



Quality Assurance Monitoring Plan

Long-Term Marine Waters Monitoring, Water Column Program



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EAP - Environmental Assessment Program

1.0 Title Page and Table of Contents

Table of Contents

	Page
1.0 Title Page and Table of Contents.....	2
2.0 Abstract.....	8
3.0 Background.....	9
3.1 Study area and surroundings.....	9
3.1.1 Logistical problems.....	15
3.1.2 History of marine waters research and monitoring in Washington State.....	15
3.1.3 Contaminants of concern.....	18
3.1.4 Results of previous studies.....	18
3.1.5 Regulatory criteria or standards.....	20
3.1.6 Other Washington marine monitoring programs.....	21
4.0 Program Overview.....	23
General strategy.....	23
4.1 Marine water monitoring strategic goals.....	23
4.2 Project objectives.....	24
4.3 Information needed and sources.....	24
4.4 Target population.....	25
4.5 Study boundaries.....	25
Water Resource Inventory Area (WRIA) for the study areas.....	25
4.6 Tasks required.....	25
4.6.1 Data collection.....	25
4.6.2 Data assessment.....	26
4.7 Practical constraints.....	26
4.8 Systematic planning process.....	27
5.0 Organization and Schedule.....	28
5.1 Key individuals and their responsibilities.....	28
5.2 Special training and certifications.....	30
5.3 Organization chart.....	30
5.4 Project schedule.....	31
5.5 Limitations on schedule.....	32
5.6 Budget and funding.....	32
6.0 Quality Objectives.....	33
6.1 Measurement quality objectives.....	33
6.1.1 Targets for precision, bias, and sensitivity.....	34
6.1.2 Targets for comparability, representativeness, and completeness.....	37
7.0 Sampling Process Design (Experimental Design).....	39
7.1 Study design.....	39
7.1.1 Field measurements.....	39

7.1.2	Sampling location and frequency	40
7.1.3	Parameters to be determined	44
7.2	Maps or diagram	45
7.3	Assumptions underlying design	46
7.3.1	Changes to the sampling process design	46
7.4	Relation to objectives and site characteristics	46
7.5	Characteristics of existing data	46
8.0	Sampling Procedures	49
8.1	Field measurement and field sampling SOPs	49
8.1.1	CTD data collection	51
8.1.2	Water sample collection	52
8.1.3	Field observations and weather and conditions	52
8.2	Containers, preservation methods, holding times	53
8.3	Invasive species evaluation	53
8.4	Equipment decontamination	53
8.5	Sample ID	53
8.6	Chain-of-custody, if required	54
8.6.1	Lab Notification	54
8.7	Field log requirements	54
8.8	Other activities and information	55
8.8.1	Sampling vessel	55
8.8.2	Navigation	55
8.8.3	Scientific party	56
8.8.3	Personnel responsibilities	56
8.9	Safety Protocols	56
8.9.1	Safety Equipment and Emergency Procedures	57
8.9.2	Emergency Contacts	57
9.0	Measurement Methods	58
9.1	Field procedures table/field analysis table	58
9.2	Lab procedures table	59
9.2.1	Analyte	59
9.2.2	Matrix	59
9.2.3	Number of samples	59
9.2.4	Expected range of results	60
9.2.5	Analytical method	60
9.2.6	Sensitivity/Method Detection Limit (MDL)	60
9.3	Sample preparation method(s)	60
9.4	Lab(s) accredited for method(s)	60
10.0	Quality Control (QC) Procedures	60
10.1	Meeting data and measurement quality objectives	61
10.1.1	Tables of field and lab QC required	61
10.2	Training of personnel	64
10.3	Instrument calibration	64
10.4	Field QC	65
10.4.1	CTD comparison samples	66
10.4.2	CTD field replicates	67

10.4.3	Field observations	67
10.4.4	Weather and conditions.....	67
10.5	Laboratory QA/QC procedures	67
10.5.1	Laboratory-based CTD QA/QC procedures	67
10.5.2	Water sample QA/QC procedures	69
10.5.3	Lab QC documentation	70
10.6	Corrective action processes.....	71
11.0	Data Management Procedures	72
11.1	Data recording/reporting requirements	73
11.1.1	Field log data and observations.....	73
11.1.2	CTD data.....	74
11.1.3	Statistical analyses	74
11.2	Laboratory data package requirements	76
11.3	Electronic transfer requirements	76
11.3.1	Analytical and QA/QC information management (summary statistics, calibration information, calculation methods and other information)	77
11.3.2	Reports, observations, and other products (descriptive summaries, graphs, photos, video).....	77
11.4	Acceptance criteria for existing data.....	77
11.5	EIM/STORET data upload procedures	77
12.0	Audits and Reports.....	78
12.1	Number, frequency, type, and schedule of audits	78
12.2	Responsible personnel	78
12.3	Frequency and distribution of report.....	79
12.3.1	Monthly data summaries.....	79
12.3.2	EOPS summaries	79
12.3.3	The Marine Waters Condition Index	79
12.3.4	Annual data assessment and summary.....	80
12.3.5	PSEMP Annual Marine Waters Overview report.....	80
12.4	Responsibility for reports.....	80
13.0	Data Verification.....	81
13.1	Field data verification, requirements, and responsibilities	81
13.2	Lab data verification	81
13.3	Validation requirements.....	81
14.0	Data Quality (Usability) Assessment.....	82
14.1	Process for determining whether project objectives have been met	82
14.2	Data analysis and presentation methods	82
14.3	Treatment of non-detects	83
14.4	Sampling design evaluation	83
14.5	Documentation of assessment.....	83
15.0	References.....	84
16.0	Figures.....	89
17.0	Tables.....	89

18.0	Appendices.....	90
	Appendix A. Glossary, Acronyms, and Abbreviations.....	90
	Appendix B. Puget Sound Assessment and Monitoring Program (PSAMP)	
	Water Column Monitoring Historical Background	95
	Appendix C. Long-Term Marine Waters Monitoring Strategy	133
	Appendix D. Example Field and Lab Sample Forms, Logs, Lists, and other coordinating documents.....	140
	Appendix E. Standard Operating Procedures and Reference Manuals.....	163
	Appendix F. Quality Assurance Glossary.....	194

List of Figures

Figure 1. Map of U.S. and Canadian waters of the Salish Sea, courtesy of Stephen Freelan, Western Washington University, 2009.	10
Figure 2. Ecology Marine Waters Monitoring study sites in Puget Sound and Coastal Bay study areas.....	13
Figure 3. Map of core sampling sites.....	45
Figure 4. Sea-Bird Electronics, Inc., Conductivity, Temperature, Depth (CTD) instruments and other sensors in a custom-made frame.....	51
Figure 5. Field log documentation using a portable tablet.....	55
Figure 6. Marine waters data workflow and data products.....	73
Figure 7. Site-specific monthly data plotted in the context of interquartile ranges based on historical results, grouped by station and month.....	75

List of Tables

Table 1. Organization of project staff and responsibilities.	29
Table 2. Proposed schedule for completing field and laboratory work, data processing, review, QC, storage in data repository, and reports.	31
Table 3. Budget (estimated) for long-term marine water column monitoring data collection during the 2013-2015 biennium.	32
Table 4. Measurement quality objectives for marine water column field sensors.....	35
Table 5. Measurement quality objectives for marine water column laboratory samples.	36
Table 6. Sample types and depths for marine waters monitoring parameters.	40
Table 7. Core stations for Ecology long-term marine water column monitoring.	42
Table 8. Rotating and seasonal stations for Ecology long-term marine water column monitoring.	43
Table 9. Parameters to be determined.....	44
Table 10. Field sample collection methods for ambient water column monitoring.	50
Table 11. Instrument measurement methods, expected range of results, lowest values...58	
Table 12. Lab measurement methods, expected range of results and reporting limits for marine data.	59
Table 13. A summary of quality control steps for field measurements.	62
Table 14. A summary of quality control steps for lab measurements.	62
Table 15. CTD calibration and maintenance schedule.	65
Table 16. Raw CTD voltage readings from one month used as a coarse QA in the field prior to every cast.....	66
Table 17. Quality assurance/quality control procedures for water column parameter analysis in the laboratory.....	70

2.0 Abstract

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

This plan describes Ecology's marine waters monitoring program for water column profiling conducted by floatplane and by boat. This sampling program covers U.S. waters of the Salish Sea, including Puget Sound and the Strait of Juan de Fuca, as well as coastal bays of Grays Harbor and Willapa Bay. The Quality Assurance Monitoring Plan includes a full description of the program's goals and objectives, monitoring strategies, field and laboratory procedures, data management, quality assurance and quality control, and safety guidelines.

3.0 Background

The purpose of the program is to examine marine water quality on a regular, long-term basis with the objectives of determining existing conditions and identifying spatial and temporal trends. As needs for information change and new findings require updated technology or procedures, changes to the program are incorporated in a planned, methodical manner. Elements of the program are described in detail in this plan.

3.1 Study area and surroundings

U.S. Waters of the Salish Sea (Puget Sound, Strait of Juan de Fuca, Strait of Georgia)

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, U.S. and southern British Columbia, Canada. These separately named bodies of water form a single estuarine ecosystem. (Figure 1)

The Puget Sound study area is part of the overall ecosystem of the Salish Sea. It is important to study and understand Puget Sound within the context of the larger ecosystem, because regional and local Puget Sound processes are influenced and regulated by large-scale ocean and climate drivers via hydrodynamic connection and exchange between basins of the Salish Sea.

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 bounded by Vancouver Island and the Olympic Peninsula. The watershed contains the Gulf and San Juan Islands; it also contains the lower Fraser River Delta and the Puget Lowlands as well as Hood Canal, Tacoma Narrows and Deception Pass (Freelan, 2009).

The geomorphology of the area includes a variety of landforms with interconnected shallow estuaries and bays, deep glacially scoured basins and fjords, 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 Marine Waters Monitoring 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. The study area 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 2). The study area extends for about 200 km and ranges in width from 10 to 40 km (Kennish, 1998).

Figure 1. Map of U.S. and Canadian waters of the Salish Sea, courtesy of Stephen Freelan, Western Washington University, 2009.



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. South of this junction, Puget Sound connects 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 also connects 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 a shoaling of the seafloor.

The entrance to the Main Basin of Puget Sound is constricted by a sill at Admiralty Inlet, and it includes both Admiralty Inlet and the Central Basin. Whidbey Basin connects to the Main Basin to the east and, as there is no true sill defining this basin, it is considered an appendage to 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. This basin consists of deep passages, many islands, and multiple finger inlets and 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).

