater river inputs to Willapa Bay are primarily from the Willapa River at the northeastern corner of the bay 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 Pacific Ocean by an extensive 45 km sand bar: the Long Beach Peninsula. The towns of Raymond, South Bend and Tokeland are 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 in the watershed.

Willapa Bay itself is important regionally as an economic center for shellfish cultivation, and produces the 2^{nd} largest oyster harvest in the U.S., annually, behind Louisiana and followed by Chesapeake Bay.

Columbia River Plume

During periods of sustained southerly (northward) winds, the Columbia River plume is driven inshore, and this warmer, fresher, nutrient-depleted water fills the water column to the depth of Washington’s coastal estuaries.

Mooring Logistical Limitations

Perhaps the foremost logistical limitation for mooring deployments is access and retrieval. Given Ecology’s interest in inter-basin water mass exchange, ideal mooring deployment is mid-channel at or beneath the pycnocline. In these areas, high currents and boat traffic can pose significant logistical challenges. Where practical, we attach packages to piers or pilings, thus simplifying installation and maintenance. From pilings, we can also establish telemetry broadcasts using wireless modem. Through collaborative partnerships, we deploy some moorings using ocean research vessels and divers. We cannot telemeter data in real-time at these stations now.

The other principal limitation is that mooring performance must be monitored and sensor packages periodically serviced by skilled technicians. Deployment periods are limited by battery endurance and by the rate of biological growth that occurs on the sensor packages. During the late spring and summer during high productivity, mooring servicing must be more frequent.

Recent Developments

Since 2008, the marine water quality monitoring at Ecology has focused on a spatially nested monitoring approach which provides information for Washington State marine waters at different temporal and spatial scales. The program compliments its monthly water column samples at core monitoring stations with continuous in-situ moored instruments and an en route ferry system and qualitative aerial and satellite observations. Jointly, these monitoring approaches offer a complementary perspective on the historic and the present dynamic of water masses and water quality at different spatial scales of observation. The spatially and temporally nested approach proved superior in communicating water quality issues to the public, scientists, and environmental resource managers.

Results from the MWM Program and various focused studies have shown that Puget Sound and Washington's coastal bays are experiencing a decline in water quality conditions; however, climate and ocean forces are significant drivers of physical conditions in these estuaries. Puget Sound Ecosystem Monitoring Program (PSEMP) partners have collaborated and selected a water quality indicator, the Marine Waters Condition Index which was developed by Ecology (Puget Sound Partnership, 2010; Krembs, 2012). The following key findings have emerged from these various studies:

- Pacific Ocean waters are significant drivers of Puget Sound physical conditions. The frequency, duration, and geographic extent of ocean water intrusions and accompanying circulation processes in Puget Sound basins is not well understood.
- Upwelled ocean waters entering Puget Sound are naturally low in oxygen. Coupled with anthropogenic influence, levels become critically low, especially in close-ended basins such as Hood Canal and South Puget Sound waters and during distinct climate regimes.
- Oxygen concentrations in deeper water are significantly influenced by the intensity of upwelling along the Washington coast.
- Weather and regional climate conditions are significant drivers on Puget Sound estuarine circulation. During cold, wet years, water is less dense, clearer, colder and higher in oxygen. During warm, dry years, water is more turbid, saltier, denser, and lower in oxygen.
- Nitrogen levels are steadily increasing, even after considering fluctuating ocean influences.
- Eutrophication effects are negatively impacting many places in Puget Sound and increased water residence time may amplify these effects in closed basins.
- Ocean acidification impacts on Puget Sound conditions are not well quantified and are also strongly influenced by patterns of upwelling along the Washington coast.
- Responses in other ecosystem components influenced by physical conditions produced by core drivers need to be better resolved in order to understand consequences of climate change.

From our moored sensor deployed at Admiralty Reach, preliminary analysis suggests that several factors need to align for low dissolved oxygen intrusions to occur (Mora et al., 2011). These factors are:

- Puget Sound dissolved oxygen declines coincide with oceanic source water, positive upwelling, and neap tides.
- The assumption that low dissolved oxygen condition is intrinsic to Puget Sound is not valid.
- Continued monitoring at Admiralty Reach is needed to better quantify and predict the magnitude of ocean water intrusions in response to weather systems under different tidal and coastal boundary conditions.

This Quality Assurance (QA) Monitoring Plan focuses on Ecology's MWM Program parts that implement continuous monitoring via moored instruments. A complete copy of Ecology's marine waters monitoring strategy is included in Appendix B.

Availability of Historical Data

Data results from Ecology MWM efforts are available by request or via the Internet at the Marine Waters Monitoring (MWM) website.

Regulatory Standards and Guidelines

The federal Clean Water Act requires that every state have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of (1) designated uses−such as aquatic life−for protection and (2) criteria−usually numeric−to achieve those uses. The Clean Water Act also requires that every state conduct an assessment of surface water quality every 2 years and submit two reports to EPA: 303(d), a list of impaired waterbodies and 305(b), a report of the results of the entire assessment.

Ecology conducts assessments on the condition of surface waters, routinely every two years, rotating between marine and fresh water systems. Washington's Water Quality Assessment reports the water quality status for waterbodies in the state and lists 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 the 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 173-201A.

Water quality assessment in Washington is guided by Water Quality Policy 1-11. This policy describes how waterbody segments will generally be assessed to determine attainment with Chapter 173-201A-WAC and then placed in various categories based on this determination. For dissolved oxygen, monitoring efforts must be able to discern a measurable decrease of 0.2 mg/L below natural conditions due to human actions.

The quality of mooring data is usually suitable for complimenting our other sampling efforts, characterizing seasonal trends and tidal patterns, determining natural conditions, characterizing processes in space and time, and providing useful data for model validation. In general, mooring data quality for temperature is very precise and reliable. Salinity measurements predominantly also fall into expected data quality needs but require closer QA protocol. Dissolved oxygen measurements, though generally meeting quality objectives, require still further examination.

Other Puget Sound Water Monitoring Programs

In partnership with Ecology, the University of Washington PRISM (Puget Sound Regional Synthesis Model) program has been conducting approximately twice-annual monitoring cruises throughout Puget Sound starting in June 1998 (http://www.prism.washington.edu/home/).

King County's Marine and Sediment Assessment Group conducts a comprehensive, long-term marine monitoring program that assesses water quality in the Central Puget Sound Basin (http://green.kingcounty.gov/marine/Default.aspx).

Ecology maintains a freshwater ambient monitoring network, described at the freshwater and river monitoring web page. The network includes numerous sites on rivers and streams within the Puget Sound drainage area. Water quality is measured monthly.

The NOAA (National Oceanic and Atmospheric Administration) Northwest Fisheries Science Center and West Coast Center for Human Health (http://www.nwfsc.noaa.gov/ohh/research/index.cfm) maintain multiple biological monitoring and research programs, including Sound Toxins, a citizen's monitoring program for Harmful Algal blooms (HABs) and related climate and environmental assessment programs.

Project Description

General Strategy

Ecology's MWM Program employs a monitoring strategy composed of multiple components in order to assess marine ecosystem processes and performance at various spatial and temporal scales. The components include (1) continuous in-situ observations at fixed locations of significant inter-basin exchange using moorings, (2) monthly sampling of the full water column at core stations, (3) near-surface measurements along extended horizontal transects via daily ferry routes, (4) qualitative satellite and aerial photography describing the scale and dynamic of surface waters and biological activity throughout Puget Sound. By placing moorings within inter-basin exchange zones, we improve complementary information on the dynamic of water masses and biological activity below the surface. More detailed information on the MWM Program strategy can be found in Appendix B.

MWM Strategic Goals

The strategic goals of the MWM Program are as follows:

- Effectively measure and provide information about long-term estuarine dynamics and conditions that affect marine water quality.
- Assess the impacts on estuarine processes and ecosystem functioning that result from the transport of water, solutes, and pollution (surface, inter-basin exchange).
- Attribute changes in ambient water quality to local, regional, or larger-scale human, climatic, and oceanographic sources.

Objectives and Data Needs

Goals of the mooring program include:

- Assure high quality sensor measurements and related laboratory analysis of reference samples.
- Safely install and maintain mooring stations.
- Report on water quality conditions and temporal variability, including features such as:
    - Conditions, given ebbing or flooding tides
    - Dominant water mass characterization and tracking, given tide changes
    - Low dissolved oxygen tracking with associated water masses
    - Diel patterns for dissolved oxygen
    - When seasonal change points occur
    - When conditions are isothermic
- Characterize and document spatial and temporal status and trends of marine water conditions in Puget Sound and the Coastal bays.
- Identify seasonal extremes and minima in tidal gradients.

- Contribute to the understanding of long-term changes of marine water quality in context of other environmental factors.
- Provide continuous data input for physical and ecological models.
- Provide real-time 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 state agencies, the public, managers, and private institutions.
- Coordinating findings with other PSEMP monitoring components to evaluate compliance with state water quality standards under the Clean Water Act [303(d) list and 305(b) report].
- Identify emerging problems and inform action agendas and regulatory processes. Quantify inter-basin water mass and oxygen exchange, and contribute to the overall understanding of the dynamic of natural conditions.

To meet our mooring program objectives, we measure a suite of core water quality parameters at each monitoring station. Parameters include the physical variables of temperature, salinity, and pressure. We add additional sensors based on the station's location and specific monitoring focus. For example, while we measure dissolved oxygen in Puget Sound, we do not do so in Willapa Bay. In Willapa Bay, we measure chlorophyll fluorescence to examine the links between oceanographic processes on the outer coast and those in the bay, including freshwater inflows from rivers. Healthy levels of dissolved oxygen are generally maintained here, due to strong mixing of water in the bay and its shallow depths; half of Willapa Bay is made up of tidal flats.

In contrast, numerous locations in South Puget Sound are at risk for low dissolved oxygen levels. Causal factors include reduced flushing, given the geological shape of the basin, and accumulation of dead organic material and microbial respiration. Therefore, we place a central focus on dissolved oxygen measurements in Puget Sound. Since water masses have distinct temperature, salinity, density, and dissolved oxygen signatures, strategically-placed continuous monitoring stations can be used to track and describe the dynamic of water mass movement in relation to larger forcing factors (e.g., weather). Based on continuous data over multiple tidal cycles, we can infer the direction, duration, and frequency of the anomalous water masses, such as oceanic and riverine, with low dissolved oxygen content.

Future data needs will likely require different combinations of sensors and deployment depths. For example, to gain information on water column stratification, near-surface instrument packages were added in November 2007 to the Manchester station in Clam Bay. They were added in July 2008 to the Squaxin Passage station at Carlyon Beach but are no longer maintained there. A stratified water column is more susceptible to certain conditions than a well-mixed water column. Such conditions are algal blooms that may lead to toxic plankton events or reductions in dissolved oxygen levels. We also focus on anomalies of temperature and freshwater intrusions such as stormwater after heavy precipitation that directly or indirectly affect water quality conditions in Puget Sound.

Organization and Schedule

The following people are involved in this project. All are employees of the Washington State Department of Ecology.

Table 1. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
David Mora Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6894	Mooring Coordinator. *Note* - Position eliminated (Sep 2013) in response to state and federal budget reductions.	Writes QAMP. Oversees mooring program. Conducts QA review, analyzes, and interprets data. Writes reports and summaries.
Suzan Pool Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-7287	Mooring Technician, Data Management, Publications Author	Conducts field sampling, laboratory analysis, equipment maintenance, data entry, and database development.
Christopher Krembs Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6675	Senior Oceanographer/ Principal Investigator, Lead Publications and Presentations Author	Determines marine waters monitoring strategy. Generates index (suite of key indicators) of water quality conditions. Determines appropriate analysis, review and interpretative methods for data reduction and reporting. Lead author of publications and presentations.
Julia Bos Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6674	Monitoring Coordinator, Data Management, Data Analyst, Publications Author	Oversees monitoring program - field and laboratory activities. Conducts QA review, analyzes and interprets data, and enters data into EIM/data management system. Writes reports and data summaries.
Skip Albertson Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6676	Physical Oceanographer, Data Analyst, Modeler, Publications Author	Analysis and reporting of climate and ocean indicators.
Carol Maloy Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6742	Unit Supervisor	Provides internal review of the QAMP, approves the budget, and approves the final QAMP.
Robert F. Cusimano Western Operations Section Ecology - EAP Phone: (360) 407-6596	Section Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAMP, and approves the final QAMP.
William R. Kammin Ecology - EAP Phone: (360) 407-6964	Ecology Quality Assurance Officer	Reviews the draft QAMP and approves the final QAMP.

EAP: Environmental Assessment Program.
EIM: Environmental Information Management system.
QAMP: Quality Assurance Monitoring Plan.

Table 2. Schedule for task assignments: completing field and laboratory work, data processing, review, quality control, storage in data repository, and reports.

Field and laboratory work	Due date	Lead staff
Field work (sample collection) completed	Monthly	Suzan Pool
Internal laboratory analyses completed	3 days (DO samples) post-collection	Suzan Pool
Internal laboratory analyses completed	1 month post-collection (chlorophyll a samples)	Laura Friedenberg
External laboratory analyses completed	3 months post-collection (nutrient samples)	Julia Bos
Data receipt/processing and upload to database		
Instrument and sensor data	Same month as collection	Suzan Pool
Internal laboratory data	1 month post analyses	Suzan Pool
External laboratory data	1 month post-analyses	Suzan Pool
Data review and quality assurance		
Instrument and sensor data	1 month post-collection	Staff
Internal laboratory data	1 month post-analyses	Suzan Pool
External laboratory data	Quarterly, one quarter post-collection	Suzan Pool
EAPMW and Environmental Information System (EIM) databases		
Product		
EIM data loaded	Same month as collection	Suzan Pool
EIM quality assurance	1 month post-collection	Staff
EIM complete	3 months after sampling year complete	Suzan Pool
Monthly reports		
Schedule		
Monthly condition summary generated	1 month post-collection	Julia Bos
Monthly summary posted to web	1 month post-collection	Christopher Krembs
Annual report		
Author lead / Support staff	Christopher Krembs/Julia Bos/Skip Albertson/ Mya Keyzers/Laura Friedenberg /Suzan Pool	
Schedule		
Draft due to supervisor	3 months after sampling year complete	
Final (all reviews done) due to publications coordinator	4 months after sampling year complete	
Final report due on web	4 months after sampling year complete	

- In general, we conduct field services for each station about once a month. The frequency varies depending on: (1) the time of year (bio-fouling mostly occurs during the late spring and summer; and (2) best professional judgment of instrument performance as monitored through telemetry. For more detail, see Quality Assurance, Instrument Service, and Maintenance section of this document.
- We typically conduct data reviews once every two weeks, usually a few weeks after servicing. The project coordinator is responsible for scheduling data reviews.