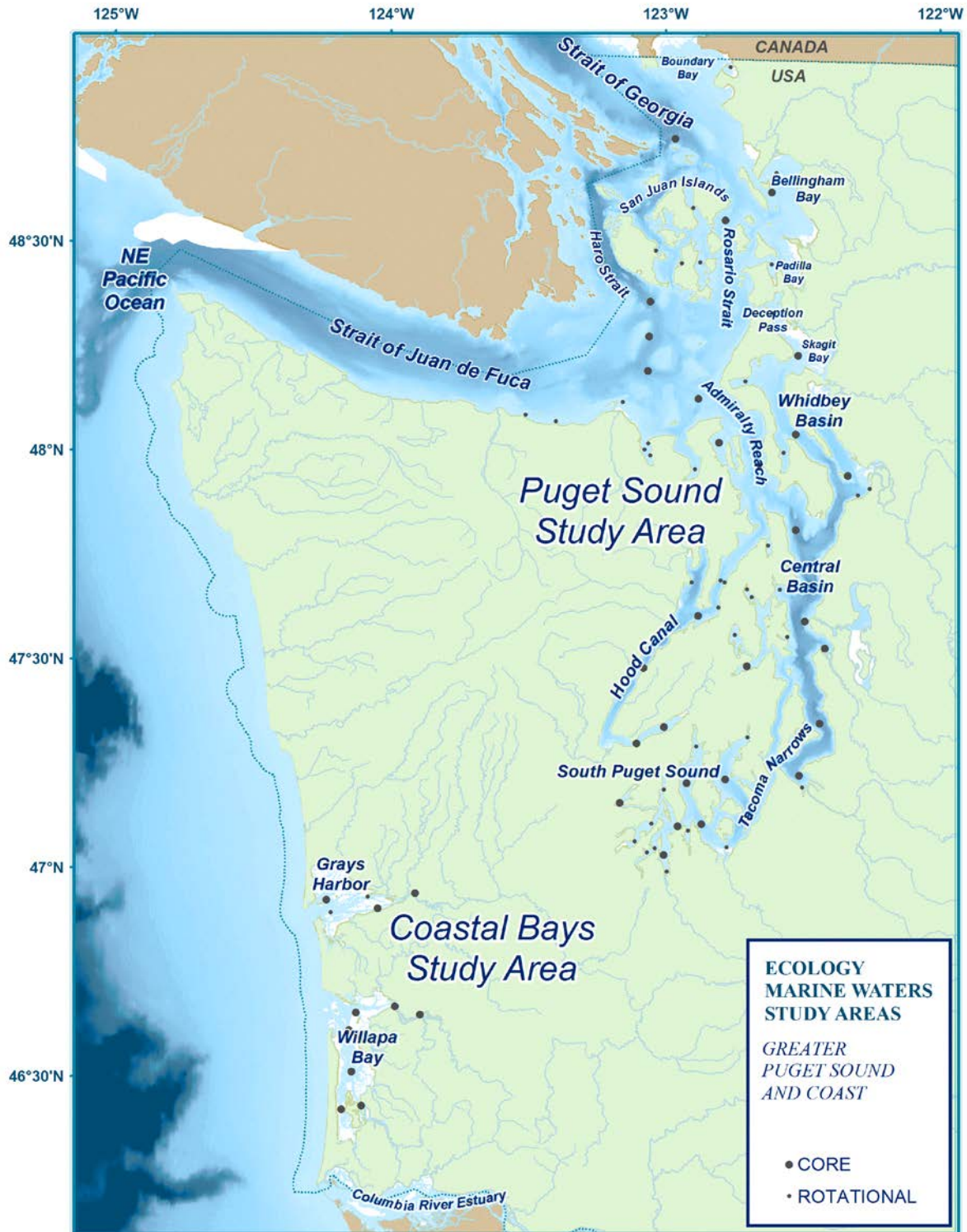
Puget Sound has depths up to 300 m, while depth over the sills, constricting water exchange, ranges from 44m at the Narrows to 60m at Admiralty Inlet. It has an area of 2632 km², a volume of 168 km³, 2141 km of shoreline and 303 km² of tideland (Burns, 1985).

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 many large streams and rivers. 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. Major rivers entering Puget Sound include the Skagit, Stillaguamish, Snohomish, Cedar, Duwamish, Puyallup, and Nisqually (Figure 2). The Skagit, Stillaguamish, and Snohomish rivers account for more than 75% of the freshwater input into the Sound.

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, 1984). Therefore, residence time for water in the Central basin can range from 160 to 290 days in isolated inlets and restricted deep basins in Hood Canal and southern Puget Sound (Khangonkar, 2012).

Puget Sound is bordered by both relatively undeveloped rural areas and highly developed urban and industrial areas. Approximately 17% of the watershed tributary to U.S. waters of the Salish Sea is developed land that represents a combination of residential, commercial/urban, and agricultural lands or alpine areas (Herrera, 2011). Major urban centers include the cities of Bellingham, Everett, Seattle, Bremerton, Tacoma, and Olympia, all of which are located at the mouths of large river systems that feed into Puget Sound's largest estuarine embayments. Overall, 7 million people live within the drainage basin of the Salish Sea (sometimes referred to as the Puget Sound - Georgia Basin watershed), and include the cities of Vancouver, Victoria, Nanaimo, Port Angeles, and Port Townsend in addition to the Puget Sound cities mentioned above (Freelan, 2009).

Figure 2. Ecology Marine Waters Monitoring study sites in Puget Sound and Coastal Bay study areas.



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 2). Currently, Ecology's monitoring program does not include nearshore and offshore waters along the Pacific coast due to resource constraints and difficulties encountered 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 km² 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 4.3m (NOAA, 1985). It is composed of connected channels surrounded by sand and mud flats (Banas, 2005).

The largest river flowing into the bay is the Chehalis at the eastern end, providing 80% of all freshwater input to Grays Harbor. Other rivers and streams include the Hoquiam River which flows into the northern inner harbor and the Humptulips River which flows into the outer harbor. The mouth of the bay, which opens to the Pacific Ocean, is just 3 km. wide and is situated between 2 low peninsulas formed by ocean-built bars. The cities and towns of Aberdeen, Hoquiam, Ocean City and Westport are all located on or near the harbor. The watershed surrounding the bay is composed primarily of forests, interspersed with agricultural lands and residential/developed areas. Significant industries in the watershed are forestry, paper and pulp production and sport, tribal, and commercial fisheries.

Willapa Bay

The Willapa Bay study area includes the lower part of the Willapa River at Raymond to the southern reaches near Long Island 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 km². Like Grays Harbor, it is 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 and 50% of the bay is intertidal, with mud and sand flats surrounding multiple-connected channels 10-20 m deep, composing the dominant geomorphology of the bay (Banas and Hickey, 2005).

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.

Columbia River Estuary

During periods of sustained southerly winds, the Columbia River plume is driven inshore, and this warmer, fresher, nutrient-depleted water fills the water column of the coastal estuaries. In addition, the plume from the Columbia and other coastal rivers is driven northward alongshore by these southerly winter winds and can enter the Strait of Juan de Fuca and, potentially, Puget Sound (Hickey, 2009).

The marine water monitoring program has not included sampling of the Columbia River estuary. Monitoring and management of the Columbia River estuary has historically been conducted by federal agencies such as the Dept. of Energy, USGS, U.S. Army Corps of Engineers, Bureau of Land Management, and NOAA amongst others. Currently, these agencies coordinate federal, state and local monitoring efforts of the Columbia River Estuary via coordinating bodies such as the Lower Columbia River Estuary Partnership. More information on Columbia River estuary monitoring can be found at their [website](#).

3.1.1 Logistical problems

While sampling by floatplane allows for an efficient, cost-effective sampling method capable of covering the extensive study area in just 5 sampling days per month, operations conducted aboard this type of platform are constrained to daylight and “fair weather” conditions. For safety reasons, floatplanes are not allowed to operate in fog, low visibility, or after dark and the planes cannot land on disturbed waters in winds greater than 15 knots. Therefore, sampling flights are not conducted during stormy, foggy, or nighttime conditions. Sampling via boat may be conducted in more challenging conditions such as stronger winds or higher waves. However, no boat-based sampling is conducted after dark or during stormy conditions necessitating small craft advisories from the National Weather Service. This results in more gaps in sampling events during winter time (more storm events).

3.1.2 History of marine waters research and monitoring in Washington State

3.1.2.1 Puget Sound, Strait of Juan de Fuca, and Strait of Georgia (Salish Sea)

The earliest routine observations of water properties in Puget Sound date back to June 1932. Then the Department of Oceanography at the University of Washington (UW) conducted longitudinal surveys of Puget Sound basins aboard the R/V Brown Bear. Surveys continued throughout the 1950s, 60s, and 70s. Observations were taken routinely for salinity, temperature, and dissolved oxygen. Silicate, nitrate, nitrite, alkalinity, orthophosphate, and other parameters were measured at select stations. Many of these data were compiled into an index and summarized in the Puget Sound Atlas by Eugene E. Collias, Noel McGary and Clifford A. Barnes, (Collias et al., 1970).

The Washington State Department of Ecology (Ecology) initiated its statewide Marine Ambient Monitoring Program in 1967. 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, 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 to mid-channel or bay locations or close to stations occupied during the historical UW surveys. (Janzen, 1992) This monitoring program sampled sites in Puget Sound and the coastal bays, Grays Harbor and Willapa Bay (described below).

In 1970, the Pacific Marine Environmental Lab at NOAA implemented an experimental program using 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. During this program, continuous observations were made in the Main Basin of Puget Sound, lasting from over a month to an entire year (Cannon, 1983).

These measurements initially involved the use of current meters 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. These meters were later supplemented with vector-averaging current meters, salinity, temperature, depth (STD) and conductivity, temperature, and depth (CTD) profilers, and nearby land-based anemometers. The NOAA current meter observations were made in the 1970s and early 1980s (Cannon, 1983).

In 1985, Puget Sound was recognized as an estuary of national significance and through implementation of EPA's National Estuary Program (NEP), state and federal agencies joined to create a comprehensive Puget Sound environmental protection campaign. The Puget Sound Water Quality Authority (MMC, 1988) was formed in the late 1980s and the Puget Sound Water Quality Management Plan was developed to guide monitoring efforts. A legislative mandate supported formation of the Puget Sound Ambient Monitoring Program (PSAMP), a regional group of professional environmental scientists from the Pacific Northwest that included scientists from Ecology.

PSAMP expanded existing Puget Sound monitoring efforts. Its primary goal was to coordinate collection of information on parts of the Sound ecosystem that might be affected by pollution. The management plan was designed to guide comprehensive long-term monitoring in Puget Sound (MMC, 1988a), and to measure ambient (background) conditions in Puget Sound, as well as to measure cumulative effects of contamination and habitat degradation from human activities. Monitoring tasks were assigned to appropriate state agencies. Ecology's Environmental Assessment Program (EAP, formerly Ambient Monitoring Section, AMS) was assigned the marine water column monitoring task of PSAMP, as well as the marine sediment and freshwater monitoring tasks.

Beginning in November 1989 at the behest of the Puget Sound Water Quality Authority, Ecology began making complete vertical, continuous hydrographic profiles of the water column with a state-of-the-art oceanographic instrument, a CTD (Conductivity, Temperature, and Depth recorder with other sensors). Up until 1989, freshwater or standard methods were used to collect

point samples from a few depths in the water column, instead of seawater methods which include taking profiles of the full vertical water column.

In 1992, the original Quality Assurance Project Plan for ambient water column monitoring was published (Janzen, 1992). Under the same authority, Ecology has also conducted focused, short-term intensive water quality monitoring and velocity (current) studies, such as the Budd Inlet Scientific Study, South Sound and Hood Canal monitoring surveys, Sinclair Inlet, Sequim and Oakland Bay data collection for modeling support.

In 1995 and 2005, PSAMP monitoring was reviewed by regional managers and scientists. As a result, issues were addressed and improvements were implemented in the monitoring strategy. A final report for the 1995 marine water column monitoring review and the 2005 PSAMP review of all monitoring components are provided in Appendix B. One of the recommendations of the 1995 review was to measure boundary conditions for Puget Sound. The JEMS (Joint Effort to Monitor the Strait) program was created and stations in the Strait of Juan de Fuca were added to the monitoring program.

The JEMS program started in 1999 as a collaborative effort between Ecology, UW-Friday Harbor Labs (UW-FHL), the UW PRISM program, the Marine Ecosystem Health Program (now Sea-Doc Society), King County Department of Natural Resources, the Puget Sound Action Team (now Puget Sound Partnership), the Washington Department of Health and NOAA. Since 2007, Ecology has been the primary supporting agency, providing funding and logistical support as well as data management and quality assurance. UW-FHL was another sustaining partner, providing a vessel and staff to conduct and manage the monthly sampling effort from 1999 to 2013. As of July 2013, Shannon Point Marine Center, operated by Western Washington University, provides staff and vessel services to support the monthly sampling at these sites.

In 2007, the coordinating body of the Puget Sound Monitoring Plan, the Puget Sound Action Team (PSAT) was dissolved and the Puget Sound Partnership was formed after passage of Engrossed Substitute Senate Bill 5372 (Appendix B.3). PSAMP was renamed PSEMP and now falls under the authority of the Puget Sound Partnership (PSP).

3.1.2.2 Washington Coast and Bays

Oceanographic observations of coastal bays and the northeastern Pacific Ocean off the Washington Coast began in the 1960s when the United States Atomic Energy Commission (now the Dept. of Energy) began supporting oceanographic research off Washington and Oregon coasts to monitor the effects of the Columbia River Plume, primarily since nuclear reactors were located upstream (Landry and Hickey, 1989). Recent studies have highlighted the connectivity of coastal marine waters and coastal rivers including the Columbia River with Puget Sound marine water quality (Sutherland, 2011; PSEMP, 2012 and 2013; Irvine, 2013).

Recurrent, routine monitoring of the Pacific Ocean off the Washington Coast (aside from Ecology's monitoring of the coastal bays) has been irregular. In recent years, intermittent coastal marine surveys have been conducted for various research projects, such as the ECOHAB harmful algal bloom program. Several moored and buoy instrument programs have been implemented, such as the seasonal mooring arrays deployed by the Olympic Coast National Marine Sanctuary

(see the [OCNMS website](#)) and the Cha Ba and NEMO observatories deployed by the University of Washington Applied Physics Laboratory. However, despite these efforts, long-term routine water quality monitoring of the northeastern Pacific Ocean off the Washington coast has not been continuously funded. NOAA's National Ocean Service and National Data Buoy Center also collect marine data off the coast of Washington. Data such as sea surface temperature, air temperature, wind, and wave conditions are accessible from www.nanoos.org.

3.1.2.3 Recent Developments

Since 2008, marine water quality monitoring at Ecology has evolved into an integrated, spatially and temporally layered program that communicates water quality information within a broader context of oceanic and climatic influences. This approach requires collaborations and coordination with academic, private and other state entities. The program has expanded from collecting monthly water column samples to also include continuous in-situ data from moored instruments, en-route ferry observations, and aerial documentation of surface properties (algae blooms, river plumes, spills, and debris) within the larger Puget Sound region. This information is communicated monthly via "Eyes Over Puget Sound" which receives 25,000 to 120,000 downloads per month on the website [Eyes Over Puget Sound](#).

This QAMP addresses the monthly vertical water column profiling of Ecology's Marine Waters Monitoring Program only, which is composed of the Marine Flight and the former JEMS program. The other components of Ecology's marine monitoring program, such as moored instrument deployments and ferry-based monitoring, are described in separate QAMPs. A complete copy of Ecology's marine waters monitoring strategy is included in Appendix C.

3.1.3 Contaminants of concern

When the Marine Monitoring Program was implementing in 1967, primary contaminants of concern were industrial and municipal discharges of oxygen-consuming wastes. Over time, with better management of industrial and municipal point-source wastes, the monitoring strategy has shifted to understanding and quantifying multiple inputs to Washington's marine waters from a variety of sources including the Pacific Ocean, rivers and freshwater inputs, atmospheric, urban and agricultural inputs and relating processes and impacts to the marine ecosystem to effects of these inputs.

As urbanization and population increases alter landscapes in the Salish Sea basin, primary contaminants of concern are those relating to human activities and landscape change. These include increasing nutrient loads, changes in sedimentation and particle transport, alteration of biogeochemical processes such as carbon cycling and effects to the marine food web. Because this is an ambient monitoring program, specific pollutants are not targeted; instead, basic water quality properties are monitored for changes indicating impacts from other elements.

3.1.4 Results of previous studies

Results from the long-term marine waters monitoring program, various focused studies and modeling efforts have shown that Puget Sound and Washington's coastal bays are experiencing a decline in water quality conditions; however, climate and ocean forces are dominant drivers of

physical conditions in these estuaries (Krembs, 2009). The current focus of Ecology's marine waters monitoring program is to understand core drivers of Puget Sound and coastal marine water conditions. For the past two decades, significant information from ocean, climate, and other local monitoring projects has been incorporated into Ecology's interpretation of marine monitoring results. A key emphasis is to differentiate between the dominant core drivers of water quality, which include climate, ocean boundary, residual or lingering effects, estuarine circulation (freshwater influence) and regional human influences. An index based on long-term marine water column monitoring results (see Audits and Reports section) was developed to report site-specific status and trends in water quality conditions. This index, the Marine Waters Condition Index, is a key indicator in the Puget Sound Partnership's dashboard indicators (Krembs, 2012).

From annual reporting collaborations with PSEMP monitoring partners and results from the Marine Waters Condition Index, the following key findings have emerged. (Krembs, 2009; Krembs 2012; PSEMP, 2012 & 2013).

- Pacific Ocean waters are the dominant driver of Puget Sound physical conditions, yet the frequency, duration, and extent of ocean water intrusions and accompanying transport processes in Puget Sound are not well understood.
- Dissolved oxygen in upwelled ocean waters entering Puget Sound is naturally low. Coupled with anthropogenic influences, levels become critically low, especially in close-ended basins such as Hood Canal and South Puget Sound waters, under certain climate and ocean conditions.
- Nitrogen and phosphate levels along the main stem of Puget Sound are increasing, and nutrient ratios are shifting. Nutrient levels in ocean waters are naturally high and biogeochemical cycling of past and current nutrient inputs to Puget Sound, including wastewater, storm water run-off and non-point sources are not fully understood. Changes in the nutrient balance are potentially affecting species composition and material cycling in the marine system.
- Eutrophication processes may potentially affect areas of Puget Sound and reduced circulation may amplify these effects in close-ended basins.
- Weather and regional climate conditions are core drivers on Puget Sound estuarine circulation. During cold, wet years, less dense waters are coupled with higher oxygen and higher water clarity. During warm, dry years, denser waters are coupled with lower oxygen and lower water clarity.

Marine monitoring programs are important for developing water quality models of these water bodies. Two studies evaluated the relative contributions to low dissolved oxygen, based on models calibrated to data collected in these long-term and focused monitoring programs (Ahmed et al., 2014; Roberts et al., 2014). The models generated the following conclusions.

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

In addition, a nutrient loading study by Mohamedali et al. (2011) generated the following conclusion.

- Over the 10-year period from 1999 to 2008, there was no noticeable increasing or decreasing trend in overall nitrogen loads to Puget Sound, though trends in individual rivers and WWTPs may exist.

In addition to concerns about nutrient impacts on Puget Sound dissolved oxygen levels, ocean acidification effects are of concern and the impacts on Puget Sound conditions are not yet well quantified. Responses of other ecosystem components (food web, particle transport) to physical properties and boundary conditions need to be better resolved in order to understand consequences of climate change (Puget Sound Partnership, 2010).

These results along with additional reports, presentations, journal articles, and conference proceedings published by the Marine Waters Group are available at Ecology's [publications website](#), as well as by request.

3.1.4.1 Availability of Historical Data

Data results from Ecology marine waters monitoring efforts are available by request or via the internet at the [Marine Water Quality Monitoring website](#).

Results from earlier studies such as the Collias and Barnes surveys were converted from paper format to digital format by Skip Albertson. These data may be obtained by submitting a request via form at the MWM website. Ecology does not have the ability to validate or verify the authenticity of these results.

3.1.5 Regulatory criteria or standards

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

Ecology conducts routine assessments on the condition of surface waters, routinely every 2 years, rotating between marine and fresh water systems. Washington's Water Quality Assessment reports the water quality status for water bodies in the state and identifies waters that do not meet water quality standards. This assessment meets the federal requirements for an integrated report under Sections 303(d) and 305(b) of the Clean Water Act.

All marine waters in Puget Sound and the coastal bays fall under *extraordinary*, *excellent*, or *good* quality designated use categories. The water quality standards associated with the various designated use categories are found in the Washington Administrative Code, [WAC 173-201A](#). These standards include numeric values for temperature, dissolved oxygen, pH, ammonium, and

fecal coliform bacteria. Numeric targets vary within marine waters of Washington, as described in [WAC 173-201A-210](#).

Water quality assessment in Washington is guided by [Water Quality Policy 1-11](#), which is used to define assessment practices, criteria and categories for designating attainment or violation of standards, data submission, and the credible data policy for data used in the assessment.

Marine water column variables used for EPA's water quality assessment include temperature, dissolved oxygen, pH, and ammonium (as a toxin). Previously, the marine monitoring program included fecal coliform bacteria, but this was discontinued in 2013 after years of very low or infrequent, non-reproducible results. In addition, the marine waters monitoring program sampling design for bacteria was outmoded and the Department of Health (shellfish) and BEACH (human health effects) monitoring programs conduct bacteria monitoring using better-quality, targeted protocols.

Data collected at all core and rotational stations sampled in the MWM long-term program are submitted for every assessment cycle.

3.1.6 Other Washington marine monitoring programs

Ecology is a partner in the Northwest Association of Networked Ocean Observing Systems (NANOOS)—a regional collaborative effort between OHSU, UW, NOAA, OSU, and others – funded by the National Office for Integrated and Sustained Ocean Observations (Ocean.US). Ecology contributes to NANOOS by providing telemetry broadcasts from moored instrument packages. These data are available in real-time and time-limited archives through the NANOOS home webpage at www.nanoos.org/. In addition to Ecology moorings, the network includes oceanographic sensors deployed off the Washington Coast, Strait of Georgia, Puget Sound and coastal bays along Washington, Oregon, and northern California. This system provides routine, continuous data and information on ocean conditions in a program similar in scope to the National Weather Service. The system 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. Ecology's mooring data can also be accessed at www.ecy.wa.gov/programs/eap/mar_wat/moorings.html.

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 since June 1998 (www.prism.washington.edu/).

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/>).

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

NOAA's Pacific Marine Environmental Laboratory (PMEL) conducts interdisciplinary scientific investigations in oceanography and atmospheric science, develops ocean observing systems, and provides information on key oceanic research areas including ocean acidification, fisheries oceanography, and long-term climate monitoring and analysis. More information is at the [PMEL website](#). Ecology's marine monitoring program uses several NOAA PMEL products to provide context for Washington marine water quality.

4.0 Program Overview

General strategy

Ecology's Marine Waters Monitoring (MWM) Program uses a monitoring strategy composed of multiple components. These components are used to assess marine water quality for the greater Puget Sound, Grays Harbor, and Willapa Bay using a suite of environmental indicators. The program relies on a variety of physical, chemical and biological variables. It describes long-term patterns and trends related to estuarine physical processes and marine eutrophication. The marine water column monitoring program focuses on monthly sampling of the water column at core monitoring stations. The program uses consistent techniques to determine long-term trends in water quality over sufficiently long temporal scales. Station redundancy in each basin allows for a better statistical representativeness of monthly conditions. A monthly temporal resolution allows for a representative description of the seasonality of the system. While physical and optical variables are continuously resolved in the vertical with in situ sensors, discrete samples are resolved at higher resolution in the upper 30m of the water column to account for the connectivity between nutrient loading and freshwater inputs.