- The mooring project coordinator also completes the following reports: (1) Eyes Over Puget Sound (EOPS), due every month two days after the EOPS marine flight. Monthly condition reports and associated data products, due within a month following data review.

Quality Objectives

MWM unit staff are responsible for strict adherence to sampling protocols and for verifying that quality objectives for field measurements are met. However, sensor performance can vary widely, especially during summer months when bio-fouling is strongest. Instrument performance can decline or improve rapidly. Thus, we may not always meet quality measurement goals under harsh field conditions. We routinely have 3 to 5 people review data quality assurance (QA) and data quality control (QC) procedures to ensure that our data meet highest quality standards. Data quality codes are applied to the data set after common consent of the reviewing group. Flagged data are retained in the data set, allowing data users to decide the appropriate level of quality for their specific analysis requirements.

For mooring data, accuracy and precision are established through annual calibrations and through diligent sensor performance assessments at the beginning and end of each deployment.

Measurement Quality Objectives

QC procedures used during field sampling and laboratory analyses provide data for quantifying the accuracy and precision of the monitoring results. All sensors, laboratory equipment, and instruments are subjected to routine and strict performance tests and undergo recommended maintenance and calibration procedures. Specific activities for testing and ensuring high quality data are performed for different data types:

- Continuous mooring data – technicians assess sensor performance before and after each deployment in a stable environment.
- Discrete water samples – technicians evaluate and control analytical precision and bias by using laboratory check standards, duplicates, and blanks analyzed along with monitoring samples in the data stream.

Tables 3 and 4 show the measurement quality objectives (MQO) for the methods selected for sensor measurements and water sample analysis.

Field Measurements

MWM staff use electronic instruments for field measurements of the water column. To assure high quality of data, instruments selected for our moorings have specific precision, bias, range, and accuracy. In addition, instruments are manufactured by reputable companies with experience in marine water measurements using electronics. Several of these instruments have the capability to measure more than one parameter. For example, a SBE 16*plus* comprises of individual sensors for pressure (SBE 29), conductivity (SBE 4), and temperature (SBE 3) and it can be connected to an auxiliary sensor such as one that measures dissolved oxygen. Table 3 lists the manufacturers and instruments we have selected for our current moorings.

Table 3. Marine water column quality assurance/quality control objectives for field measurements using sensors.

Measurement - Field	Precision (% relative standard deviation, RSD)	Bias (% deviation from true value)	Mfg model number	Mfg reported range	Mfg reported accuracy	Lowest value
Chlorophyll Fluorescence	10%	5%	WET Labs, Inc. (ECO FLNTUSB)	0–50 ug/l Chl	[1]0.025 ug/l Chl	0.1 ug/l Chl
Conductivity	10%	5%	Sea-Bird Electronics (SBE 4)	0.0 - 7.0 Siemens/ meter (S/m)	0.0003 S/m	1 uS/cm
Density	10%	5%	Sea-Bird Electronics	Dependent on T,C	Dependent on T,C	0.1 σ_t
Dissolved Oxygen	5%	5%	Sea-Bird Electronics (SBE 43)	0 - 120% of saturation	2% of saturation	0.05 mg/L
Pressure	5%	1%	Sea-Bird Electronics (SBE 29)	0-500m	0.1% of full scale range	0.1 db
Temperature	0.025 °C	0.05 °C	Sea-Bird Electronics (SBE 3)	-5.0 to +35 °C	0.001 °C	0.01 °C
Turbidity	10%	5%	WET Labs, Inc. (ECO FLNTUSB)	0-25 NTU	0.01 NTU	0.1 NTU

[1] Reported as *sensitivity*.
*RSD is calculated as the ratio of the standard deviation and the mean of several values.

Laboratory Measurements

Seawater salinity sample analyses are conducted by the University of Washington's Marine Chemistry Laboratory (UW-MCL). Dissolved oxygen (Winkler) and chlorophyll *a* samples are analyzed in the Marine Laboratory (ML) of the MWM Program. Each laboratory must be accredited through Ecology's Laboratory Accreditation Unit. All work is expected to meet the QC requirements of the analytical methods used for this project. These requirements are summarized in the *Measurement Procedures* and *Quality Control Procedures* sections of this document and in the standard operating procedures (SOPs) for each analysis. Many of these procedures can also be found in detail in the Puget Sound Partnership's recommended guidelines and protocols (Puget Sound Water Quality Authority, 1991; Puget Sound Water Quality Action Team, 1997).

Table 4 summarizes the measurement quality objectives for *analytical laboratory* values for marine data. Ecology will be responsible for verifying that all MQOs are met.

Table 4. Marine water column quality assurance/quality control objectives for analytical laboratory measurements.

Measurement – Laboratory	Precision (% relative standard deviation, RSD)	Bias (% deviation from true value)	Lowest value
Dissolved Oxygen	5%	5%	0.05 mg/L
Chlorophyll *a*	10%	N/A	0.02 ug/L
Salinity	5%	5%	0.002 PSU

Sampling Process Design (Experimental Design)

Marine mooring stations are configured to produce data records with high temporal resolution for assessing the dynamic of long-term water quality indicators. This is an on-going monitoring effort that requires year-round coordinated field, laboratory, and data processing and handling. A schematic of work flow for a single mooring station is shown in Figure 2.

Work flow includes the following elements:

- Before we deploy, we assure that each mooring instrument is calibrated in accordance with manufacturer recommendations.
- We program our mooring instrument packages to take measurements, every 15 to 60 minutes, depending on station and length of deployment, and record these measurements on internal data loggers.
- To maintain instruments and assure data quality we routinely service our moorings and assess performance before and immediately after deployments.
- Via cellular modem, sensor data are automatically uploaded into the Marine Water's database (EAPMW) and telemetry feeds are automatically posted to the Internet.
- We monitor Internet posts. If sensor performance appears compromised, we schedule an early servicing.
- To ensure complete data records, we upload to a laptop computer while on site.
- At Ecology's Marine Laboratory, we analyze dissolved oxygen and chlorophyll samples and log results, which we use to help verify sensor performance.
- Routinely, we review and statistically explore mooring data in context with other available monitoring information, apply final QA/QC codes, and report errors (based on sensor performance tests including verification sampling). When development of the EAPMW database is finalized, our final data will be transferred to this database.

As new ecological information emerges and different questions about estuarine dynamics arise, the monitoring priorities and strategy will adapt accordingly. Updates to station locations, monitoring methods, and collected data are implemented as information priorities are updated and scientific needs evolve. Updates will be reported in addenda to this QA Monitoring Plan.

Specific information on sample collection methods, data quality assessment, management, analysis, and reporting are discussed in the following sections.

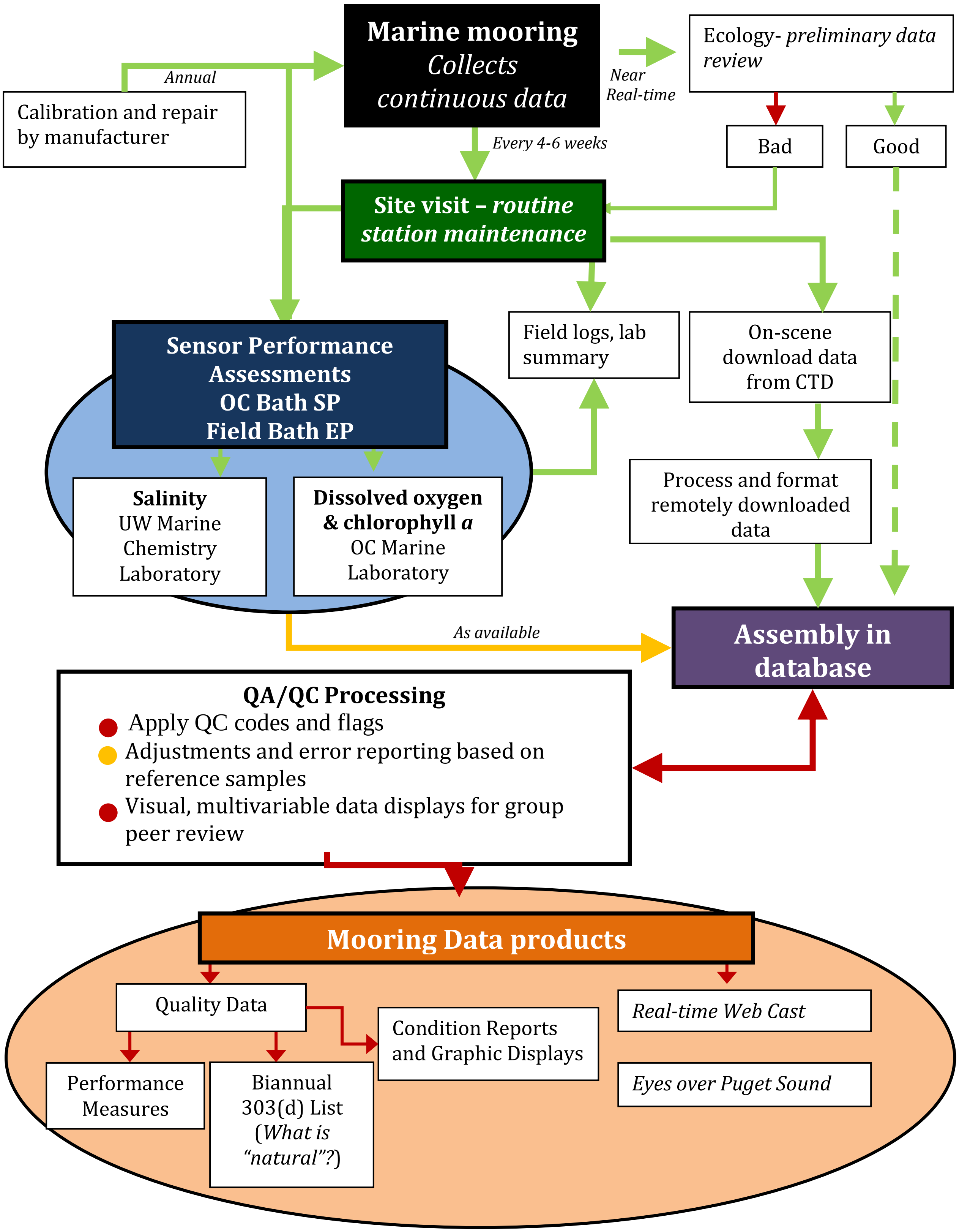

Figure 2. Flow chart of field, laboratory, and data processing and data handling steps.

Station Locations

Locations and active dates of current and past stations are given in Table 5. Station type, water depth, and parameters measured for each location are given in Table 6.

Table 5. Station designation and location information (current and past stations).

Station Designation ID Name Description	Latitude (N)	Longitude (W)	Active Date Start	Active Date End
SPM01 Western Washington University, Shannon Point Marine Center, West Guemes Channel	48.51	-122.69	Jan 2010	Aug 2013
ADM01 Admiralty Inlet, Admiralty Head	48.15	-122.69	Aug 2009	Oct 2013
MUK01 Possession Sound, Mount Baker Terminal, Port of Everett, Mukilteo	47.95	-122.29	Sep 2009	Present
MCHO1 Manchester, Clam Bay at Manchester Environmental Lab Pier	47.57	-122.55	Jan 2007	Jul 2013
SQX01 Squaxin Passage, Sandy Point at Carlyon Beach Dock	47.18	-122.94	Oct 2005	Feb 2012
BUD01 Budd Inlet, Olympia	47.05	-122.91	Nov 2005	Oct 2008
WPA04 Toke Point, Willapa River Light	46.70	-123.95	Jul 1997	Dec 2007
WPA13 Bay Center, Bay Center Channel Light	46.64	-123.99	Jul 1997	Aug 2013
WPA06 Oysterville, Nahcotta Channel Day Beacon	46.55	-123.99	Aug 1997	Jun 2007
WPA08 Naselle, Stanley Pt. Junction Light	46.46	-123.94	Aug 1997	Sep 2008

Table 6. Station depths at mean lower low water (MLLW) and parameters measured for recent deployments.

Table also denotes if station is configured for real-time data transmission (i.e., telemetry).

Water body	Station ID	Position ID	Type	Sensor depth at MLLW (m)	Water depth at MLLW (m)	Temperature (°C)	Salinity (psu)	Pressure (db)	Chlorophyll *a*	Dissolved oxygen (mg/L)	Telemetry
Willapa Bay											
Bay Center	WPA13	SF	surface, floating	0.5	6	X	X		X		
	WPA13	CR	mid-depth, rigid*	5.0	8.0	X	X	X			X
Puget Sound											
Rich Passage	MCH01	BR	bottom, rigid	8.9	10.4	X	X	X		X	X
	MCH01	SR	surface, rigid	1.9	10.4	X	X	X			X
Admiralty Reach	ADM01	BR	bottom, rigid	53.0	54.0	X	X	X		X	
Possession Sound	MUK01**	BR	near-shore, bottom, rigid	13.3	14.4	X	X	X		X	X
	MUK01**	SR	near-shore, surface, rigid	3.3	14.4	X	X	X			X
Guemes Channel	SPM01	BR	bottom, rigid	6.6	7.1	X	X	X		X	

* rigid: non-floating in a fixed position
** currently active and maintained

Puget Sound Stations

Tables 5 and 6 identify locations of sensor package deployments and what parameters we measure. At Puget Sound stations we focus on the variables temperature, salinity, pressure, and dissolved oxygen. Because dissolved oxygen concentrations in estuaries generally decrease with depth, sensor packages are deployed near the bottom surface (1- 1.5 m above the bottom), when practical. For near-bottom deployments, we currently use a Sea-Bird Electronics (SBE) model SBE 16*plus* with an integral pressure sensor and a dissolved oxygen sensor (model SBE 43). In the future, we may deploy newer models (e.g., SBE 37-SMP-IDO, SBE 37-SMP-ODO, SBE 16*plus* V2). To describe near-surface stratification we deploy near-surface sensors at 2-6 meters (about 3.0 m at MLLW) below the surface at selected stations. For these deployments, we may capture a reduced suite of variables and measure only density, conductivity, and salinity using Sea-Bird Electronics model SBE 37-SM or SBE 37-SMP.

Willapa Bay Stations

In recent years we have deployed two instrument configurations at the Willapa Bay (WPA13) station: one tracking the water surface using a tethered float at 0.5 meters and one fixed at 5.0 meters depth (MLLW, Figure 3). The floating package has sensors for temperature, salinity, and chlorophyll fluorescence (model SBE 16*plus* and a WET Labs WETStar fluorometer). Instruments are mounted into a custom-designed frame that is tethered to floats. The package is attached to a fiberglass I-beam track that allows it to ride up and down with the tide (Figure 3). The I-beam track is fixed to the steel piling of a United States Coast Guard (USCG) navigational marker. A second package, deployed at a fixed depth, measures water temperature, conductivity, pressure, and salinity, recently consisting of an SBE 37-SM or SBE 37-SMP attached to a chain inside a PVC pipe. Sensor packages are self-contained, with sufficient internal battery life and memory to collect and store data for several months.

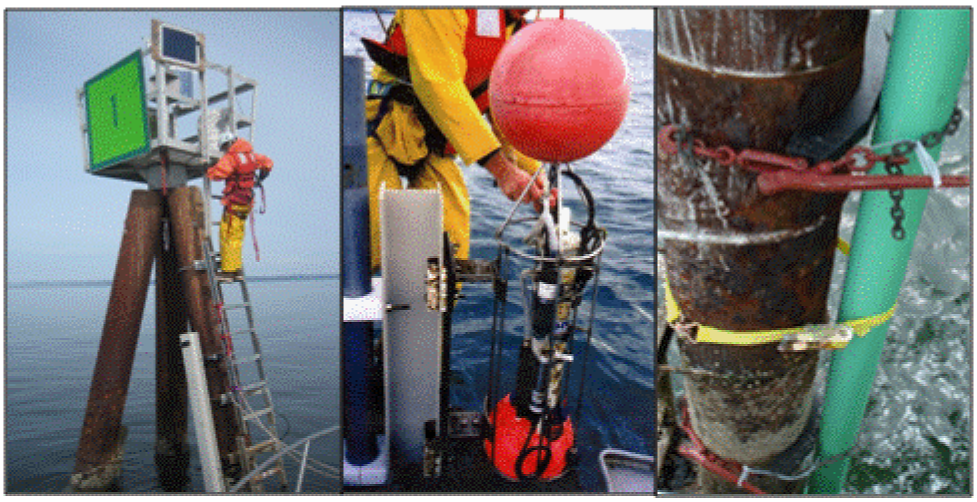

Figure 3. Left: Servicing the Bay Center mooring in Willapa Bay. Center: Instrument package attached to track follows a floating water depth. Right: Fixed position measuring variable water depth over a tidal cycle; SBE 37-SM hung by chain inside PVC pipe.

Telemetry

Where practical, we set up telemetry connections to our moorings to monitor performance and post data to the Internet. Telemetry connections are established through cellular modems that are attached to our mooring instruments. Once a day we contact our moorings through a telnet connection and download data collected by the CTD over the previous 24 hours. This process is automated using python scripts. Figure 4 shows our current telemetry configuration.[1] See the Data Management Section of this document for a description of telemetered data acquisition and management. More information telemetry set-up is available in the SOP No. EAP051, Standard Operating Procedure for Installation, Deployment & Retrieval of Oceanographic Sensors and Safety at Marine Mooring Stations (Mora et al., 2013).

[1] In 2010, we phased out the use of Free-Wave radios in favor of direct transmission through cellular modems.

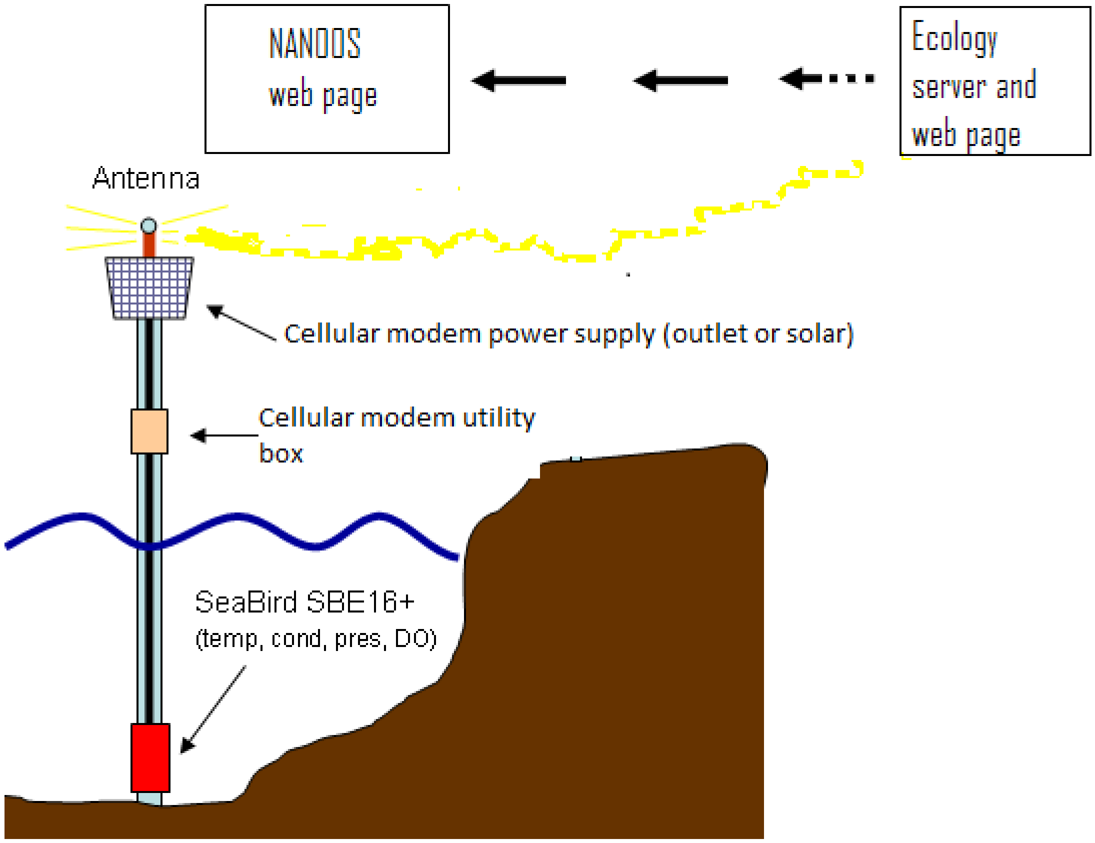

Figure 4. Telemetry configuration.

Because each sensor package is self-contained with sufficient internal battery life and memory to collect and store data for several months, no data are lost during transmission interruptions.

Permits and permissions

Willapa Bay – Mooring equipment is attached to navigational markers that are the property of the USCG. The USCG requires licenses in order to operate and maintain data collection equipment on these markers. Provisions for the licenses are described in documentation for each station. The licenses are valid for a 5-year term and subject to renewal. We maintain a copy of these licenses in our paper and electronic files.

Puget Sound – Moorings are fixed to existing docks and piers, and permissions for mounts are granted by the authority of the property. The Port of Everett manages the pier at the Mukilteo (MUK01) and EPA and NOAA manage the pier at the Manchester Environmental Laboratory on Clam Bay (MCH01). Access information is available in SOP No. EAP051, Standard Operating Procedure for Installation, Deployment & Retrieval of Oceanographic Sensors and Safety at Marine Mooring Stations (Mora et al., 2013).

Representativeness

The limited number of mooring deployments is not representative of the entire study area. To optimize mooring representativeness of spatial and temporal variability, we place moorings in locations of high inter-basin exchange, thereby probing multiple water masses during a tidal cycle. Moorings placed beneath the pycnocline are suited to detecting denser water intrusions. Moorings placed at or near the pycnocline are suited to describing variability in daily averaged pycnocline depth.

Both flight and mooring data are used to evaluate representativeness at most of our stations. We use marine flight vertical profiling data to routinely assess spatial representativeness of mooring data. Vice versa, we use mooring data to assess the temporal representativeness of flight profile data.

We assess site location representativeness based on:

- Cross channel Acoustic Doppler Current Profile (ADCP) transects, which help describe flow of water around the mooring and basin filling characteristics.
- Distinctness of water during flooding or ebbing tides. Temperature-salinity signatures are relatively conservative variables and may be used to match mooring data with profile data from adjacent marine flight stations.
- Degree of stratification. During high mixing periods samples may be broadly representative and during periods of stratification may be limited to the strata sampled.

Relation of Objectives to Site Characteristics

As discussed in the section titled Background, our study areas include Puget Sound and Coastal Bays. The high frequency of mooring measurements assures that temporal variability is well characterized for parameters of interest at the location of moorings. Spatially, moorings are limited in their ability to characterize broader areas. Water source can be traced using salinity and temperature which can tie to distant influences. We place moorings at key water mass exchange points that can represent water from the following water bodies:

- Willapa Bay deployment represents the influence of coastal Pacific Ocean water on the estuarine waters of Willapa Bay (particularly the Palix River).
- Admiralty Inlet deployment captures the exchange of water from Puget Sound with waters from North Puget Sound and Strait of Juan de Fuca and upwelled water off the coast of Washington.
- Shannon Point deployment represents water from Guemes Channel, Rosario Strait, Padilla Bay, Bellingham Bay, and distant influences of the Fraser River.
- Mukilteo deployment represents water from Possession Sound, Saratoga Passage, Snohomish and Skagit River, and Central Puget Sound.
- Manchester deployment represents water from Central Puget Sound, Rich Passage, Sinclair Inlet, and Little Clam Bay.

As discussed in previous sections, we may choose to redeploy sensor packages to different sites or depths at any time, based on data needs, resource availability, and program objectives.

Completeness

EPA has defined completeness as 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 to collect 95% of the data to be collected as described in this QA Monitoring Plan. The principal reasons why all data may not be collected are: (1) malfunctioning equipment or (2) compromised sensor performance from fouling. To minimize the risk of unexpected data loss, we monitor telemetry feeds for signs of malfunctioning equipment.

Comparability

It is important that data collected and analyzed for long-term monitoring by different technicians or monitoring groups are comparable. In order to ensure comparable data collection techniques, Ecology technicians operate with overlapping responsibilities and regularly coordinate checks to ensure method and technical consistency between individual staff. Standard protocols are followed for all sampling events and laboratory analyses. Data from the same water mass (same salinity temperature signature) are routinely compared between the moorings and flight program to assure comparability within the program.

Design Assumptions

An inherent design assumption of automated sampling devices is that they are functioning properly during deployments.

Though we take steps to assure representativeness, data users must be careful not to over-generalize the mooring measurements. A single mooring alone cannot ascertain cross-channel or vertical variability. This is especially the case for measurements taken within the pycnocline where values change rapidly with depth or in a highly stratified water column.

Sampling Procedures

Safety Protocols

Safety procedures are described in Ecology's Environmental Assessment Program Safety Manual (Washington State Department of Ecology, 2012) and in SOP No. EAP051 (Mora et al., 2013). Collecting water samples and mooring servicing pose a number of potential safety hazards. Hazards include falling, handling heavy gear, being struck by heavy equipment, exposure to hazardous materials (NaINaOH-azide), fatigue, and exposure to extreme temperatures and sunlight.

Station installation and maintenance will be done with at least two staff, in addition to a boat operator, if needed. For safety against lifting hazards, instrument packages are generally raised and lowered to the water using ropes, davits and pulleys. However, these types of operations pose the risk of becoming entangled or pinched by taut lines. Field operations will be discontinued if personnel determine that weather, sea-state, or other conditions pose a risk to personal safety.

A corrosive chemical is used during the water column task. This chemical is alkaline azide (NaOH-NaI-azide) and is used for dissolved oxygen sample fixing. All samples fixed with this reagent are stored in a secured container. Foul weather gear should always be available and donned as needed. Mooring technicians are responsible for their own clothing and gear. First aid kits will be available in the mooring servicing vehicle; they are stored in secondary containment at all times. Materials for managing spills are also brought along.

Safety Equipment and Emergency Procedure

Safety equipment includes:

- Coast Guard approved life preservers
- Ship-to-shore (VHF) radio
- First aid kit
- Fire extinguisher
- Cell phones and a list of emergency phone numbers

Emergency procedures require the field staff to have current First Aid/CPR training and knowledge of agency procedures for emergencies.

Minimizing Spread of Aquatic Organisms

Regarding minimizing the spread of aquatic organisms, we will follow protocols set in Standard Operating Procedures to Minimize the Spread of Invasive Species Version 2.0. SOP No. EAP070 (Parsons, 2012)

Equipment and Supplies

The required field equipment for mooring deployment and servicing is listed in SOP No. EAP051 (Mora et al., 2013). This list will serve as a checklist to use before the surveys and will be modified as sampling methods are changed or updated.

Field Logs and Notebooks

Field log sheets (paper or digital) are used to record information such as mooring station, servicing date and time, weather conditions, equipment serial numbers, instrument status, data file names, QC sample information, and unusual circumstances affecting interpretation of the data (See Appendix C).

Digital copies of the field and sample logs are stored for future reference on a shared, secure, frequently backed up network drive in a designated folder. Examples of field log forms and sample logs are included in Appendix C.

Field notebooks include back-up paper field logs, maps, checklists, station and sampling plans, various SOPs and technical notes, and safety and contact information.

Field Observations and Photos

Photos may be taken during mooring servicing to record observations and events. These photos are used to document mooring servicing activities and the condition of instruments upon recovery. A photo log will be kept in the field log to help document instances when there are hazards or likely impairment of data quality.