Data from the monthly water column monitoring provides the temporal backbone of Ecology's Marine Waters Monitoring program. These data are part of a spatially-nested approach using different sensor platforms to address the range of scales required to address marine water quality. The water column program is supplemented by continuous in-situ mooring observations, information from en route ferry transects, satellite data and aerial photography collected on different time scales. More detailed information on the Marine Waters Monitoring Program strategy can be found in Appendix C.

4.1 Marine water monitoring strategic goals

The strategic goals of the Marine Waters Monitoring Program are as follows:

1. Effectively measure and provide information about long-term estuarine dynamics, temporal and spatial variations, and trends relative to established baseline conditions that affect marine water quality.
2. Assess the interaction of different impacts on estuarine processes and ecosystem functioning that result from the transport of water, solutes and pollution (surface, inter-basin).
3. Assess changes in ambient water quality in context of local, regional, or larger-scale human, climatic, and oceanographic factors.

4.2 Project objectives

Goals of the marine water column profiling program include:

1. Assure high quality sensor measurements and related laboratory analysis of reference samples.
2. Report on water quality conditions and regional conditions, including attributes such as:
 - Status of physical conditions such as salinity and temperature.
 - Status of biochemical properties including dissolved oxygen, nutrient concentrations, and ratios.
 - Status of bio-optical properties such as water clarity and chlorophyll fluorescence as a proxy for biomass.
 - Seasonal variability in water quality conditions such as temperature and dissolved oxygen.
 - Inter-annual variability in water quality conditions, connected to large-scale climate and weather patterns.
 - Spatial and temporal trends of marine water conditions in Puget Sound and the coastal bays.
 - New monthly extremes and significantly different conditions.
3. Contribute to the understanding of long-term changes of marine water quality in context of other environmental factors through the following activities:
 - Provide continuous data input for physical and ecological models.
 - Provide monthly observations and inform the public, management, and the Puget Sound Partnership about unexpected current conditions.
 - Provide water quality information and baseline data to other Ecology programs and state agencies, the public, managers, and private institutions.
 - Coordinate findings with other PSEMP monitoring components
 - Provide data to evaluate compliance with state water quality standards under the Clean Water Act [303(d) list and 305(b) report].
 - Identify emerging problems and inform action agendas and regulatory processes.
 - Identify water masses and exchange between Salish Sea basins, and contribute to the overall understanding of the dynamic of natural conditions.

4.3 Information needed and sources

Marine water quality data is analyzed and interpreted in the context of weather and ocean data. The MWM group uses data from other agencies including river flow data from the [US Geological Service](#) and [Environment Canada](#), ocean and climate condition data from NOAA branches such as the [Upwelling Index](#), [Pacific Decadal Oscillation](#), [NE Pacific sea surface temperature](#), and the [North Pacific Gyre Oscillation Index](#) from Scripps Institution of Oceanography. [Local weather information](#) is obtained from University of Washington's Atmospheric Sciences Program.

4.4 Target population

Direct measurements are not made of any specific target population. By design, the Marine Waters Monitoring program is designed to provide basic water quality information for the Puget Sound region of the Salish Sea Ecosystem and Washington's coastal bays.

4.5 Study boundaries

The study boundary for the marine waters monitoring program is broad, covering a large area of the southern Salish Sea and Washington's coastal bays. As information on these ecosystems evolves, monitoring needs may change and the sampling areas may also. The extent of the study area is described in section 3.1 of this plan.

A map showing coarse boundaries of project study area is found in Figure 1.

Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area

Water Resource Inventory Area (WRIA) for the study areas

The marine monitoring program includes WRIAs 1-19, 22, and 24.
(See Tables 7 and 8 for WRIA numbers associated with all sampling locations.)

The marine monitoring program includes these HUC numbers:

- 17100105
- 17100106
- 17110018
- 17110019
- 17110020
- 17110021
- 17110002
- 17110003

4.6 Tasks required

The marine water column program includes specific tasks that achieve the overall monitoring program's strategic goals via two extensive activities: data collection and data assessment.

4.6.1 Data collection

On a year-round, monthly basis, we collect vertical water column profile data on salinity, temperature, dissolved oxygen, turbidity, ambient light conditions, fluorescence, chlorophyll *a*, pH, and nutrients at 39 core marine water sampling stations, based on directives from the original Puget Sound monitoring plan for the water column. As knowledge of the Puget Sound

ecosystem evolves and new monitoring needs are identified, we add more variables to the sampling program. These may include variables such as alkalinity, dissolved inorganic carbon, and other variables related to hydrography, food webs or biogeochemical processes. Sampling is conducted monthly at selected open basin and embayment stations to maintain a long-term record of water column conditions. Year-round sampling is necessary because certain parameters, such as chlorophyll, nutrients, and dissolved oxygen, show their peak values (or highest rates of change) during the summer, while others (fresh water, pathogen indicators) peak during the winter. Sampling is conducted during all 12 months to ensure that all major hydrographic trends are observed and to provide a complete data set for analysis of temporal trends (MMC, 1988).

Specific information on station sampling is found in the Sampling Design section.

4.6.2 Data assessment

Water column information collected during this program will be used to accomplish the following objectives.

1. Characterize and document spatial and temporal status and trends of marine water conditions in Puget Sound and the coastal bays.
2. Characterize and track the movement of water masses in Puget Sound and the coastal bays. Provide interpretation and information to understand and evaluate coastal and estuarine processes and to identify pathways of transport associated with the density structure and movement of water masses
3. Identify and characterize significant changes to water quality (estuarine, oceanic, climate, or anthropogenic factors), using key environmental indicators relative to baseline data from the period 1999-2008, established in Krembs, 2012.
4. Provide water quality information and baseline data to other Ecology programs and state agencies, the public, managers, and private institutions and coordinating findings with other PSEMP monitoring components. Provide data to assess compliance with state water quality standards under the Clean Water Act (303d list and 305b report), identify waters affected by pollution and sensitive to contamination, and identify emerging problems and inform action agendas and regulatory processes.
5. Support related environmental research activities through the availability of consistent, scientifically and statistically valid data and to help interpret results from other regional monitoring programs.

4.7 Practical constraints

Data collection is not conducted under adverse or unsafe conditions. In addition, data collection may be suspended when access is denied or operations are prohibited by federal agencies such as the U.S. Coast Guard, FAA, or Department of Defense. Data collection may be cancelled or

curtailed when budget constraints result in staff reductions or limited availability of resources such as equipment and supplies, laboratory analyses, or calibration and maintenance services.

Data assessment may be limited or not performed when data collection is suspended, equipment fails to generate data that meet quality standards, or when budget constraints result in staff reductions or limitations to resources such as equipment and supplies, analytical laboratory or information management services.

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

4.8 Systematic planning process

As described in the background section of this plan, the program plan evolved based on agency monitoring needs in the early 1970s and in 1989 by a regional effort to design a comprehensive monitoring program for Puget Sound.

As new ecological information emerges and different questions about estuarine dynamics arise, the monitoring priorities and strategy will change. Updates to station locations, monitoring, and data collected are implemented as information priorities evolve and scientific needs change on an annual basis. Any updates will be captured in future addenda to this program plan or, if significantly different, will be captured in a new quality assurance monitoring plan.

The specific plan for monitoring marine water quality continues to change as advances are made. Every fall, the Marine Monitoring Unit conducts annual planning for making small internal agency changes to sampling logistics. Every 10 years, all agencies involved in conducting monitoring in Puget Sound participate in a regional assessment and review of the plan. This last occurred in 2005.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 1 describes the roles and responsibilities of people involved with the Marine Waters Monitoring Program. All are employees of the Washington State Department of Ecology. Table 2 summarizes the routine activities conducted during a routine sampling year under the monitoring plan.

Table 1. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Julia Bos Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6674	Monitoring Coordinator, Data Management, Data Analyst, Publications Author	Writes the QAPP. 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.
Christopher Krembs Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6675	Senior Oceanographer, Lead Presentations & Publications Author	Determines monitoring strategy. Generates index/indicators of water quality conditions. Determines appropriate analysis, review and interpretative methods for data reduction and reporting. Generates data products. Lead author of publications and presentations.
Skip Albertson Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6675	Physical Oceanographer, Data Analyst, Modeler, Publications Author	Analyses and reports on climate, weather and ocean indicators. Generates data products and analytical tools. Conducts QA review of data, analyzes and interprets data. Writes reports and data summaries.
Mya Keyzers Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6395	Marine Flight Lead Technician	Conducts field sampling, laboratory analysis and instrument maintenance. Records and manages field information. Conducts QA review, analyzes and interprets data. Writes reports and data summaries.
Laura Hermanson Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-0273	Marine Flight Technician	Conducts field sampling, laboratory analysis and instrument maintenance. Records and manages field information. Conducts QA review, analyzes and interprets data. Writes reports and data summaries.
Carol Maloy Marine Monitoring Unit Western Operations Section Ecology - EAP Phone: (360) 407-6742	Unit Supervisor	Provides internal review of the QAPP, approves the budget, and approves the final QAPP.
Robert F. Cusimano/ Jessica Archer Western Operations Section Ecology - EAP Phone: (360) 407-6596	Section Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
William R. Kammin Ecology - EAP Phone: (360) 407-6964	Ecology Quality Assurance Officer	Reviews the draft QAPP and approves the final QAPP.

EAP: Environmental Assessment Program

EIM: Environmental Information Management database

QAMP: Quality Assurance Monitoring Plan

5.2 Special training and certifications

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.

All personnel who conduct laboratory activities should have college education in introductory level biology and analytical chemistry and some direct experience with sample analysis, sample handling, QA/QC, and chemical safety. Each staff person is required to be familiar with this QA Monitoring Plan and lab procedures described in SOPs.

5.3 Organization chart

Marine Monitoring Unit
Robert Cusimano/Jessica Archer – Section Manager
Carol Maloy – Unit Supervisor
Christopher Krembs – Lead Oceanographer
Skip Albertson
Julia Bos
Laura Hermanson
Mya Keyzers

5.4 Project schedule

Table 2. Proposed schedule for completing field and laboratory work, data processing, review, QC, storage in data repository, and reports.