Weather & Conditions

The weather and related conditions are also recorded during a survey. These data include:

- Approximate wind speed and direction.
- Tidal stage at the time of instrument recovery.
- General weather condition, such as overcast, cool, rainy, foggy, sunny, or warm.

Currently, these data are captured in field logs, Microsoft Excel files, and a Microsoft Access database. In the near future, data will be transferred to the EAPMW database that is under development.

Field Sample Collection Methods

A brief summary of field sample collection methods are outlined in Table 7.

Table 7. Field sample collection methods.

Sample Parameter	Collection Method or Sensor	Sample Container	Preservation Method	Holding Time
Chlorophyll *a*	UNESCO, 1994 (JGOFS Protocols)	125 mL brown polyethylene bottles	Store on ice - filter immediately upon arrival at lab. Filter stored frozen in 90% acetone.	1 month
Salinity	UNESCO, 1994 (JGOFS Protocols)	250 mL brown polyethylene bottles	Keep in a well-sealed container.	6 months
Dissolved Oxygen	UNESCO, 1994 (JGOFS Protocols) *1st sample collected	130 mL DO glass-stoppered flasks	Fix with $MnCl_2$ & NaOH-NaI azide reagents. Stopper & shake. Store in cold, dark conditions. Upon arrival at lab, shake again and apply DI cap.	5 days
CTD Parameters				
Conductivity	Sea-Bird Electronics SBE 16*plus*, SBE 37-SM, and SBE 37-SMP	NA	Internally Recorded	NA
Temperature	Sea-Bird Electronics SBE 16*plus*, SBE 37-SM, and SBE 37-SMP	NA	Internally Recorded	NA
Dissolved Oxygen	Sea-Bird Electronics SBE 43	NA	Internally Recorded	NA
Pressure	Sea-Bird Electronics SBE 16*plus*, SBE 37-SM, and SBE 37-SMP	NA	Internally Recorded	NA
Fluorescence	WET Labs WETStar, and ECO FLNTUSB	NA	Internally Recorded	NA
Turbidity	WET Labs ECO FLNTUSB	NA	Internally Recorded	NA

JGOFS: Joint Global Ocean Flux Study

CTD Data Collection

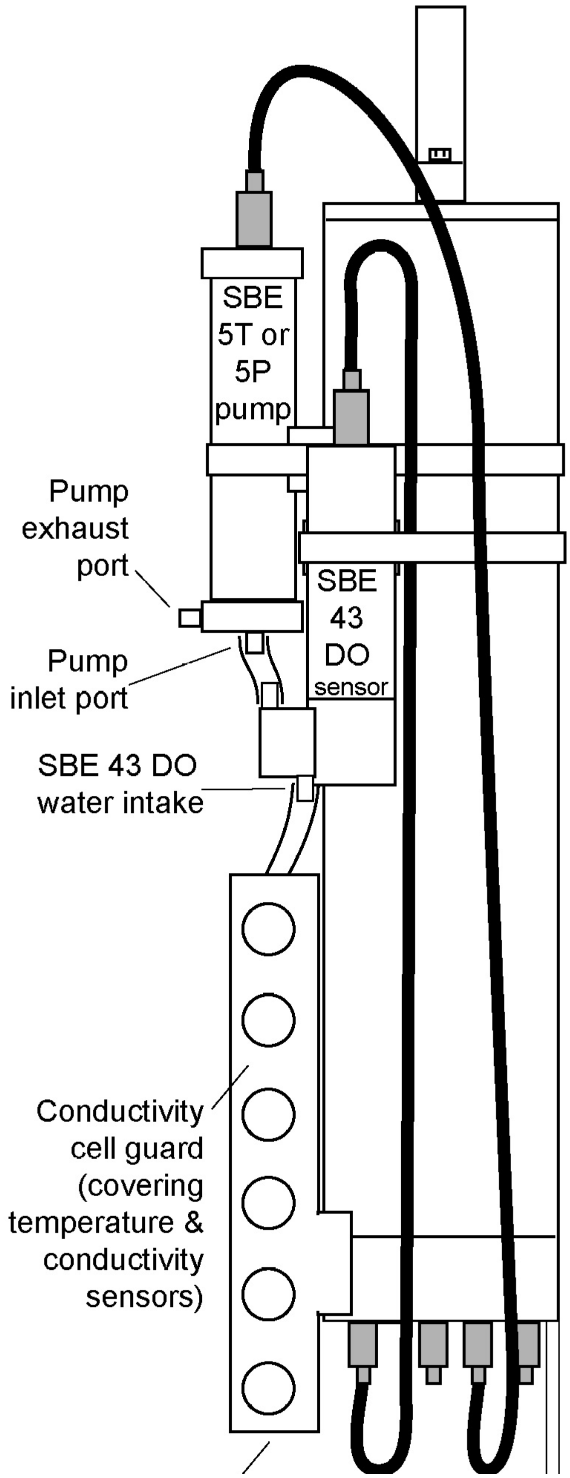

Figure 5. Sea-Bird Electronics, Inc., conductivity, temperature, depth (CTD) instrument with auxiliary dissolved oxygen sensor.

Illustration copied from Sea-Bird Electronics, Inc.'s manual on SBE 16plus.

Sea-Bird Electronics, Inc. CTDs built for moored applications are used for measuring hydrographic conditions at each mooring station (Figure 5). The base unit measures conductivity and temperature with depth. The CTD may be interfaced with sensors that measure dissolved oxygen, in situ chlorophyll fluorescence, and turbidity. Specific sensors used for measuring each parameter are listed in Table 9.

CTD Field Sampling

Typically we program our instrument packages to sample every 15 minutes (i.e., about 3000 samples per month). This frequency represents a balance between the need for frequent measurements and instrument battery power supply and data storage capacity. We may vary the sample interval because of power budget limitations. For example, our Admiralty Reach deployment spans two months or more, on average. Therefore, to conserve power we decrease the sampling frequency to every 45 minutes.

We program the SBE 16*plus* instrument packages to run the pump 30 seconds before sampling. Final programming of the instrument sampling interval is usually done in the field, following sensor performance checks. We log data pertinent to instrument performance and sampling into our field log. Principles of CTD and sensor operations are described in manufacturer operating manuals. More details on optimum CTD data collection are outlined in these manuals.

Technicians regularly review manuals and technical notes from manufacturers to stay up-to-date on improvements and changes to sensor operation methods.

Using a CTD for Quality Control (QC) Sampling

We use freshly calibration-checked CTDs to assess the performance of sensors before they are deployed and then again after they are retrieved. For dissolved oxygen Sea-Bird Electronics refers to this type of sampling as reference sampling (Sea-Bird Electronics Application Note 64-2, 2012). This step allows us to let both sensors run side-by-side in an environment that is better controlled than in open water. A side-by-side (paired sample) approach increases the data volume for a more statistically robust comparison of sensors. Sensor-to-sensor paired sampling is done within a controlled tank environment where the effects from currents and advection are minimal. For more information, see the discussion in the Sensor Performance Assessment section of this document. We use two types of tanks:

- A 12-inch diameter cylinder PVC pipe (tank) that we use in the field with height sufficient to submerge the entire CTD. This tank is primarily used for end of deployment (End Point) assessments, when sensors tend to be fouled. For additional detail please see Standard Operating Procedure for Marine Waters Sensor Performance Assessment - Field Procedure. SOP No. EAP087 (Pool et al., 2013).
- A 187-gallon (5' long x 3' wide x 3' high) tank maintained at the Operations Center lab. This tank is used primarily for start of deployment (Start Point) assessments, where sensors have been previously cleaned and prepped for redeployment. For additional detail please see Standard Operating Procedure for Marine Waters Sensor Performance Assessment - Lab Procedure. SOP No. EAP086 (Friedenberg et al., 2013).

For CTDs with fluorometers, rather than immerse the CTD in a bath, we instead compare duplicate sample measurements between the reference and assessed instruments by pushing samples into the sampling chamber using a syringe and Tygon tubings.

We log the time and location of QC sample collection onto forms that we later enter into our database. The forms include samplers, date, sampling time, sampling location by station ID, and bottle number. More detail on sensor performance assessments is provided in the Quality Control Procedures section of this document.

Water Sample Collection

As discussed in the Quality Control Section, we collect seawater samples for a paired and second and independent CTD sensor performance check. This independent approach, albeit more labor intensive and subject to its own analytical biases, proves valuable for troubleshooting sensor and calibration disagreements. We collect QC samples for dissolved oxygen, chlorophyll *a*, and salinity before and after each mooring servicing. The samples are labeled with station, depth, and sample identification numbers and these are recorded in the data log. These additional samples ensure consistency and cross calibrations with other programs in Puget Sound.

Seawater sampling methods are described in SOP No. EAP025, Standard Operating Procedure for Seawater Sampling (Bos, 2010a). These methods are derived from standard international oceanographic sampling methods published by UNESCO (1994). Our seawater sampling protocols adhere to the most current seawater sampling methods (Grasshoff et al., 1999) and adhere to Puget Sound Partnership's recommended guidelines and protocols for measuring conventional water column variables in Puget Sound (Puget Sound Water Quality Authority, 1991; Puget Sound Water Quality Action Team, 1997). If deviations from the protocols occur, a brief explanation will be given and be published as annual addendums to this QA Monitoring Plan.

Sample Chain-of-Custody Procedures

After sample collection, analytical grab samples are labeled and stored on ice in a cooler. Copies of field sample logs are delivered to the lab with the corresponding samples. Once the samples are delivered, lab personnel will log in each sample and assign a lab number to each, using the sample label number and a date extension. Each laboratory sample number corresponds to a particular date, station, and depth. Examples of chain-of-custody logs sent to each laboratory are included in Appendix C.

Measurement Procedures

Laboratory Procedures

Salinity samples are analyzed at University of Washington's Marine Chemistry Laboratory in Seattle, Washington using analytical methods described in Table 8. Dissolved oxygen and chlorophyll *a* samples are analyzed at Ecology's Marine Laboratory using the method described in Table 8. QA/QC protocols are discussed in the Quality Control section of this plan. More details on laboratory procedures are described in Manchester Environmental Laboratory's Lab Users Manual (Manchester Environmental Laboratory, 2008).

Table 8. Laboratory measurement methods and reporting limits.

Analyte	Lab	Analytical Method	Reporting Limit	Holding Time
Dissolved oxygen	ML	Carpenter, 1965	0.01 mg/L	3 - 5 days
Chlorophyll *a*	ML	Arar and Collins, 1997	0.01 mg/L	4 weeks
Salinity	MCL	Grasshoff et al., 1999	0.01 PSU	6 months

ML: Ecology's Marine Laboratory
MCL: UW's Marine Chemistry Laboratory

Field Measurements

MMU staff measure data using various combinations of sensors from Sea-Bird Electronics, Inc. and WET Labs, Inc. With our sensor packages, we measure temperature, conductivity, pressure, density, salinity, fluorescence, turbidity, and dissolved oxygen. Parameters measured at each station may change based on the need to meet strategic objectives. Manufacturer specifications and model numbers for the instruments and associated sensors are shown in Table 9.

Table 9. Instrument manufacturers' specifications.

These specifications represent a best-case scenario, and many factors such as biofouling of sensor membranes and sediment build-up can affect the accuracy and sensitivity of instruments in the field.

Measurement	Accuracy (or % Deviation from True Value)	Resolution	Stability
Sea-Bird SBE 16			
Temperature	0.01 ºC	0.001 ºC	
Conductivity	0.001 S/m	0.0001 S/m	
Sea-Bird SBE 16*plus*			
Temperature	0.005 ºC	0.0001 ºC	0.0002 ºC
Conductivity	0.0005 S/m	0.00007 S/m	0.0003 S/m
Pressure	0.1% of full range	0.002% of full range	0.004%
Sea-Bird SBE 37-SM, SBE 37-SMP			
Temperature	0.002 ºC	0.0001 ºC	0.0002 ºC
Conductivity	0.0003 S/m	0.00001 S/m	0.0003 S/m
Sea-Bird SBE 43			
Dissolved oxygen	2% of saturation		2% per 1000 hrs
WET Labs WETStar			
Fluorescence	≥0.03 µg/l (sensitivity)		
WET Labs ECO FLNTUSB			
Fluorescence	0.01 µg/l (sensitivity)		
Turbidity	0.01 NTU (sensitivity)		

Sea-Bird Electronics equations (Sea-Bird Electronics, Inc., 2012c) are used to calculate dissolved oxygen from the SBE 43 sensor's raw voltage. In addition to the measurement of SBE 43 raw voltage, the SBE equation takes into account measurements of pressure, temperature, and salinity. We complete these calculations using SBE software, Excel, or MATLAB routines. SBE software calculates salinity and density from CTD measurements of conductivity, temperature, and pressure measurements.

See Quality Control section of this document for more information on how we interpret instrument measurements.

Quality Control Procedures

Quality Assurance/Quality Control

High data quality is mandatory for Ecology's Long-Term Marine Waters Monitoring Program and ensures that trends accurately reflect true environmental change. We routinely perform data QA, data QC, and data group reviews with 3 to 5 staff to ensure that our data meet highest quality standards. Following data review, data quality codes are applied to the data set allowing users to decide the appropriate level of quality for specific analyses. The effort to provide high quality data occurs in many steps before, during and after data collection. QA/QC procedures include the following activities:

- Training of personnel
- Equipment maintenance
- Assessing the attainment of QA/QC objectives
- Calibrating equipment
- Conducting sensor performance checks prior to deployment
- Reducing environmental sensor fouling issues
- Analytical laboratory and field data QA/QC procedures
- Performing proper sample custody
- Performing proper data and information management
- Data verification and validation through routine data review
- Periodic data usability (method) assessment
- Conducting audits

In subsequent sections, we discuss data management, verification and validation through data reviews, usability assessments, and conducting audits.

Steps in the QC process have evolved with improved knowledge and technology advancement. Therefore, every three years we update SOPs applicable to this QA Monitoring Plan.

Training of Personnel

All personnel who conduct field activities receive training on CTD usage and calibration, sample handling, program QA/QC, and safety. Each staff person is required to be familiar with this QA Monitoring Plan and field procedures described in SOPs. New technicians are given demonstrations of field procedures before they perform field activities. Also, they are accompanied by an experienced senior technician on their initial field trips to verify that they understand and follow procedures. Periodic field checks are conducted by the monitoring coordinator to ensure consistent sampling performance among staff. Results from these checks are discussed with the team and appropriate updates or changes are implemented.

Mooring Maintenance

Servicing procedures are described in detail in SOP No. EAP051 (Mora et al., 2013). SBE 16*plus* and SBE 43 sensors are cleaned in accordance with manufacturer recommendations (Sea-Bird Electronics, Inc., 2012a, and 2012b). SBE 37-SM and SBE 37-SMP sensors are cleaned in accordance with Sea-Bird Electronics Application Note No. 83 (2012d) and Application Note 2D (2012a).

Typically we service stations every 4 weeks in the summer, when fouling is strongest, and every 5 to 6 weeks in the winter, when fouling is low. We monitor telemetry feeds and push up scheduling dates when we detect anomalies that suggest poor sensor performance. During a field servicing, we conduct sensor performance tests, download data, clean sensor packages, replace batteries and biofouling protection (antifoulants), collect quality reference samples, and collect other ancillary data as required.

We strive for full swap-outs for SBE 16*plus* with SBE 43 (aka CTD-DO) and SBE 16*plus* with WETStar or ECO FLNTUSB (aka CTD-FL) packages when sufficient sensors are available. During a full swap-out we exchange instrument packages with packages serviced at the Operations Center. Swapping out instrument packages decreases the complexity of field operations, enables a higher degree of QA through additional performance checks, and provides the capacity for tighter QC.

To help protect instruments from floating debris we use sensor packages inside protective cages, as needed. To help reduce corrosion we insulate against different metal-to-metal contacts and use zinc anodes. We place pingers on our instrument packages to assist in retrieval should they become dislodged.

Sensor Protection from Biofouling and Scouring

In a coastal or estuarine environment, the most common detriment to instrument performance is the growth of organisms such as seaweed, algae, bacteria, and invertebrates (e.g., barnacles and mussels). The reduced sensor performance due to growth on or around instruments is known as biofouling (Figure 6). We use antifoulant devices in the conductivity cell intake and outtake and a piece of copper tube on the pump exhaust to slow the accumulation of biofouling inside sensors and extend instrument deployments. These leaching reservoirs containing small amounts of bis(tributyltin) oxide antifoulant devices. For details, see SOP No. EAP051 (Mora et al., 2013).

Sensor impairment may also occur by sediment suspended in high energy sampling settings. The volume and velocity of suspended sediment varies with depth, so it is possible to mitigate scouring by redeploying at a more favorable depth.[2]

[2] At a previous location in Squaxin Passage deployment, dissolved oxygen sensor membranes were severely damaged by scouring. This problem was mitigated by redeploying from near-bottom to 5.5 meters depth.

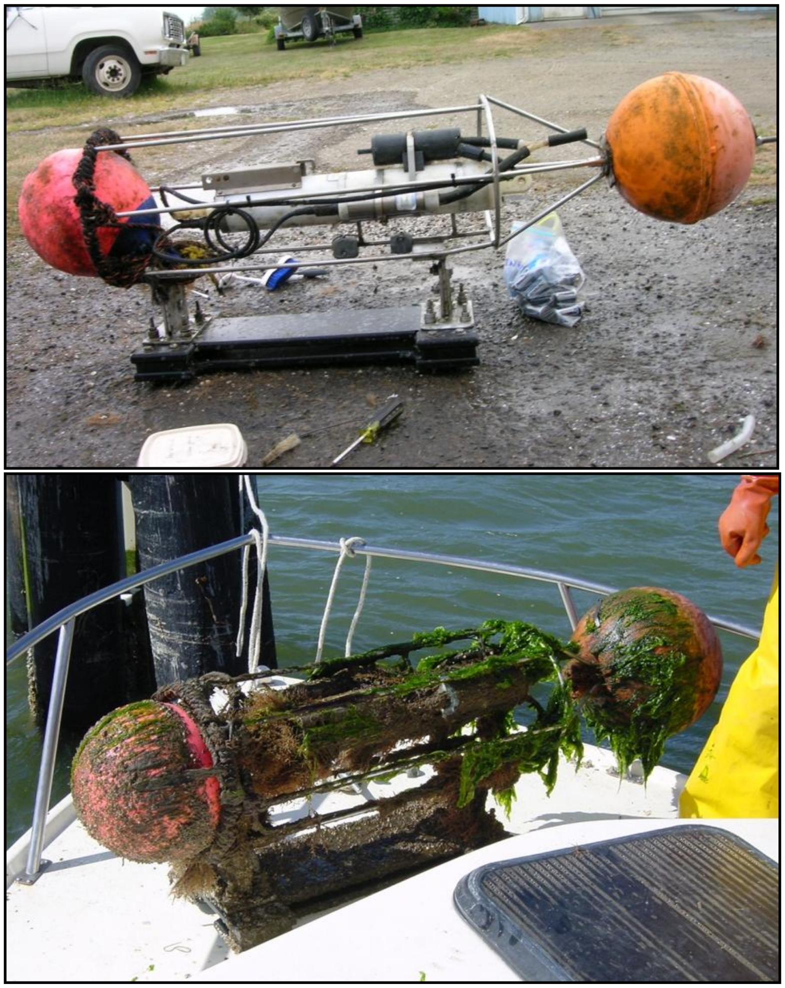

Figure 6. Before (top) and after (bottom) servicing the Willapa Bay mooring.

The outside of the instrument package shows a great deal of biofouling (e.g., growth of macroalgae, barnacles) following a 4-week deployment during the summer.

Meeting Quality Assurance/Quality Control Objectives

A major pre-requisite for establishing QC standards for field sensor data collection is a strong QA program. A national consensus among a broad group of oceanographers and marine scientists 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. (Babin et al., 2009) For this reason, we have implemented multiple levels of QA to test performance and operation of sensors before, during and after deployment.

The MWM group engages in frequent data quality assessments to test if measurement procedures are functioning as expected. Technicians routinely collect and present results from a variety of QC samples and conduct frequent evaluations to test whether quality objectives are being met, in the field and in the lab. Tables 3 and 4 list criteria for quality objectives specified for marine water column variables, including precision, bias and reporting limits.
Table 10 identifies our quality objectives of mooring data and steps that we follow toward meeting these objectives.

Table 10. A summary of quality control steps for field measurements.

Field Measurement	Precision (relative standard deviation, %RSD)	Bias (% from true value)	Manufacturer Annual Calibration Report	Preliminary Review and Automated Flagging of Real- Time Data	Performance Assessment Laboratory SOP	Performance Assessment Field SOP	Data Review and Flagging	Adjustment Based Performance Assessments
Dissolved Oxygen	5%	5%	✓	✓	✓	✓	✓	✓
Temperature	1%	1%	✓	✓	✓	✓	✓	
Conductivity	10%	5%	✓	✓	✓	✓	✓	
Pressure	5%	1%	✓	✓	✓	✓	✓	
Density	10%	5%	✓	✓	✓	✓	✓	
Salinity	10%	5%	✓	✓	✓	✓	✓	
Chlorophyll Fluorescence	NA	NA	✓				✓	

Instrument Calibration

We use high quality manufacturer calibrations to help us assure that quality objectives can be met. Manufacturer calibration procedures are fully described in various operating manuals and application notes for the specific sensors used (Sea-Bird Electronics, Inc., 2006, 2007a, 2007b, 2012b, 2012c; WET Labs, Inc., 2012, 2013). In addition, we follow Sea-Bird Electronics Application Note 64-1 for proper connections of the SBE 16*plus* and SBE 43 (Sea-Bird Electronics, Inc., 2008). A full list of sensors is included in Table 7. We send our instruments in for manufacturer calibration on an annual-use basis. With each calibration, the manufacturer generates a new set of calibration coefficients. We apply the most recent set of calibration coefficients to instrument data for processing and entry into the database. We track deployment time and, following one year of deployment, return instruments to the manufacturer for recalibration. Our calibration and maintenance schedule also helps track age and behavior of sensors over each instrument's operational lifetime. Between scheduled manufacturer calibrations, if performance checks and data review indicate that instrument performance may be compromised, we then return instruments to the manufacturer for diagnostics and repair.

In addition to providing a new set of calibration coefficients, the manufacturer also reports on drift and loss of sensitivity relative to the previous calibration. We investigate and resolve instances where manufacturer calibration assessments differ from our own assessments.

Sensor Performance Assessment

Sensor performance assessments also help us assure that quality objectives were met. To verify CTD performance and check calibrations we conduct start point and end point sensor performance assessments before and after each mooring deployment. We conduct start point assessments using the Operations Center laboratory-controlled water bath and end point assessments using a portable water-filled field bath (Figure 7). More details of this process are found in previously mentioned SOPs for the field and laboratory sensor performance assessments.

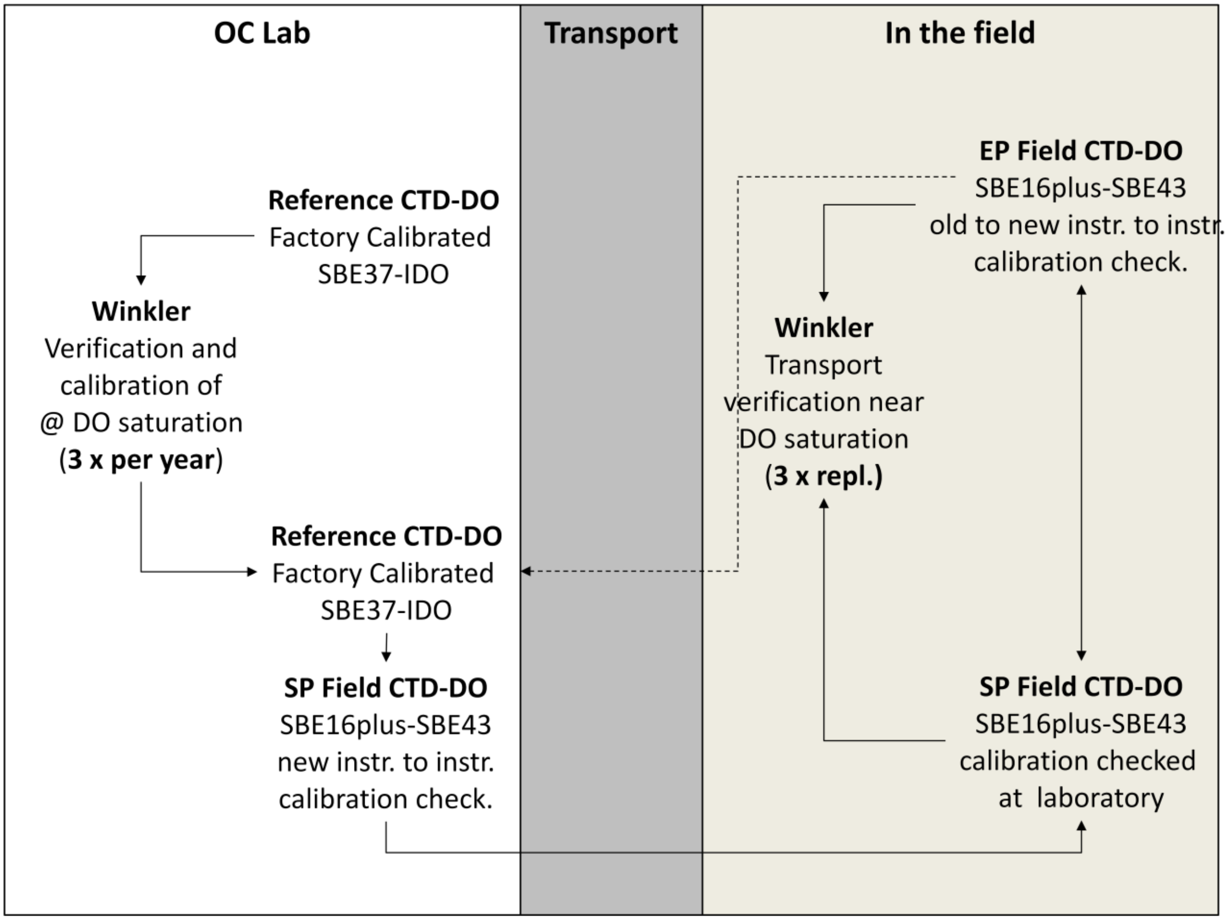

Figure 7. Sensor performance assessment scheme for CTD-DO instruments.

In the lab bath at near saturation, we determine CTD start point (SP) and end point (EP) calibration conditions using a reference CTD-DO. The dark area indicates transport from the lab to the field. Winkler samples are collected to help verify results of instrument-to-instrument assessments.

Dissolved Oxygen Sensor Performance Assessment

For the laboratory bath procedure, we use a reference CTD-DO (SBE 37-SMP-IDO) to evaluate the performance of field instruments. Periodically the calibration of the reference instrument is checked against laboratory methods to ensure highest data quality. To minimize air exposure and dissolved oxygen bias in Winkler samples, the lab bath must be maintained near 100% dissolved oxygen saturation. Both a CTD with a SBE 43 to be deployed into the field and a reference CTD (SBE 37-SMP-IDO) are placed within a laboratory bath and programmed to concurrently take parallel samples. Dissolved oxygen measurements between the field CTD and the reference instrument are quantitatively compared to evaluate field sensor performance and whether measurement quality objectives for accuracy and precision are met.

After the start point condition of a CTD-DO sensor ready for deployment has been verified and quantified, the sensor is taken to the field. Before deployment, an instrument-to-instrument comparison is performed in the field using this CTD-DO and another CTD-DO sensor that is recently retrieved from the mooring and being returned to the laboratory. The parallel sensor comparison allows us to assess the end point calibration condition of the previous CTD-DO deployment and makes a data overlap that can be used to construct a continuous data record.