Activity	Due date	Lead staff
Field and laboratory work		
Field work (sample collection) completed	Monthly	Mya Keyzers
Internal (Ecology) laboratory analyses completed	3 days (DO samples) post-collection	Laura Hermanson
Internal (Ecology) laboratory analyses completed	1 month post-collection (chlorophyll <i>a</i> samples)	Laura Hermanson
External (UW) laboratory analyses completed	3 months post-collection (nutrient samples)	Julia Bos
Data receipt or processing and upload to EAPMW (Marine Waters) database		
Instrument and sensor data	Same month as collection	Julia Bos
Internal laboratory data	1 month post-analyses	Laura Hermanson
External laboratory data	1 month post-analyses	Mya Keyzers
Data Review and QA/QC		
Instrument and sensor data	1 month post-collection	Julia Bos, Christopher Krembs, Skip Albertson, Mya Keyzers, Laura Hermanson
Internal laboratory data	1 month post-analyses	Laura Hermanson
External laboratory data	Quarterly, one quarter post-collection	Mya Keyzers
Environmental Information System (EIM) database		
EIM data loaded	Same month as collection	Julia Bos
EIM quality assurance	4 months after sampling year complete	Julia Bos
EIM complete	4 months after sampling year complete	Julia Bos
Monthly reports		
Monthly condition summary generated	1 month post-collection	Julia Bos
Monthly summary posted to web	1 month post-collection	Christopher Krembs
Annual Assessment - data products and written summary		
Draft assessments & products due	3 months after sampling year complete	Christopher Krembs, Julia Bos, Skip Albertson; Mya Keyzers, Laura Hermanson
Final reviews and QA/QC summarized	4 months after sampling year complete	Christopher Krembs, Julia Bos
Final summary due on web	4 months after sampling year complete	Christopher Krembs
Final data posted and performance measures reported		
Final data and analytical plots due on web	4 months after sampling year complete	Christopher Krembs, Skip Albertson
Final Performance calculated and submitted to OFM	Annually in July	Julia Bos

5.5 Limitations on schedule

Marine waters data collection by floatplane allows for an efficient, cost-effective sampling method capable of covering the extensive study area in just 5 sampling days per month. However, operations conducted aboard this type of platform are constrained to daylight and “fair weather” conditions. For safety reasons, floatplanes are not allowed to operate in fog, low visibility, or after dark, and the planes cannot land on disturbed waters in winds greater than 15 knots. Therefore, sampling flights are not conducted during stormy, foggy or nighttime conditions. Sampling via boat may be conducted in more challenging conditions such as stronger winds or higher waves; however, sampling is not conducted after dark, nor in stormy conditions resulting in small craft advisories. The result is that there are more gaps in sampling events during winter time (more stormy periods) and data could be biased.

5.6 Budget and funding

Table 3. Budget (estimated) for long-term marine water column monitoring data collection during the 2013-2015 biennium.

Provider	Item	Units	Quantity	Cost per Unit	Total 2013-2015
University of Washington Marine Chemistry Lab ¹	Seawater Nutrient Analysis (NO ₃ , NO ₂ , NH ₄ , Si(OH) ₄ , PO ₄) ²	samples	2800	\$16.80	\$47,040.00
	Salinity Analysis	samples	412	\$19.65	\$8,095.80
	Chlorophyll <i>a</i> Analysis ²	samples	108	\$12.72	\$1,373.76
Total					\$56,509.56
Kenmore Air Harbor, Inc. ³	flight time	engine hours	364	\$634.00	\$230,776.00
Total					\$230,776.00
Shannon Point Marine Center ⁴	Research Vessel	ship hours	192	\$110.00	\$21,120.00
	Lab Fee	month	24	\$295.00	\$7,080.00
Total					\$28,200.00
Total Cost					\$315,485.56

¹Costs include 15.6% overhead

² Includes lab check standards and blanks sent with every batch.

³State Contract No. 02407

⁴Inter-agency Agreement No. C1400008

6.0 Quality Objectives

Marine water column profiling data have to be accurate, precise, representative and continuous. In addition, data must be sensitive, comparable, and complete to meet monitoring objectives (Lombard and Kirchmer, 2004). Marine sensor profiles and discrete sample data serve as Ecology's core data set to determine long-term trends and patterns in water quality related to eutrophication and estuarine processes. Consistent, high quality data are used to determine long-term shifts in water quality baseline conditions, using statistical methods to determine significant changes. Vertical profile data are also used to verify in situ time-series data from moored instruments and spatial transect data collected by Ecology and its partners. Finally, high quality data are assessed against the water quality standards set for these parameters to determine if water quality issues exist.

High quality data collection and analyses are mandatory for Ecology's Marine Waters Monitoring Program and ensure that trends accurately reflect true environmental change. We use standard, widely accepted, oceanographic procedures conducted by highly trained technicians, with education and experience in oceanography or marine science. We adhere to the most up-to-date quality assurance and quality control protocols accepted and recommended by the global oceanographic and marine monitoring community. We routinely perform data quality assurance (QA), and data quality control (QC) procedures utilizing group data reviews to ensure that our data meet highest quality standards. Data quality codes are applied to the data set allowing users to decide the appropriate level of quality for their specific analysis requirements.

6.1 Measurement quality objectives

Measurement quality objectives (MQOs) for this study are to obtain data of sufficient quality and quantity so that the data can be used to evaluate the stated objectives of the monitoring program. These objectives will be achieved through careful planning, sampling, and adherence to the procedures described in the Quality Assurance Monitoring Plan and all associated addendums.

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

- **Continuous vertical sensor profiles (CTD data)** - pre-sampling sensor performance tests and independent sensor verification samples are collected during marine flights and monitoring events.
- **Discrete water samples** - analytical precision and bias are evaluated and controlled by use of laboratory check standards, duplicates, and blanks analyzed along with monitoring samples in the data stream.
- **Field observations** - site-specific observations of weather and general conditions are made with accepted techniques and are standardized between technicians by using pre-designated, standardized data types, data units, and lists of pre-defined, descriptive terms.

Tables 4 and 5 show the measurement quality objectives (MQO) for the methods used for sensor measurements and water sample analysis.

6.1.1 Targets for precision, bias, and sensitivity

6.1.1.1 Precision

For marine water column profile data, precision is established for all data, using replicate water samples collected during every field sampling event, multiple (repeated) sensor readings taken before, during, and after site visits, and repeated sensor performance checks in test tank facilities under controlled conditions.

6.1.1.2 Bias

For marine water column profile data, accuracy is established for laboratory data through the use of blanks and check standards (laboratory control samples) when possible. Accuracy for CTD and sensor data is established through annual calibrations performed at the manufacturer's or other appropriate facility, the use of blanks and check standards (where possible), through the use of independent verification samples (where possible), and sensor performance checks in test tank facilities under controlled conditions.

6.1.1.2.1 Systematic bias

Data collected under this monitoring program may be affected by a systematic bias. While sampling by floatplane allows for an efficient, cost-effective sampling method capable of covering the extensive study area in just 5 sampling days per month, operations conducted aboard this type of platform are constrained to daylight and "fair weather" conditions. For safety reasons, floatplanes are not allowed to operate in fog, low visibility, or after dark and the planes cannot land on disturbed waters in winds greater than 15 knots. Therefore, sampling flights are not conducted during stormy, foggy, or nighttime conditions. The result is that there are more gaps in sampling events during winter (more stormy periods), and data could be biased.

6.1.1.3 Sensitivity

Sensitivity of marine water column profiling data is reported as lowest value detectable for a given method.

Tables 4 and 5 list precision, accuracy (bias) and sensitivity for all current marine water column profiling measurements.

6.1.1.4 Field sensor MQOs

Sensors are used to measure a broad suite of hydrographic, chemical, optical, and biological conditions at each monitoring station. Specific information on field measurements made via sensor technology is found in the *Sampling Procedures* section. All work is expected to meet the QC requirements of the 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) used for each variable.

Table 4. Measurement quality objectives for marine water column field sensors.

This table summarizes measurement quality objectives for in situ values for marine data.

Ecology is responsible for verifying all MQOs are met.

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. (ECOFL-NTU)	0-50 µg/l Chl	¹ 0.025 µg/l Chl	0.1 µg/l Chl
Conductivity	10%	5%	Sea-Bird Electronics (SBE4)	0.0 - 7.0 Siemens/meter (S/m)	0.0003 S/m	1 uS/cm
Density	10%	5%	Sea-Bird Electronics	dependant on T,C	dependant on T,C	0.1 s _t
Dissolved Oxygen	5%	5%	Sea-Bird Electronics (SBE43)	0-120% of saturation	2% of saturation	0.05 mg/L
Light Transmission	10%	5%	WET Labs, Inc. (C-Star)	0-100%	² 99% R ²	0.01%
PAR (Photosynthetically Active Radiation)	5%	5%	Biospherical Instruments, Inc. (QSP-2200)	1.4x10 ⁻⁵ µmol/(cm ² ·sec) to 0.5 µmol/(cm ² ·sec)	±5%	0.01%
pH	0.1 pH	N/A	Sea-Bird Electronics (SBE18)	0-14 pH	0.1 pH	0.1 pH
Pressure	5%	1%	Sea-Bird Electronics (SBE29)	0-500m	0.1% of full scale range	0.1 db
Secchi Depth	0.5 m	N/A	N/A	N/A	N/A	N/A
Temperature	0.025 °C	0.05 °C	Sea-Bird Electronics (SBE3)	-5.0 to +35 °C	0.001 °C	0.01 °C
Turbidity	10%	5%	WET Labs, Inc. (ECOFL-NTU)	0-25 NTU	0.01 NTU	0.1 NTU

*RSD is calculated as the ratio of the standard deviation and the mean of several values.

6.1.1.5 Laboratory MQOs

Seawater nutrient and salinity sample analyses are conducted by the University of Washington Marine Chemistry Laboratory (UW-MCL). Dissolved oxygen (Winkler) and chlorophyll *a* samples are analyzed by the Marine Lab (ML) of the Marine Waters Monitoring Group. All labs conducting analyses for the marine waters monitoring program are accredited through Ecology's Laboratory Accreditation Program.

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) used for each analysis. Many of these procedures can also be found in detail in the Puget Sound Estuary Program (PSEP) Protocols (1997).

Table 5. Measurement quality objectives for marine water column laboratory samples.

This table summarizes measurement quality objectives for analytical laboratory values for marine data. Ecology is responsible for verifying all MQOs are met.

Measurement - Laboratory	Precision	Accuracy (Bias)	Lowest Value (Reporting Limit)
	(relative standard deviation, RSD)	(% deviation from true value)	
*Alkalinity	10%	5%	1 µM/kg
*Dissolved Inorganic Carbon	10%	5%	1 µM/kg
Dissolved Oxygen	5%	5%	0.05 mg/L
Marine Nitrate	10%	5%	0.15 µM
Marine Nitrite	10%	5%	0.01 µM
Marine Ammonium	10%	5%	0.05 µM
Marine Orthophosphate	10%	5%	0.02 µM
Marine Silicate	10%	5%	0.21 µM
Chlorophyll <i>a</i>	10%	N/A	0.02 µg/L
Salinity	5%	5%	0.002 PSU

*Not currently collected

6.1.1.6 Field observation MQOs

Field observations include information about individual site conditions such as actual location, tide, time, weather, and other notable features during vertical sampling events. Contextual observations made by field technicians have an important role in high-quality data interpretation and assessment of monitoring results. Field activities require excellent observation procedures that are detailed, consistent, accurate, applicable, and well-documented.

For critical field data such as actual sampling location (latitude and longitude), time of sampling, and tidal height, technicians use the most current, accepted technologies for generating and

recording this information. Location is generated using the standard positioning service provided through the Global Positioning System (GPS). Time is recorded using GPS or cellular telephone data, both considered to be highly accurate. Location information for tide data is generated using Nobeltec® Tides and Currents software™. Tide and current predictions are based upon harmonic data from the U.S. National Oceanic and Atmospheric Administration (NOAA) and the Canadian Hydrographic Service (CHS). The same information from NOAA digital raster sources can be found at www.nauticalcharts.noaa.gov/mcd/Raster/. Tide and current information are taken from the National Ocean Service website at www.tidesandcurrents.noaa.gov/. Occasionally, an alternate source is used for these data, Nomad Electronics at www.deepzoom.com. Secchi disk depth is taken to the nearest 0.5 meter, following standard oceanographic protocol. A complete list of field observation data types and descriptions can be found in Appendix D.

6.1.1.6.1 Weather and conditions

Technicians record observations of local sea surface conditions, weather, and other notable features while sampling in the field. Many of these observations are subjective, depending on the experience and background of the observer. Technicians and volunteers use standardized guides whenever possible to make observations. Exceptions to this may include wind speed and direction, which can be determined by meteorological instruments aboard the floatplane or vessel. A complete list of weather and conditions data types and descriptions can be found in Appendix D. Guidelines (“Tech Notes”) for collecting weather information can be found in Appendix E.

6.1.2 Targets for comparability, representativeness, and completeness

6.1.2.1 Comparability

It is important that data collected and analyzed for long-term monitoring by different technicians or monitoring groups are comparable. To ensure comparable data collection techniques, we use the same methods and procedures whenever possible for collecting and analyzing marine water column data throughout the program. MWM technicians operate with primary and backup responsibilities for ensuring that high quality data are generated and moved into the data management system. Regular field and lab audits of technical staff are conducted to ensure individual staff members are consistent with each other in their technical proficiency and field and lab practices.

A list of all standard procedures used for data collection and data assessment is included in Appendix E of this plan. All protocols used by MWM are based on the most current, standard, internationally accepted seawater methods. In addition, all procedures are reviewed every 2-3 years and updated to include improvements and necessary modifications. Using these standardized procedures for analyzing marine monitoring data supports comparability between other studies and long-term monitoring.

MWM staff also compares inter-lab nutrient standards of different monitoring partners, such as King County Environmental Laboratory. Standard protocols are followed for generating lab control samples and for conducting laboratory analyses. Seawater nutrient standards are

prepared in replicate by Ecology's Marine lab once or twice a year, for comparative analyses by both UW Marine Chemistry Lab and King County Environmental Lab. King County Department of Natural Resources analyzes and reports results. (King County, 2014). This same inter-lab comparison could be extended to other partner labs to validate and verify results.

6.1.2.2 Representativeness

The long-term marine waters monitoring program is designed to collect data that adequately represents the study area, across seasonal cycles, including spatial and temporal variations. With monthly data collection, a wide variety of seasonal conditions are represented. Regional sampling surveys are conducted over 5 different days a month, with no set date or condition imposed for any survey. Surveys are conducted monthly with at least 3 weeks between consecutive visits to the same region. By our sampling of 39 select marine sites with full vertical resolution, the data will adequately represent the study area, including spatial variation. These sites are located near the middle of inlets or passages to reflect basin-scale water quality and not conditions near a specific wastewater or river discharge.

Technicians will control sampling variability by strictly following standard procedures and collecting quality control samples, but natural spatial and temporal variability may contribute greatly to overall variability in the parameter value.

6.1.2.3 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 that 95% of all collected data meet measurement quality objectives. There is no attainment objective established given the safety considerations specific to marine water sampling. We make all efforts possible to complete all sampling every month to avoid gaps in the data record.

Reasons why sampling may be cancelled:

1. Severe weather that precludes vessels from sailing or flying. To mitigate this, Ecology schedules multiple backup dates. In instances when the weather is too severe to fly but not to operate a vessel, Ecology will use the R/V Skookum to visit and sample core stations.
2. Malfunctioning equipment. To minimize this risk, we maintain interchangeable sets of auxiliary equipment, ensure equipment is well maintained, and thoroughly check functionality before starting fieldwork.
3. Measurement/data quality objectives are not met. To minimize this, we conduct regular pre- and post-sampling assessment of all procedures and equipment to ensure all are operating correctly.

7.0 Sampling Process Design (Experimental Design)

7.1 Study design

Long-term ambient sampling at key sites is conducted to monitor the overall health of Washington's marine waters over multiple years. If long-term monitoring results from a water body are assessed using standard practices and the assessment indicates poor water quality, further investigations may be conducted.

Ideally, long-term trends should be assessed for each body of water. The federal government and the Clean Water Act request this as part of a nationwide monitoring program. To locate a station in each water body, however, would result in an exhaustive and expensive station network. To accomplish long-term monitoring efficiently and effectively, three sampling approaches are employed:

1. Core station monitoring.
2. Rotating station monitoring.
3. Seasonal rotating station monitoring.

This section describes the core and rotating stations as well as the monitoring approach for each type of station.

Figure 4 identifies the core and rotating stations that comprise the marine waters vertical profile monitoring program. Station locations were determined by integrating three existing and recommended station networks. These are (1) existing Ecology sites, (2) sites recommended in 1988 by the Puget Sound Water Quality Authority – Monitoring Management Committee (MMC, 1988a), and (3) historical stations surveyed by Collias et al. during the 1950s and 1960s. Station locations from historical lists were incorporated to promote long-term trend analyses. Where possible, recommendations for sites from the program's clients are incorporated into the sampling strategy to report on localized conditions for these users. Currently, Ecology has active and inactive stations at 166 locations, including historical sites very rarely sampled.

Thirty nine stations are designated for core monitoring, with another forty seven for rotating monitoring. Table 7 lists the core stations and their locations. Monthly core station data feed the Marine Water Condition Index. As monitoring needs change, stations may be added or removed from the core list of routinely sampled stations.

7.1.1 Field measurements

Attributes measured at core and rotating stations and the depths measured are listed in Table 6. At all core stations in the major Puget Sound basins, complete CTD profiles of the entire water column are taken at 0.5 m. intervals, with nutrient and chlorophyll *a* samples collected at three depths: 0, 10 and 30 meters. Additional samples for dissolved oxygen and salinity are collected to check sensor measurements during field sampling.

Table 6. Sample types and depths for marine waters monitoring parameters.

Sample Type	Depth in Meters
*Weather & Conditions	NA
*Field Observations	NA
Secchi Depth	**
CTD Parameters:	
Temperature	0-Bottom
Conductivity (Salinity)	0-Bottom
pH	0-Bottom
Dissolved Oxygen	0-Bottom
Transmissometer	0-Bottom
Chlorophyll <i>a</i> Fluorescence	0-Bottom
Turbidity	0-Bottom
PAR (Photosynthetically Active Radiation)	0-Bottom
Water Samples:	
***Alkalinity & Dissolved Inorganic Carbon (DIC)	10 m
Chlorophyll <i>a</i> and Phaeopigments	0, 10, 30
Dissolved Oxygen (Winkler)	Near Bottom
Dissolved Inorganic Nutrients: PO ₄ , SiO ₄ , NO ₃ , NO ₂ , NH ₄	0, 10, 30
Salinity	10 or 30 m

*Most observations are estimates made by technician during sampling

**Depth at which the Secchi disc disappears.

***Not currently collected

7.1.2 Sampling location and frequency

7.1.2.1 Core station monitoring and locations

Core station monitoring is intended to provide a base of continuous, widespread, long-term water quality data at selected points throughout the Puget Sound system. Measurements provide a basis for determining the following:

- Temporal changes and spatial differences in water quality between water bodies in deep open basins and select embayments.
- Annual variability of marine water quality.
- Changing water quality conditions and emerging problems.
- Relationships with spatial and temporal patterns in other monitoring components.

Core stations are located to capture ambient conditions. Stations are located in the center of distinct hydrographic regions, separated mainly by major sills, and include deep, open basins, passages, and select major urban areas and rural embayments. These stations provide a long-term record of ambient water column conditions, annual variability, and changing marine water quality conditions. These stations also record relationships with spatial and temporal patterns in other Puget Sound monitoring components.

7.1.2.2 Rotating station and seasonal rotating station monitoring and locations

The rotating station component of the water column sampling program is intended to augment the data collected during the core station monitoring. Rotating stations are sampled on a periodic basis. The additional stations allow a more extensive look at specific regions and increase the geographic coverage of the station network. Seasonal monitoring of select rotating stations provides a brief data set useful for determining the need for more intensive monitoring or continuous studies. Rotational station monitoring is used for the following purposes:

- Provides supporting information to characterize water quality conditions within selected basins.
- Provides additional information to assess spatial differences in processes and exchange between water bodies in deep, open basins and select embayments.
- Determines changes in water quality conditions and emerging problems.
- Provides short-term, supporting information for other monitoring efforts.

7.1.2.2.1 Rotating stations

Rotational stations tend to be located offshore, yet more in semi-enclosed embayments. They have an interrupted, inconsistent data record, being sampled for twelve months every 10-12 years, as funding allows. A total of forty seven sites in Puget Sound are designated for rotational monitoring. Two to three stations are visited every year on a rotating schedule that cycles between North, Central, and South Puget Sound. Due to current resource limitations and limited capacity for sampling such a large geographical area, most rotational stations are not visited more than once every decade. Table 8 lists the rotating stations for this program.

Rotating stations are chosen by a ranking system that scores stations according to the last year sampled, overall amount of sampling data collected, and priority for eutrophication assessment. Stations that have long intervals between sampling years, a well-populated data set, and potential eutrophication effects are ranked higher in the selection process.

Rotating stations selected for sampling each year will be identified in the annual plans, published as addenda to this QAMP.

7.1.2.2.2 Seasonal rotating stations

Seasonal rotating stations are selected annually, based on recommendations and data needs of clients, and may be moved to fill or improve data records for other sections of the marine monitoring program. Final stations are selected by Ecology Marine Monitoring staff. These locations may be visited for one sampling period or may be revisited when necessary. The number of seasonal rotational stations monitored each year may vary, depending on the need and the resources available. Seasonal rotating stations may be sampled for 4 to 6 months during the critical summer months when low dissolved oxygen or other water quality issues are a concern.

Seasonal rotating stations are selected using the same selection process as rotating stations, but they are sampled only during a brief time period, due to resource constraints and other factors. These stations will also be identified in the published annual sampling plan.

Table 7. Core stations for Ecology long-term marine water column monitoring.