For dissolved oxygen, the sensor performance check is considered passing if values fall within 2% of the expected value *(*i.e., the paired bath measurement values off the assessed instrument are 98-102% of the reference instrument measurements). This determination should be made before deployment and instruments that fail this test should not be deployed. The instrument-to-instrument comparison ratio is confirmed by laboratory analysis (Winkler replicates) and the deploying instrument and Winklers should fall within 5% of the expected result. We use the DO Winkler titration method to determine the dissolved oxygen concentration in collected reference samples (see Bos and Keyzers, 2012). In a laboratory performance assessment, Winkler sample verification is not required before deployment. Verification Winkler samples are analyzed by staff in the Ecology's Marine Laboratory.

For pressure, we verify performance in the bath by confirming whether values are near expected pressure values, given the depth of the bath water, and whether there is general agreement among CTDs held at the same depth within the bath.

For salinity, which is derived from the CTD's conductivity measurements, we verify performance based on whether there is agreement (difference <0.2%) between the reference CTD and the assessed CTD. In general, we expect sensors to hold their calibration well within measured quality objectives (McPhaden et al., 1990). Verification salinity samples are sent to the UW's Marine Chemistry Laboratory for analysis.

For temperature, we verify performance based on whether there is agreement (difference <0.2%) between the reference CTD and the assessed CTD.

Fluorometer Sensor Performance Assessment

During mooring servicing, we collect verification samples for chlorophyll *a* laboratory analysis (Bos, 2012). In addition, we use seawater to assess the fluorometer cell while commanding the CTD to sample. Similarly, we also sample deionized water as a blank verification of the sensor. We conduct this type of assessment before (cleaned sensor) and after each deployment (potentially biofouled sensor). To improve the quality of the fluorometer assessments, we remove air bubbles from the sensor cell before CTD measurements. SOP No. EAP051 provides further detailed information.

Assessment Assumptions

Performance assessments at start and end points are only one aspect of how we meet measured quality objectives. Overall performance for the entirety of a deployment may or may not be assured. For example, pump flow may be temporarily obstructed by debris. Such impediments to sensor performance are detected and evaluated during data review meetings.

CTD Comparison Samples

As previously discussed in the “Sensor Performance Assessment” section, CTD comparison samples are measured by a reference CTD in laboratory and field baths used to indicate independently a possible sensor malfunction or drift. Water samples for salinity, dissolved oxygen, and chlorophyll *a* are also collected from the test baths and compared with sensor values to independently verify CTD sensor performance. If the CTD values differ substantially from the analyzed water samples, CTD data will be "flagged" until differences are resolved.

CTD Field Replicates

Numerous replicate CTD sensor samples are taken as part of SOP No. EAP087: Marine Waters Sensor Performance Assessment - Laboratory Procedures (Friedenberg et al., 2013) and SOP No. EAP086: Marine Waters Sensor Performance Assessment - Field Procedures (Pool et al., 2013). Before completing sensor performance assessments, our technicians, through replicate measurements, must establish that the test bath water and instruments being tested are stable and the precision of measurements far exceeds measurement quality objectives.

Laboratory Quality Assurance/Quality Control Procedures

Replicate Sample Collection

Replicate comparison samples are collected during sensor performance assessments. Replicates are used to help establish precision and bias of sampling methods. Parameters to be replicated include dissolved oxygen Winklers, salinity, and chlorophyll *a*. These replicates are used to assess whether the data quality objectives for precision are met. If the objectives are not met, the discrepancy will be qualified and evaluated and result in flagging the data. In addition, UW’s Marine Chemistry Laboratory and Ecology’s Marine Laboratory all routinely perform replicate sample analyses using sample splits within laboratory batches for QC purposes.

Check 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 are flagged and any measurement problem is determined and resolved.

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.

A positive blank can indicate laboratory contamination. Blanks are important to determine the accuracy at low concentration level. Blank responses are used to determine method detection limits (MDLs) and in some cases, to correct sample results depending on the procedure.

Table 11 lists the QA/QC samples used to perform quality assessment of laboratory procedures and data results.

Table 11. Quality assurance/quality control procedures for parameter analysis in the laboratory.

Analytical Parameters	Calibration and Standardization	Lab Control (Check) Samples -or- Standards (30 or less samples)	Replicates (30 or less samples)	Blanks per Batch
Laboratory Samples				
Chlorophyll & Phaeopigments	Calibration – 2x/year	4 total - 2 high, 2 low	3	2 - method 2 - reagent
Dissolved Oxygen	3 point standardization	3	3	2
Salinity	1 (batch)	1	1	2

Dissolved oxygen and chlorophyll *a* are replicated from the field or assessment baths.

Lab QC Documentation

QC procedures for the UW's Marine Chemistry Laboratory are documented and followed per standard seawater analysis protocols. The laboratory is able to assess laboratory bias by using standards, replicates, and laboratory splits to analyze error and MDLs during analyses. The laboratory is accredited by Ecology's Laboratory Accreditation Section for the methods listed in this QA Monitoring Plan.

Full QC procedures for Ecology's Marine Laboratory are documented in Bos (2008, 2010a, 2010b, and 2012) and in Bos and Keyzers (2012). Laboratory bias is assessed by running blanks and standards during all analytical procedures. Bias is minimized by strictly following standard methods. The laboratory is accredited by Ecology's Laboratory Accreditation Section for the methods listed in this QA Monitoring Plan.

Corrective Actions

QC results may indicate problems with data during the course of sensor deployment or sample processing. 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

Sample Custody

During sample collection, a chain-of-custody form is generated for samples based on field logs. Chain-of-custody forms are delivered to labs with the corresponding samples for management of sample counts and scheduling and tracking analysis. When data results are delivered, chain-of-custody forms are reconciled with data to ensure complete delivery and correct invoicing for all results. If discrepancies exist, research and investigation of the discrepancy is conducted in coordination with the lab(s) until the problem is resolved.

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. There are several levels of information management required in this system.

- Field, lab, and CTD 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 lab 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)

At many levels, it is essential for information and products to be thoughtfully organized for the efficient and reliable output. The MWM group uses a managed information and file system to make this possible.

Field, Laboratory, and CTD Data and Observations

Field Data and Observations

Field data and observations are recorded in either paper or electronic field logs during mooring servicing and instrument performance assessments (Appendix C). After mooring servicing and performance assessments are completed, information from the printed version is checked and entered into the digital log in the office and loaded to the database. The digital forms are backed up onto a secure network server after verification is complete and data are uploaded to the database.

Laboratory Data

Laboratory reports and results for marine water sample analysis performed by external labs are typically sent as files attached to email. These are reviewed and checked and then loaded into the EAPMW data management system. Laboratory results generated by internal labs are entered into digital forms and stored on a secure network server. All laboratory results are reviewed, loaded to the EAPMW database and further assessed using QA/QC procedures (Bos and Albertson, in press, b). All data are given QC codes when finalized.

All data from labs include:

- Results for all parameters measured.
- A narrative or report identifying 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 including results for all required field and analytical (laboratory) control replicates, laboratory control (check) samples, reference materials or standards, method blanks (Table 9).

CTD Data

Processing and managing all sensor data involve many procedures and calculations, performed at different steps and levels in the data management system. These procedures are constantly being updated and improved as sensor technology evolves and national standards are established. Thus, the specific procedures and calculations used for processing marine water column data are documented and managed per the Standard Operating Procedures for Marine Waters Data Processing and Adjustment (Bos and Albertson, in press, a) which is updated every 3 years.

At our telemetered stations, moored CTD data are uploaded daily through our in-house telemetry system. This system, through a wireless cellular modem, uses a telnet connection and software (Python scripts) to communicate with the moorings. Once the connection is established, the Python script commands the CTD to stop logging data and requests a status update. The status update indicates the CTD serial number, CTD time, number of samples taken, and other diagnostic information. The script then commands the CTD to upload data in ASCII and hexadecimal formats. When uploading is complete, the script instructs the CTD to start logging again. The entire communication session is recorded as a text file. The telemetry system then transfers data from the text file into the EAPMW database for the purposes of web pages postings.

At the end of each mooring deployment cycle, we upload CTD data in ASCII and hexadecimal formats. We process hexadecimal data into ASCII format using Sea-Bird Electronics software and then archive onto Ecology’s network servers.

When development of the EAPMW database is complete, processed CTD data ultimately will be transferred to the EAPMW database.

The goal of the Marine Waters Data Management System is to keep CTD-related data in the EAPMW database, currently under development. The EAPMW database covers the life cycle of marine water quality data management including pre-monitoring equipment calibration, raw data uploads from instruments, adjustments of electronic data based on QA/QC protocols, data analysis, long-term data storage, and data dissemination (Erickson, 2010). The database is integrated with the Environmental Information Management System (EIM) to allow the final data to be archived in and publicly-accessed from EIM.

In the interim (until design and development of the EAPMW database is completed), we archive CTD-related data on Ecology's network servers using Excel and Access database files. This includes calibration data, data from field servicing and sensor performance assessments, and laboratory results of sensor verification samples. Additionally, we retain paper copies and compact discs (CDs) of sensor service reports and calibration data provided by the sensors' manufacturers. We store electronic copies on Ecology's network servers.

Document Management

Mooring technicians have the option of using either digital or paper forms during sampling and sensor performance assessments. These documents are updated annually or as needed, primarily as digital files. Any paper logs and relevant information are entered electronically or scanned into digital files (.pdfs) after the servicing and maintained in a secure, organized file system. Eventually all paper documents are transferred to the state archive, following the state's public information protocols, once all related information and data have been reviewed and finalized.

Data File Management

All digital data files, including logs, lab reports, forms, location information such as maps or site descriptions, field and lab data, and other summaries are stored on a secure, shared network server. Folders are organized by topic or data parameter type. Higher level folders are used to organize other digital files by type, including project data and information, multi-program documents such as inventories, forms and lists, procedures, manuals, software programs, equipment information, manuals, and other related information.

Analytical and QA/QC information management (summary statistics, calibration information, calculation methods and other information)

Specific analysis results of field and lab data are stored on a secure, shared network server. Analytical information and related methods are organized and stored by specific program or project. Summary statistics are stored with the data used to generate specific results.

Reports, observations and other products (descriptive summaries, graphs, photos, video)

All reports, data summaries, graphical products, photos, and other visualizations are stored on a secure, shared network server. All products and related information are organized and stored by specific program or project. Products relating to one or more programs or projects are stored in higher level program folders on a secure network drive that is routinely backed up. All final products are available to the public by request or at the MWM group's website.

The MWM group is moving to the use of a SQL Server database (i.e., EAPMW database) to store all raw data files, photo, and other large objects. Any updates and changes to this structure will be captured in future addenda to this project plan.

All digital files are kept on a secure network server that is backed up regularly to enable recovery of any information lost by accident or equipment failure.

Audits and Reports

Audits

All laboratories participate in routine performance and system audits of various analytical procedures. Audit results are available upon request. The Laboratory Accreditation Unit of Ecology's EAP accredits all contract laboratories that conduct environmental analyses for the agency, and the accreditation process includes performance testing and periodic lab assessments. No additional audits are envisioned.

MWM technicians track and reconcile the status of samples being analyzed by the laboratories, being particularly alert to any significant QC problems as they arise. The monitoring coordinator periodically performs QA/QC of files including raw data field sheets, calibration records, laboratory QA/QC, and other program-related materials. Summaries (statistical evaluations and plots) of all QC information collected during a sampling year are generated and reviewed routinely by the MWM group.

The results of QA/QC and audits including performance assessment of all measurement systems, significant QA problems, and recommended solutions are available upon data finalization following the completion of a sampling year.

Reports

Monthly Data Summaries

The Mooring Project Coordinator plots data and performs initial QA/QC of:

- Anomalous data points or unexpected data behavior
- Missing data
- Data issues which may need further action

Monthly conditions are generated during data reviews and include a summary of the previous month, statistics such as minimums, maximums, means, maximum daily ranges, correlation between variables, tidal exchange characteristics, and intra-tidal variability. Data products are under development which will further illustrate the condition report summaries. These reports will be posted on Ecology's MMU web page.

EOPS Summaries

The Mooring Project Coordinator is responsible for generating the "Mooring Observations and Trends" portion of a monthly online report titled "Eyes Over Puget Sound" (EOPS). This report is released two days following an EOPS marine flight. In the mooring portion of these reports, we summarize trends of water characteristics over the previous two weeks and report on the pycnocline depth at the Mukilteo mooring station in relation to influencing weather and climate factors.

NANOOS Reports

The Mooring Project Coordinator and the Unit Supervisor are responsible for contributing to biannual NANOOS reports currently due in June and December of each year. These reports summarize key events within the mooring program over the reporting period.

Statistical Analyses

A station-specific statistical evaluation of mooring data is conducted every month. Historical results are calculated and current monthly data are compared to the historical envelope. Data that appear anomalous are flagged and reviewed. Reports on monthly trends in water properties are then generated.

Further analysis to detect significant changes in water quality is performed via mathematical and other statistical analysis of the data. Parametric and non-parametric statistical tests are conducted to further interpret oceanographic processes. The data set may include some of the following attributes that must be considered when conducting statistical analysis:

- Missing data
- Weather events that cause anomalous values
- Laboratory method changes
- Field data collection method changes
- Personnel changes
- Equipment malfunctions
- Non-detects

Annual Report

An annual report including summaries of key variables in each region and Puget Sound-wide is generated at the end of every sampling year and available on the web within 3 months after the sampling year ends. Products from the annual summary may be used in other publications generated by partner agencies such as NOAA or the Puget Sound Partnership.

Public access to electronic versions of the data and reports generated from this project will be available via Ecology's home page at the "Ecology for Scientists" site (www.ecy.wa.gov/science/) and the Marine Waters website.

Data Verification and Validation (including Data Review)

Data Verification

Data verification and review are conducted by the MWM group by jointly 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 accompany the sample results.
- Established criteria for QC results were met.
- Data qualifiers (QC codes) are properly assigned.

UW's Marine Chemistry Laboratory and Ecology's Marine Laboratory provide verified data packages for all data analyzed. Laboratories and contractors submit interim data reports to the monitoring coordinator.

The report includes:

- Raw data in electronic format.
- QA sample results.
- Any problems encountered and corrective actions that were taken.
- Any qualification of the results.