Station	Location	Basin	Sampling Region	Latitude NAD83 (deg/dec min)	Longitude NAD83 (deg/dec min)	County	WRIA	Max depth	Designation
ADM001	Admiralty Inlet - Bush Pt.	Admiralty Inlet	North/Central Sound	48 1.789	122 37.076	Island	06	148	C
ADM002	Admiralty Inlet (north) - Quimper Pn	Admiralty Inlet	North/Central Sound	48 11.239	122 50.577	Jefferson	17	82	C
ADM003	Admiralty Inlet (south)	Admiralty Inlet	North/Central Sound	47 52.739	122 28.992	Kitsap	15	210	C
BLL009	Bellingham Bay - Pt. Frances	San Juan Island/Georgia St.	North Sound	48 41.156	122 35.977	Whatcom	01	20	C
BUD005	Budd Inlet - Olympia Shoal	South Basin	South Sound	47 5.522	122 55.092	Thurston	13	15	C
CMB003	Commencement Bay - Browns Point	PS Main Basin	Central Sound	47 17.423	122 27.007	Pierce	10	150	C
CRR001	Carr Inlet - Off Green Point	South Basin	South Sound	47 16.589	122 42.575	Pierce	15	95	C
CSE001	Case Inlet - S. Heron Island	South Basin	South Sound	47 15.872	122 50.658	Pierce	15	58	C
DNA001	Dana Passage - S. of Brisco Point	South Basin	South Sound	47 9.689	122 52.308	Thurston	13	40	C
EAP001	East Passage - SW of Three Tree Po	PS Main Basin	Central Sound	47 25.023	122 22.824	King	09	213	C
ELB015	Elliott Bay - E. of Duwamish Head	PS Main Basin	Central Sound	47 35.789	122 22.174	King	09	82	C
GOR001	Gordon Point	South Basin	South Sound	47 10.989	122 38.074	Pierce	15	168	C
GRG002	Georgia Strait - N. of Patos Island	San Juan Island/Georgia St.	North Sound/San Juans	48 48.490	122 57.245	San Juan	02	190	C
GYS004	Grays Harbor - Chehalis R.	Grays Harbor	Coast	46 58.672	123 47.077	Grays Harbor	22	20	C
GYS008	Grays Harbor - Mid-S. Channel	Grays Harbor	Coast	46 56.239	123 54.793	Grays Harbor	22	6	C
GYS016	Grays Harbor - Damon Point	Grays Harbor	Coast	46 57.205	124 5.577	Grays Harbor	22	11	C
HCB003	Hood Canal, Eldon	Hood Canal Basin	Hood Canal	47 32.2722	123 0.576	Mason	14	144	C
HCB004	Hood Canal - Gt. Bend, Sisters Point	Hood Canal Basin	Hood Canal	47 21.372	123 1.492	Mason	14	55	C
HCB007	Hood Canal - Lynch Cove	Hood Canal Basin	Hood Canal	47 23.8889	122 55.7755	Mason	14	21	C
HCB010	Hood Canal - Send Creek, Bangor	Hood Canal Basin	Hood Canal	47 40.2	122 49.2	Kitsap	15	100	C
NSQ002	Nisqually Reach - Devils Head	South Basin	South Sound	47 10.039	122 47.291	Pierce	13	101	C
OAK004	Oakland Bay - Near Eagle Point	South Basin	South Sound	47 12.806	123 4.659	Mason	14	19	C
PSB003	Puget Sound Main Basin - West Poin	PS Main Basin	Central Sound	47 39.589	122 26.575	King	08	67	C
PSS019	Possession Sound - Gedney Island	Whidbey Basin	Whidbey Basin	48 0.656	122 18.075	Snohomish	07	101	C
PTH005	Port Townsend Harbor - Walan Poin	Admiralty Inlet	North Sound/San Juans	48 4.989	122 45.877	Jefferson	17	26	C
RSR837	Rosario Strait	San Juan Island/Georgia St.	North Sound/San Juans	48 36.990	122 45.778	San Juan	2	56	C
SAR003	Saratoga Passage - East Point	Whidbey Basin	Whidbey Basin	48 6.456	122 29.493	Island	06	149	C
SIN001	Sinclair Inlet - Naval Shipyards	Main Basin	Central Sound	47 32.956	122 38.608	Kitsap	15	16	C
SJF000	Strait of Juan de Fuca - S. of San Jua	Strait of Juan de Fuca	North Sound/San Juans	48 25.0	123 01.5	San Juan	2	180	C
SJF001	Strait of Juan de Fuca - SE of Hein E	Strait of Juan de Fuca	North Sound/San Juans	48 20.0	123 01.5	San Juan	2	160	C
SJF002	Strait of Juan de Fuca - SW of Easter	Strait of Juan de Fuca	North Sound/San Juans	48 15.0	123 01.5	San Juan	2	145	C
SKG003	Skagit Bay - Str. Point (Red Buoy)	Whidbey Basin	Whidbey Basin	48 17.789	122 29.376	Island	06	24	C
WPA001	Willapa Bay - Willapa R., Raymond	Willapa Bay	Coast	46 41.239	123 44.993	Pacific	24	11	C
WPA003	Willapa Bay - Willapa R., John. Slo	Willapa Bay	Coast	46 42.239	123 50.243	Pacific	24	10	C
WPA004	Willapa Bay - Toke Point	Willapa Bay	Coast	46 41.206	123 58.41	Pacific	24	14	C
WPA006	Willapa Bay - Nahcotta Channel	Willapa Bay	Coast	46 32.723	123 58.810	Pacific	24	21	C
WPA007	Willapa Bay - Long Isl., S Jenson Pt	Willapa Bay	Coast	46 27.1893	124 0.5762	Pacific	24	14	C
WPA008	Willapa Bay - Naselle River	Willapa Bay	Coast	46 27.789	123 56.476	Pacific	24	14	C
WPA113	Willapa Bay - Bay Center	Willapa Bay	Coast	46 38.64	123 59.58	Pacific	24	11	C

Table 8. Rotating and seasonal stations for Ecology long-term marine water column monitoring.

Station	Location	Basin	Sampling Region	Latitude NAD83 (deg/dec min)	Longitude NAD83 (deg/dec min)	County	WRIA	Max depth	Designation
BL011	Bellingham Bay - off Nooksack	Strait of Georgia	North Sound	48 43.9897	122 35.0771	Whatcom	01	23	R
BML001	Burley-Minter Lagoon	Southern Basin	South Sound	47 22.6557	122 38.0246	Pierce	15	14	R
BUD002	Budd Inlet - S. End Oly Port	Southern Basin	South Sound	47 3.0891	122 54.375	Thurston	13	12	R
CMB006	Commencement Bay - Mouth of City WW	PS Main Basin	Central Sound	47 15.6892	122 26.2407	Pierce	10	39	R
CSE002	Case Inlet - Off Rocky Point	Southern Basin	South Sound	47 21.189	122 48.875	Mason	14	23	R
DIS001	Discovery Bay - Near Mill Point	Strait of Juan de Fuca	North Sound/San Juans	48 1.0887	122 50.8768	Jefferson	17	42	R
DRA002	Drayton Harbor - Inner Harbor	Strait of Georgia	North Sound	48 58.99	122 45.7772	Whatcom	01	12	R
DUN001	Dungeness Bay	Strait of Juan de Fuca	North Sound/San Juans	48 10.3889	123 6.8773	Clallam	18	19	R
DYE004	Dyes Inlet - NE of Chico Bay	PS Main Basin	Central Sound	47 37.3389	122 41.3754	Kitsap	15	38	R
EAG001	Eagle Harbor - Inner	PS Main Basin	Central Sound	47 37.2891	122 31.3746	Kitsap	15	20	R
EAS001	East Sound - Rosario Point	Strait of Georgia	North Sound	48 38.5728	122 53.0109	San Juan	02	33	R
ELD001	Eld Inlet - Flapjack Point	Southern Basin	South Sound	47 6.3724	122 56.9919	Thurston	13	16	R
ELD002	Eld Inlet - S. Flapjack Point	Southern Basin	South Sound	47 5.7724	122 58.5253	Thurston	13	10	R
FID001	Fidalgo Bay - E. of Anacortes	Strait of Georgia	North Sound	48 30.7562	122 35.7102	Skagit	03	12	R
FRI001	Friday Harbor - San Juan Island	Strait of Georgia	North Sound	48 32.2893	123 0.7774	San Juan	02	19	R
FSH001	Fisherman Bay - Lopez Island	Strait of Georgia	North Sound	48 30.5893	122 55.0773	San Juan	02	5	R
GYS009	Grays Harbor - Moon Island Reach	Grays Harbor	Coast	46 57.872	123 56.977	Grays Harbor	22	15	R
GYS015	Grays Harbor - N. Whitcomb Flats	Grays Harbor	Coast	46 55.372	124 4.610	Grays Harbor	22	15	R
HCB002	Hood Canal - Dabob Bay Pulali Point	Hood Canal Basin	Hood Canal	47 44.7722	122 50.9096	Jefferson	17	50	R
HCB006	Hood Canal - King Spit, Bangor	Hood Canal Basin	Hood Canal	47 44.856	122 43.893	Kitsap	15	76	R
HCB008	Hood Canal - King Spit, Bangor-post9/11	Hood Canal Basin	Hood Canal	47 45.2	122 44.7	Kitsap	15	111	R
HCB009	Hood Canal - Hazel Pt, Bangor	Hood Canal Basin	Hood Canal	47 41.3	122 45.0	Kitsap	15	87	R
HLM001	Holmes Harbor - Honeymoon Bay	Whidbey Basin	Whidbey Basin	48 3.8223	122 31.9925	Island	06	54	R
HND001	Henderson Inlet - Cliff Point	Southern Basin	South Sound	47 9.0724	122 50.0582	Thurston	13	23	R
JDF005	Strait of Juan de Fuca - Sequim Bay	Strait of Juan de Fuca	North Sound/San Juans	48 3.6554	123 1.8605	Clallam	17	39	R
JDF007	Strait of Juan de Fuca - Sequim Bay, Goose Point	Strait of Juan de Fuca	North Sound/San Juans	48 2.9054	123 0.5771	Clallam	17	17	R
LOP001	Lopez Island - Decatur Island	Strait of Georgia	North Sound	48 30.7894	122 51.0773	San Juan	02	15	R
NRR001	Tacoma Narrows - Point Defiance	Southern Basin	South Sound	47 18.9892	122 32.991	Pierce	12	60	R
NSQ001	Nisqually Reach	Southern Basin	South Sound	47 6.7391	122 41.9078	Pierce	15	29	R
PAH003	Port Angeles Harbor - Ediz Hook Head	Strait of Juan de Fuca	North Sound/San Juans	48 8.0887	123 27.6445	Clallam	18	19	R
PAH008	Port Angeles Harbor - Morse Creek	Strait of Juan de Fuca	North Sound/San Juans	47 7.2889	123 21.076	Clallam	18	19	R
PCK001	Pickering Passage - Harstene Island	Southern Basin	South Sound	47 14.9057	122 55.4919	Mason	14	22	R
PGA001	Port Gamble - Inner Harbor	Hood Canal Basin	Hood Canal	47 50.3889	122 34.8754	Kitsap	15	22	R
PMA001	Port Madison - S. of Buoy 65	PS Main Basin	Central Sound	47 44.0891	122 32.0748	Kitsap	15	51	R
PNN001	Penn Cove Park (Whidbey Island)	Whidbey Basin	Whidbey Basin	48 13.8559	122 40.5434	Island	06	31	R
POD006	Port Orchard - Liberty Bay/Virg. Point	PS Main Basin	Central Sound	47 42.889	122 38.0754	Kitsap	15	16	R
POD007	Port Orchard - Inner	PS Main Basin	Central Sound	47 43.989	122 39.0755	Kitsap	15	6	R
PSS008	Possession Sound - PG Bay Pier 3	Whidbey Basin	Whidbey Basin	47 58.889	122 13.4081	Snohomish	07	37	R
PSS010	Possession Sound - Added post-9/11 for TFR	Whidbey Basin	Whidbey Basin	47 57.900	122 15.800	Snohomish	07	99	R
QMH001	Quartermaster Harbor - Burton	PS Main Basin	Central Sound	47 22.7892	122 27.9742	King	15	21	R
QMH002	Quartermaster Harbor - Inner Harbor	PS Main Basin	Central Sound	47 23.7892	122 26.5742	Pierce	10	11	R
SEQ002	Sequim Bay - Northern	Strait of Juan de Fuca	North Sound/San Juans	48 4.5888	123 1.0771	Clallam	17	26	R
SKG001	Skagit Bay - Hope Island	Whidbey Basin	Whidbey Basin	48 23.7394	122 34.91	Island	06	29	R
STL001	Steilacoom - Off Chambers Creek	Southern Basin	South Sound	47 11.0891	122 36.6743	Pierce	15	122	R
SUZ001	Port Susan - Kayak Point	Whidbey Basin	Whidbey Basin	48 8.1058	122 22.2422	Snohomish	05	107	R
TOT001	Totten Inlet - Windy Point	Southern Basin	South Sound	47 9.8557	122 57.8753	Mason	14	31	R
TOT002	Inner Totten Inlet	Southern Basin	South Sound	47 7.289	123 1.2754	Thurston	14	12	R

7.1.2.2 Sampling schedule

Core long-term monitoring stations are visited once a month, year-round, to ensure that all major seasonal hydrographic conditions are observed. Since not all stations can be visited in 1 day, stations are aligned by region and separated into 5 regional surveys a month for the most efficient operations. Regions covered are the Strait of Juan de Fuca (JEMS), Coastal Bays (MF1), San Juans/North Sound/Whidbey Basin (MF2), Admiralty Inlet/Central Sound/Hood Canal (MF3) and Central Sound/South Sound (MF4). Stations are sampled at intervals no less than 3 weeks apart to ensure reasonable adherence to a monthly sampling scheme.