All data received from external providers are verified and reviewed by MWM staff against the verification criteria listed above. Any discrepancies are discussed with the laboratories or contractors for amendment. Once data have been reviewed and verified, MWM staff enters the data into the EAPMW database.

Field and Lab Verification Procedures

Throughout field sampling, the lead technician and all crew members are responsible for carrying out sample collection and sensor deployment procedures as specified. Additionally, technicians systematically review all field documents (e.g., field logs, chain-of-custody sheets, sample labels) to ensure data entries are consistent, correct, and complete, with no errors or omissions. Lab technicians verify sample and data disposition by conducting continual tracking and reconciliation procedures.

Data Validation

As previously mentioned, we perform group reviews by reviewing plots and statistical summaries of data. Staff individually review various data sets, documenting problems and applying QC qualifier codes as necessary. This initial coding is then reviewed by the MWM group, consisting of 3 to 5 staff, including the lead Oceanographer. Once the sampling year is complete, all reviewed data are re-assessed in the context of the annual summary and then finalized once all QA/QC and validation are complete.

Data Review

Through our review of data plots we can readily detect many types of sensor issues. Examples include:

- Out of expected range may indicate a sensor malfunction or samples taken outside of the intended sampling environment.
- Highly erratic values may indicate sensor or pump issues.
- Values rapidly shifting outside of surrounding intra-tidal ranges may indicate sensor issues.
- Changes in dissolved oxygen and salinity but not temperature levels may indicate sensor issues.
- A rapid and simultaneous drop in salinity and dissolved oxygen and loss of variability may indicate blocked flow.
- Outliers in T-S or DO-S space indicate sensor performance issues.
- A lengthening of the time interval between sampling may indicate power supply issues.

Our review process consists of automated quality coding, preparation of data review plots (e.g., time series, inter-variable), preliminary quality coding of unacceptable data, review of sensor performance and verification/error analysis, group review meetings and documentation relating different variables to one another for consistency, data coding, and data adjustment (Bos and Albertson, in press, a; Bos and Albertson, in press, b).

Data reviews are a team effort. The mooring coordinator prepares data review plots and identifies patently unacceptable data. The coordinator then tasks other members of the review team to focus on particular aspects of the review including site characteristics, sensor performance assessments, relevant profile data, climatic and oceanic influences, seasonality, and trends and patterns associated with water masses.

Before finalizing data, we:

- Check for discontinuity between deployments. This can be caused by applying incorrect calibration coefficients or by sub-optimal instrument performance.
- Evaluate, verify, and reference sampling. For dissolved oxygen, we may provide an adjusted value estimate based on start point reference sampling.

Additional guidance is found in a Quality Assurance of Real Time Oceanographic Data (QARTOD) Manual for Real-Time Quality Control of Dissolved Oxygen Observations (Bushnell et al., 2012).

Data Quality (Usability) Assessment

Upon completion of the QA/QC, data review and the data verification process, Data Quality (Usability) Assessment (Lombard and Kirchmer, 2004) is conducted by the MWM group.

Data from laboratory QC procedures, as well as results from field replicates, laboratory duplicates, check samples, and sensor performance tests, provide information to determine if measurement quality objectives (MQOs) have been met. The usability assessment includes review of laboratory and sensor precision, accuracy, and the success of meeting control limits. Sample results from laboratory analyses and sensor deployments are examined for completeness (all samples, all analyses). Processing logs and laboratory reports are scrutinized for adherence to specified methods and QA/QC requirements.

A review of sample results is performed after each sampling year to determine a need for modifications to the sampling or analysis program. Laboratory and QA staff familiar with assessment of data quality are consulted if expert guidance is needed for assessment. Annual summaries include reporting on whether data quality is acceptable and whether project objectives are being met. If limitations in the data are identified, they are noted.

If MQOs are met, the quality of the data is considered usable for meeting project objectives. If MQOs have not been met, MWM staff examine the data to determine whether they are still usable and whether the quantity is sufficient to meet project objectives.

Sampling Design Evaluation and Meeting Project Objectives

The sampling design for the MWM Program was restructured to support questions about the ocean influence and inter-basin transport of water masses on water quality. Periodically, we evaluate whether our existing mooring locations are meeting objectives of the mooring project. Stations may be decommissioned and new stations chosen to better meet strategic goals. Station selection and evaluation will be an ongoing effort to optimize the project. This is similar to the project framework for continuous monitoring in Chesapeake Bay described by the Maryland Department of Natural Resources (Michael et al., 2006).

Factors we consider when evaluating mooring placement include:

- Personnel and resources available
- Ability to describe low dissolved oxygen intrusion and inter-basin water exchange
- Supporting decisions on classifying/declassifying specific waterbodies under the Clean Water Act
- Need for data input into circulation and ecological models
- Assessing natural water variability

- Requests from partners or other agencies
- Logistical practicality for routine work and efficiency of efforts (e.g., access and structure available from piers and pilings, power supply for telemetry)
- Station representativeness of overall waterbody conditions
- Risk of damage to instruments
- Value of maintaining a continuous record. When investigating inter-annual variability or climate change

As budgeting allows, we may also choose different sensors in the future. In addition to the above, factors we will consider when evaluating new sensors:

- Accuracy
- Precision
- Susceptibility to drift due to biofouling
- Compatibility with existing instrument packages
- Endurance and power supply logistics

Data Analysis and Presentation Methods

The MWM group use methods to reduce, analyze, and present the data and determine these based on the various aspects of the data analysis. Methods used are generally the best available, appropriate practices according to relevant statistical and analytical research published in peer-reviewed literature. Descriptions of analytical methods are published in conjunction with the analysis.

Data are summarized and displayed, using various types of plots. Outliers and out-of-range data are reviewed to determine if these are possible real events or otherwise removed. Unexplained data issues that appear during data analysis, especially during graphical exploration, will be excluded or corrected, and analysis will be redone. Summary statistics are computed for all variables and reported with the final data and analytical results.

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Appendices

Appendix A. Glossary, Acronyms, and Abbreviations

Glossary

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 total maximum daily loads 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 and is used to derive salinity.

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

Parameter: A physical chemical or biological property whose values determine environmental characteristics or behavior.

303(d) list: Section 303(d) of the federal Clean Water Act requires 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

ADCP	Acoustic Doppler Current Profile
ASCII	American Standard Code for Information Interchange
CTD	Conductivity, temperature, and depth sensor
CTD-DO	A CTD outfitted with an auxiliary dissolved oxygen sensor
CTD-FL	A CTD outfitted with an auxiliary fluorescence sensor
CWA	Clean Water Act
DO	Dissolved oxygen
EAPMW	EAP Marine Waters database
EIM	Environmental Information Management (system)
EPA	US Environmental Protection Agency
EOPS	Eyes Over Puget Sound
GMT	Greenwich Mean Time (equivalent to Coordinated Universal Time, UTC)
GOMOOS	Gulf of Maine Ocean Observing System
IOOS	Integrated Ocean Observing System
MDL	Method Detection Limits
MEL	Manchester Environmental Laboratory
MISU	Modeling and Information Service Unit
ML	Ecology's Marine Laboratory
MLLW	Mean Lower Low Water (tidal reference point)
MMU	Marine Monitoring Unit

MQOs	Measurement quality objectives
MWM	Marine Waters Monitoring
NANOOS	Northwest Association of Networked Ocean Observing Systems
OTFP	On-the-Fly Plotter, designed in house
PSEMP	Puget Sound Ecosystem Monitoring Program
QA	Quality assurance
QARTOD	Quality Assurance of Real-Time Oceanographic Data
QC	Quality control
SBE	Sea-Bird Electronics, Inc.
SOP	Standard operating procedure
TMDL	Total Maximum Daily Load
UTC	Coordinated Universal Time equivalent to GMT

Units of Measurement

°C	degrees centigrade
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams.
m	meter
mg	milligram
mg/L	milligrams per liter (parts per million)
mL	milliliters
psu	practical salinity units
ug/g	micrograms per gram (parts per million)

Appendix B. Strategic Objectives of the Marine Waters Program

Long-Term Marine Waters Monitoring Strategy

Introduction

The Long-term Marine Waters Monitoring Program (LTMWP) occupies a unique strategic position. Its historical perspective and geographic extent constitutes an unprecedented framework to evaluate Washington's marine water conditions. Since 1973, a comprehensive temporal perspective on estuarine processes and water quality for Washington State has developed. The historical data record and network is a growing asset for environmental science and management. It routinely supports agencies in evaluating, leveraging and extending studies of limited spatio-temporal resolution.

The LTMWP acquires, maintains and provides environmental data from inshore waters in Washington State. A suite of natural physical, chemical and biological indicators describe marine ecosystem processes and performance. Routine data analyses evaluate the status, trends and variability of environmental conditions that are relevant to estuarine hydrography, human eutrophication and ecosystem functioning. Periodic comparisons of marine water quality indicators against historical values and water quality standards inform environmental management, science and the public about significant changes in the environment.

Consistency in methods and data quality is necessary to assess significant changes in the spatial, seasonal and long-term status of marine water quality. Data precision, accuracy, and the use of rigorous statistical tests are therefore at the core of the programs' daily operations.

Indicators are measured routinely at a network of ambient marine-monitoring stations. The statewide network consists of marine core (visited monthly), and rotational (visited infrequently) stations which provide the temporal and spatial environmental framework of the program. The statewide scale places local water quality into a large-scale context and helps determine the causality between local water quality issues and distant large-scale environmental influences, such as climatic and oceanographic variability.

To sample the large geographical extent, staff visit stations by float plane and complements these data with in situ measurements from ships, aircraft/satellites and continuous in situ sensors (attached to moorings) (Figure 1). The combination of approaches improves the spatial and temporal information in strategically important areas.

Mission of the Long-Term Marine Waters Monitoring Unit

The LTMWP gathers quantitative information to protect, and improve Washington's marine environments while enhancing our understanding of estuarine and coastal processes. Reporting the status and trends in marine water quality to management, agencies and the public in the context of long-term and large-scale environmental conditions is paramount.

Program goals

1. Effectively measure and inform about long-term estuarine dynamics and conditions that affect marine water quality.

2. Assess the impacts on estuarine processes and ecosystem functioning that result from the transport of water, solutes and pollution (surface, inter-basin).

3. Attribute changes in ambient water quality to local, regional or larger-scale human, climatic and oceanographic causes.

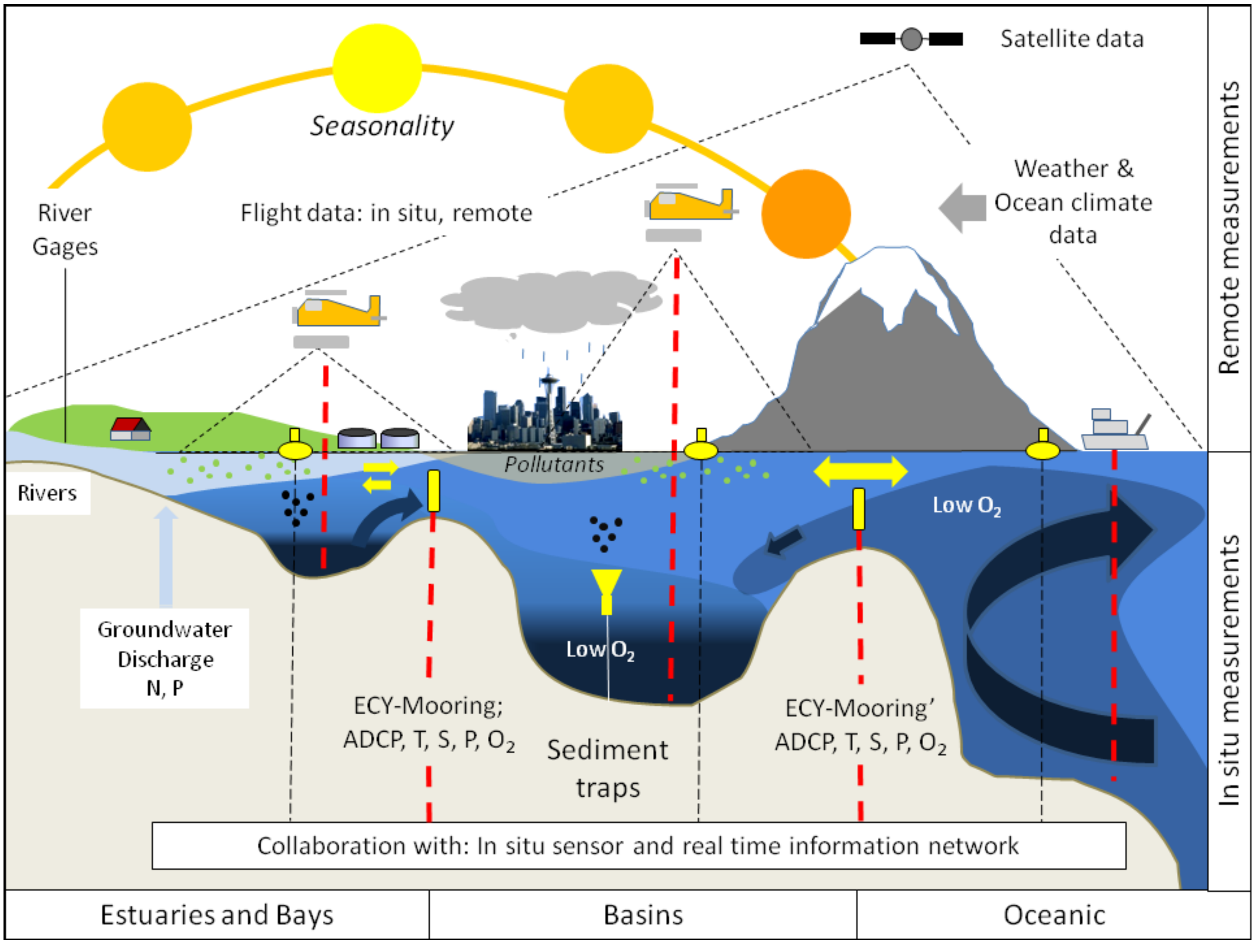

Figure C-1. Ecology's state wide marine monitoring program describes the status and trend of estuarine processes and marine eutrophication in Washington State. The spatially nested program detects changes in estuarine water quality and reports its observations in context of large-scale climatic, oceanographic and human influences. The sampling network relies on accurate and precise measurements and combines information from moorings, long-term stations, survey flights and satellites. The mooring and station network is accessed from piers, by plane and ships. To understand the complexity of tidally driven environments, aerial surveys complement the sampling and modeling efforts on the ground. The entire sampling network is the framework to capture the small, intermediate- and large-scale variability and trends in the system. The program will expand into monitoring particle transport and rate measurements in key locations of Puget Sound to improve its understanding of the system.

Activities to support the program goals 1-3

1. Effectively measure and inform about long-term estuarine dynamics and conditions that affect marine water quality

A. Monitoring the marine environment

Ecology's long-term marine monitoring program evaluates temporal and spatial variability in eutrophication and physical state indicators (n=16) and maintains a long-term environmental data archive that it makes available through the Internet. Staff periodically visits the core station network representing ambient water conditions at 33 sites in the greater Puget Sound region, Willapa Bay and Grays Harbor and the Strait of Juan de Fuca. Consistent and statewide data coverage provides the large-scale, inter-annual and long-term context to support other sampling programs (e.g., King County, DOH, UW, and Ecology), modeling, water quality programs and research. The programs' sampling resolution is monthly; its strength resides in the synoptic and year-round sampling activities, consistent measurements, and open-data access. The program collects data with high accuracy and precision using rigorous sensor performance tests, statistical filters and error reporting procedures.

The program routinely samples a subset of stations (rotational stations) that are subjected to stronger local influences. Specific influences include; a) bay morphology and hydrodynamics, b) freshwater input, and c) land use practices. Frequent assessment of the status of water quality in these areas ensures that local needs for better water quality are addressed. The program evaluates anomalies in water quality at rotational stations by alternating monitoring efforts according to two criteria:

- Low versus high freshwater influence
- Low versus high potential human impact

This grouping ensures that sites with similar and contrasting conditions are visited on a routine basis. Historical data record complements the spatial comparison and defines the baseline conditions to evaluate long-term changes.

- The program supports focused studies on estuarine processes and water quality in Washington State. Staff provides marine and technical expertise, logistic support and can independently execute focused study of limited size or in collaboration with agency programs.

The impetus of the marine monitoring program is to maintain a state-of-the-art capability to distinguish natural from human impacts on water quality. The program continuously improves its sensitivity and effectiveness by:

- Refining its sampling strategy,
- Improving data access and analysis,
- Broadening its selection of water quality indicators

B. **Communicating environmental information**

Effective communication of environmental conditions is paramount as the program strives to remain a competitive contributor to Puget Sound and coastal marine protection and restoration efforts. Effective environmental information hinges on three virtues:

i. Easy access to high quality and relevant data archives

Open data access requires an accessible data structure, consistency in data quality, temporal coverage and stringent quality control procedures. The strategy of the program is to work within a partially automated, structured workflow to ensure that variables are quickly processed, quality control procedures are applied and data are reviewed in context of other relevant information. Timely access to the database defines the external perception of the program's performance. Feedback loops ensures effective communication between the program and data users. This gives the program an ability to address emerging problems and better serve the needs of end users.

ii. **Timely analysis of data, statistical hypothesis testing and stringent data review**

Timely data analysis requires that environmental databases are quickly finalized and populated with meaningful quality flags. Routine analyses include:

- integration of variables over depth (reduces environmental noise),
- de-seasonalizing data (improves inter annual comparison)
- statistical analysis and summary statistics (fosters objective interpretation of data)

iii. Effective aggregation, prioritization and communication of relevant information

Large data volumes require effective mechanisms for aggregating information into timely, meaningful and effective information products. This includes the computation of:

- Marine water quality composite index
- Maps summarizing the spatial and temporal environmental context of water quality, hydrographic features and transport
- Water quality report cards
- Summary statistics and data tables
- Water quality standards exceedances

The program's workflow leverages the capabilities of its staff in the interpretation, prioritization and communication of current environmental information. A monthly data review process ensures the timely communication of current environmental conditions to the public and improves the program's relevance. As part of this strategy, the program develops and maintains a field blog.

The program collaborates directly with Ecology's Water Quality Program; the Puget Sound Partnership; environmental sensor networks and external monitoring programs. Collaborations expand the geographical extent and public impact. The monitoring program supplies data to:

- In situ sensor networks,
- Local and state-wide water quality programs
- Ecosystem and hydrological models

2. Assess the impacts on estuarine processes and ecosystem functioning that result from the transport of water, solutes and pollution (surface, inter-basin)

Transport of water, salt and pollutants are linked in tidally influenced water bodies. To understand water quality in the context of transport, dilution and redistribution (Figure 1) corridors and vectors for pollution have to be known. Information on the variability of transport corridors provides the framework to assess exposure, ecological impact and environmental response.

To improve the programs' capability to evaluate the estuarine dynamics in response to external forcing (e.g., weather, storm water) its temporal and spatial resolution has been enhanced in strategically important locations. These locations are sites of:

A. Dynamic mass exchange (waterways were physical state variables are continuously measured with in situ sensors, Figure 1)
B. The near-surface environment (using remote sensing products, Figure 1)

A. Moorings and in situ sensors

The program situates *in situ* sensors in restricted waterways to capture the variability of the inter-basin mass (water, biomass), and solute (salt and oxygen) transport. In situ data can be used to compute changes in the directional and temporal patterns of inter-basin transport and attenuation (e.g., oxygen) (Figure 1). Sampling sites that meet the needs of programs are (e.g., Rosario Strait, Admiralty Reach, the Narrows, Mukilteo, Dana Passage, Squaxin Passage, Manchester).

Sensor packages record physical, biological and oceanographic variables (temperature, pressure, salinity, oxygen and fluorescence). Monitoring focuses on events such as tides, weather, storm water discharge, and large-scale oceanographic intrusions. The moorings provide high temporal resolution to understand:

- Variability of inter-basin transport (e.g., visualizing intrusions)
- Impact of water exchange on low-oxygen and local water quality
- Day-to-day variability and real time information.

The program provides real time and quality-controlled data to agency-, state-, and nation-wide real-time networks (NANOOS, IOOS). Critical to the posting of real-time data are automated data quality flags and an effective web presentation. Real time coverage is given to sites with higher public and scientific interest.

Long-term mooring data analysis follows rigid data assurance and control procedures including routine sensor performance checks. A partially automated workflow ensures timely data processing and assignment of quality flags and entry into a database. Frequent mooring data reviews summarize current environmental conditions in context of large-scale patterns and trends. Monthly and yearly mooring reports focus on inter-basin transport, variability and anomalies in the environment. *To improve the information impact, measurements are presented in a historic and geographic context.*

B. Remote measurements

Near the surface, accumulation, transport and biological exposure to pollution have high day-to-day variability. Hydrological, hydrodynamic and climatic factors cause the greatest variations in addition to tidal flows. Remote sensing products can be used to provide a more extensive spatial and temporal context to support environmental management and sampling programs.

The goal of remote observations is to statistically describe the extent and location of hydrographical boundaries and optical features (e.g., water clarity, watercolor, suspended sediment concentration, algae blooms and the accumulation of debris and oil) and relate them to physical processes. Environmental anomalies in surface water characteristics can be monitored using time-averaged baseline conditions and statistical distribution maps that delineate geographic change. Over time, remote sensing provides the statistical, spatial and historical context to identify regions with frequent biological responses to eutrophication. Remote sensing also supports the strategic placement of monitoring stations and focused studies (e.g., TMDL).

Remote sensing from aircraft and satellite cover a wide range of geographic scales. A spatially nested approach spans from patches (fish swarms, oil sheens, debris etc.) to regional gradients (coastal bays, Puget Sound, etc). Spatial distribution maps of debris, freshwater, suspended sediments and algae are information products of high public interest and are delivered following a marine flight. Satellite images and processing procedures are obtained from available sources. The Marine Monitoring Unit (MMU) and Modeling unit (MU) processes and combines satellite data from different scales and platforms into effective publicly accessible information products.

Information products include short-term (tidal cycle), intermediate-term (seasonal) and long-term (inter-annual) spatial statistics. The suite of information products include:

- Near surface transport pathways of pollutants (including oil).
- Predictions of fecal abundance and beach closure based on weather and hydrodynamic patterns.
- Probabilistic maps of areas of upwelling, convergences, vertical mixing, high organism abundances and debris.

The extensive image database provides a repository of relevant and historic images to support education, agency public communications and public interests.

3. Attribute changes in ambient water quality to local, regional or larger-scale human, climatic and oceanographic causes.

The scale of the sampling network allows for the quantitative separations of internal and external drivers of water quality. By separating the drivers, environmental management can raise water quality issues to the appropriate levels of attention.

Modeling quantitatively evaluates the causality of water quality and external pressures.

Coupled hydrodynamic and biogeochemical models provide tools to illustrate the connectivity and sensitivity of marine-, climatic-, terrestrial- and human systems to environmental perturbations. Modeling critically complements environmental monitoring efforts with limited spatial and temporal resolution. By integrating data modeling efforts provide:

- Spatially, temporally inter and extrapolated information
- Sensitivity and vulnerability estimates to current and predicted environmental disturbances
- Short comings in data coverage and monitoring strategies

Models scale the relevance of external pressures (ocean, freshwater, anthropogenic) to ecosystem processes and supports:

- Determining the structure and dynamic of corridors of pollution transport
- Assigning probabilities of pollution (fecal, HAB) and/or eutrophication (algae growth, DO drawdown) to environmental conditions.

Ecology has a 3-D hydrodynamic model. The model can be expanded with data from near surface processes. To achieve this goal the LMP is collaborating with the modeling unit. The collaboration and mutual review of activities between units will leverage information products. It is the long-term strategy to integrate existing models with remote sensing data, mooring data, and long-term monitoring data. The combination of data streams allows Ecology to improve its model capabilities and produce for- and hind- casts of marine water quality for Washington State. Monitoring data can help verify forecasts and determine model performance parameters that result in model improvements over time.

Appendix C. Sample Field Logs

Bottom Mooring Service Log

Station:		Date:		Technicians:			
Tide:			Temperature	Clouds	Wind	Other	
		Weather:					
	capture file name (same file for both retrieved and deployed CTDs)						

RETRIEVED

CTD serial #		ql time (*local*)		.hex file name			
	(ql = quit logging)	ql time (*GMT*)		vmain		# of samples	
Aux sensor types	DO / fluorom		serial #		fluorom avg seawater volts		
(SBE43, WS, ECO	pump		serial #		fluorom avg DI water volts		
SBE 5T)	pinger		serial #				

Retrieval Comments

DEPLOYED

CTD serial #		start time (*GMT*)		cleared memory?		new antifouls?	
		sample interval		new vmain		new zinc?	
		pump delay					
Aux sensor types	DO / fluorom		serial #		fluorom avg DI water volts		
(SBE 43, WET Star	pump		serial #		fluorom avg seawater volts		
ECO, SBE 5T)	pinger		serial #				

Deployment Comments

DO FIELD BATH

Winkler Sampling Technician:

DO Sensor Assessment				Winklers Sample Info		
CTD #	SBE 43 #	SP / EP / AP	.hex & .cap file name (each bath file type has same name)	Bottle#	Line # in capture file	CTD Time
Salinity bottle #	CTD Time					

Bath Comments

GENERAL COMMENTS

Surface Mooring Service Log

Station:		Date:		Technicians:		
Tide:			Temperature	Clouds	Wind	Other
		Weather:				
	capture file name (same file for both retrieved and deployed CTDs)					

RETRIEVED						
CTD serial #		ql time (*local*)		.hex/.asc file name		
(ql = quit logging)		ql time (*GMT*)		vmain		# of samples
Aux sensor types	DO / fluorom		serial #		fluorom avg seawater volts	
(SBE43, WS, ECO	pump		serial #		fluorom avg DI water volts	
SBE 5T)	pinger		serial #			
Retrieval Comments						

DEPLOYED							
CTD serial #		start time (*GMT*)		cleared memory?		new antifouls?	
		sample interval		new vmain		new zinc?	
		pump delay			fluorom avg DI water volts		
Aux sensor types	DO / fluorom		serial #		fluorom avg seawater volts		
(SBE 43, WET Star	pump		serial #				
ECO, SBE 5T)	pinger		serial #				
Deployment Comments							

DISCRETE SAMPLES FROM NISKIN					
		Chlorophyll		**Salinity**	Water Sampling Technician
Pre-service	Time (*local*)	Bottle#	Tube#	Bottle#	
					Chl Filter Technician
Post-service	Time (*local*)	Bottle#	Tube#	Bottle#	
Sampling Comments					

GENERAL COMMENTS

LONGTERM - MF / Moorings

Marine Waters Monitoring - Chain of Custody

DISSOLVED OXYGEN SAMPLES

Date			Project	# of Samples	Sample Numbers	Expiration Date			Transf. to freezer by	Date + Time placed in freezer					Comments
M	D	Y				M	D	Y		M	D	Y	Hr	Min	

SALINITY SAMPLES

Date			Project	# of Samples	Sample Numbers	Expiration Date			Transf. to freezer by	Date + Time placed in freezer					Comments
M	D	Y				M	D	Y		M	D	Y	Hr	Min	

CHLOROPHYLL SAMPLES

Date			Project	No. of Samples	Sample Numbers	Expiration Date			Transf. to locker by	Date + Time placed in freezer					Date delivered			Delivered by	Comments
M	D	Y				M	D	Y		M	D	Y	Hr	Min	M	D	Y		

DO Lab Bath Log

Date:		Technicians:	

MOORING CTDs ON MMU SHELF

CTD #	SBE 43 #	Comments

CTD & SBE 43 TO ASSESS

CTD #	SBE 43 #	SP / EP / AP	start vmain	vlith	.cap file name	sampling interval	end vmain

CONFIRM MINIMAL VARIATION

			sample 1		sample 2		sample 3	
CTD #	Avg DO volts	DO volts diff	temp	sal	temp	sal	temp	sal

WINKLER SAMPLES INFO

Collector		
Bottle#	Line # in capture file	CTD Time

			Time
SALINITY	bottle #		

COMMENTS