Every year, as rotating stations are added to the sampling plan, station groupings by region may change slightly. A list and maps of the regional sampling (flight) plans will be published in the annual plan as addenda to this QAMP.

7.1.3 Parameters to be determined

Data are collected for salinity, temperature, density, dissolved oxygen, turbidity, light transmission, fluorescence, chlorophyll *a*, pH, PAR, and dissolved nutrient and nutrient ratios. New parameters are added to the sampling program based on advances in monitoring. These may include parameters such as alkalinity, dissolved inorganic carbon, and other measurements related to hydrography, food webs or biogeochemical processes.

Table 9. Parameters to be determined.

Parameter	CTD Sensor	Discrete Water Sample
Ammonium (dissolved)		X
Beam Attenuation	X	
Chlorophyll <i>a</i>		X
Colored dissolved organic matter		
Conductivity	X	
Density	X	
Dissolved Oxygen	X	X
Dissolved Oxygen-Saturation	X	
Fluorescence	X	
Light Transmission	X	
Nitrate (dissolved)		X
Nitrite (dissolved)		X
N:P ratio		X
Ortho-Phosphate (dissolved)		X
pH	X	
Pheopigments		X
Photosynthetically-Active Radiation (PAR)	X	
Salinity	X	X
Secchi Depth		X
Silicate (SiOH ₄) (dissolved)		X
Si:N ratio		X
Si:P ratio		X
Temperature, water	X	
Turbidity	X	

7.2 Maps or diagram

Figure 3. Map of core sampling sites.



7.3 Assumptions underlying design

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

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

7.3.1 Changes to the sampling process design

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

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

7.4 Relation to objectives and site characteristics

Monthly sampling of multiple sites throughout Puget Sound basins and coastal bays assures that seasonal and spatial variability are well characterized for marine water quality parameters. However, due to limitations on resources and schedule, the profiling program is limited in its ability to spatially characterize sub-regions such as very small inlets and bays and nearshore waters. Also, due to constraints of the instrument package configuration, the very surface layer (less than 0.5m depth) of the marine water column is not adequately measured. However, water sources can be identified using salinity and temperature which can tie to different influences such as the Pacific Ocean and rivers. Tables 7 and 8 list the basins and region that each station represents.

As discussed in previous sections, we may choose rotating stations to monitor every year in addition to core stations to assess different water bodies, supplement existing data or identify new water quality issues, based on data needs, resource availability, and program objectives.

7.5 Characteristics of existing data

Since the program has been in place since 1973, a suite of basic information exists since that time. As the monitoring program has evolved and data gaps were identified, the number of variables measured and amount of data has significantly increased. The data set is now recognized by the broader, regional scientific community as a high-quality primary data set for understanding Washington's marine water quality.

From 1973 to 1989, grab samples were collected for temperature, salinity, dissolved oxygen, pH and total nitrogen, total phosphorus, and total ammonia. In 1989, sensor profiles to 100 meters depth were incorporated. In addition to existing variables, light transmission was added along with grab samples for chlorophyll *a*. In 2001, more sensors were added and continue to be added. This plan includes the list of variables collected since 1999. These are shown in Table 9.

Water column data collected from Puget Sound, the Strait of Juan de Fuca, and coastal bays exhibit broad variability, both on temporal and spatial scales. Physical variables such as salinity and temperature vary seasonally with ocean and freshwater inputs, while biochemical and optical variables exhibit variability with seasonal processes such as algae growth, organic matter cycling, sedimentation, and other inputs from terrestrial processes and with water column depth.

Salinity in Puget Sound and the coastal bays is dominantly driven by the Pacific Ocean, freshwater inputs, and on a lesser scale by evaporation and precipitation. Sites closer to the Pacific Ocean exhibit higher salinities at depth. Sites close to rivers have lower surface salinities. Freshwater inputs via rivers occur in 2 dominant seasons, depending on the type of precipitation. Rain-fed river discharge is typically high during the rainiest season of the year, winter-spring. Snow-fed river discharge is highest during the summer, as warmer temperatures melt mountain snowpack. In areas close to rain-fed rivers, surface salinity is lower during the winter, whereas at sites close to snow-fed rivers, surface salinity can be impacted in the summer. Salinity ranges from close to 0 PSU at the very surface at sites within river plume influence to 33-34 PSU at sites near the Pacific Ocean at depth for sites in the Strait of Juan de Fuca.

Temperature in Puget Sound is characterized by two patterns. In small, shallow bays and inlets that have limited vertical mixing, temperature shows high seasonal variation: high temperatures in summer and low temperatures in winter. In these areas, the ambient atmospheric temperature has more influence on sea-surface temperature. On the other hand, temperatures in deep basins are cooler, show less seasonal variation, and generally follow the oceanic water temperature. This is because cold, oceanic waters are mixed into the surface water by turbulent tidal mixing. Temperatures are more uniform throughout the water column in the winter, and more variable during the summer when cold, upwelled ocean water can intrude into Puget Sound and solar radiation heats surface waters in shallow, quiescent bays. Typical winter temperatures range from 7-9°C in the Salish Sea to 5-9°C in the coastal bays. Summertime temperatures range from 10-14°C in the Salish Sea to 12-17°C in the coastal bays, with surface values as high as 21°C routinely seen in shallow, closed bays during the late summer.

Dissolved oxygen levels are influenced by (1) inputs of low DO water from the Pacific Ocean, inputs of ventilated water from rivers and land-based sources, (2) biological productivity which increases surface concentrations during the spring and summer, and (3) respiration which decreases concentrations at depth as organic matter is consumed. In closed, quiescent embayments and inlets such as southern Hood Canal, density stratification of the water column and reduced circulation can prevent renewal of bottom water oxygen for long periods of time. This leads to very low DO levels. Typical DO concentrations range from less than 1.00 mg/L (in Hood Canal) up to 15.00 mg/L. Higher concentrations may be observed in surface waters during episodes of high algae growth or plankton blooms.

Nutrient ranges reflect inputs of high nutrient water from the Pacific Ocean, inputs from freshwater and land-based sources, and biological activity that could deplete surface concentrations in the summer or processes that remineralize organic matter at depth. Nitrate + nitrite concentrations in the winter are at 10-36 μM and in the summer may dip to 1-5 μM , coincident with episodes of algae blooms or with pulses of freshwater inputs (Mackas, 1997). Phosphate concentrations typically fall in the range of 0-3 μM , with coastal stations exhibiting concentrations typically <1 μM . Typical ammonium concentrations are within 0-5 μM , with episodic higher concentrations (>5 μM) corresponding to the die-off of plankton blooms or plumes from local wastewater treatment plant discharges. The geological substrate found in the Salish Sea region includes high quantities of silicate; therefore, levels in Puget Sound and the coastal bays can be high, especially near river inputs. Values in Puget Sound are typically within 20-100 μM , with episodic lows coinciding with plankton (diatom) blooms in the summer. At sites near rivers, values can be as high as 200 μM .

8.0 Sampling Procedures

8.1 Field measurement and field sampling SOPs

Seawater sampling methods are described in Bos (2010a), Standard Operating Procedure for Seawater Sampling and are derived from standard international oceanographic sampling methods published by UNESCO, 1994.

www.ecy.wa.gov/programs/eap/ga/docs/ECY_EAP_SOP_SeawaterSampling_v_2_0EAP025.pdf.

These protocols adhere to the most current seawater sampling methods (Grasshoff, 1999) and to PSEP's recommended protocols for measuring conventional water column variables in Puget Sound (PSEP, 1990). These protocols are followed during all Puget Sound water column sampling efforts. This will ensure consistency with other programs in Puget Sound. If deviations from the protocols occur, a brief explanation is given in the annual plan that will be published in the future as annual addendums to this plan. A brief summary of field sample collection methods are summarized in Table 10.

Required field equipment for marine flight or vessel surveys is listed in Appendix D., Table D.6. This list serves as a checklist prior to the surveys and is modified as sampling methods change.

Table 10. Field sample collection methods for ambient water column monitoring.

Sample Parameter	Collection Method or Sensor	Sample Container	Preservation Method	Holding Time
Alkalinity and Dissolved Inorganic Carbon (DIC)	UNESCO, 1994 (JGOFS Protocols)	500 mL pre-combusted, acid-washed, borosilicate glass, stoppered volumetric flasks	Preserve sample with 100 µL super-saturated HgCl ₂ . Apply Apiezon® L grease to stopper, insert and twist to remove all air. Store in cool, dark conditions.	3 months
Chlorophyll <i>a</i>	UNESCO, 1994 (JGOFS Protocols)	125 mL clean brown polyethylene bottles	Store on ice. Filter immediately upon arrival at lab. Filter stored frozen in 90% acetone.	1 month
Dissolved Nutrients	UNESCO, 1994 (JGOFS Protocols)	125 ml clear acid-washed plastic bottles	Store on ice. Filter immediately upon collection. Filtrate frozen.	3 months
Dissolved Oxygen	UNESCO, 1994 (JGOFS Protocols) *1st sample collected	130 mL clean, dry borosilicate glass stoppered volumetric flasks	Fix with MnCl ₂ & NaOH-NaI azide reagents. Stopper and shake. Store in cold, dark conditions. Upon arrival at lab, shake again and apply DI cap.	5 days
Salinity	UNESCO, 1994 (JGOFS Protocols)	250 mL brown equilibrated polyethylene bottles	Keep in a well sealed container.	6 months
Secchi Disk Depth	Lower in water until disk disappears, then bring up until it reappears. Record reading.	NA	NA	NA
CTD Parameters				
Conductivity	Sea-Bird Electronics SBE4	NA	Internally Recorded	NA
Temperature	Sea-Bird Electronics SBE3	NA	Internally Recorded	NA
pH	Sea-Bird Electronics SBE18	NA	Internally Recorded	NA
Dissolved Oxygen	Sea-Bird Electronics SBE43	NA	Internally Recorded	NA
Light Transmissivity	WET Labs C-Star	NA	Internally Recorded	NA
Pressure	Sea-Bird Electronics SBE29	NA	Internally Recorded	NA
Fluorescence	WET Labs ECOFLNTU	NA	Internally Recorded	NA
Turbidity	WET Labs ECOFLNTU	NA	Internally Recorded	NA
Photosynthetically Active Radiation (PAR)	Biospherical QSP-2200	NA	Internally Recorded	NA

*Not currently collected

8.1.1 CTD data collection

Figure 4. Sea-Bird Electronics, Inc., Conductivity, Temperature, Depth (CTD) instruments and other sensors in a custom-made frame.



A Sea-Bird Electronics profiling CTD is used for measuring hydrographic conditions at each monitoring station (Figure 5). The base unit measures conductivity and temperature with depth. The CTD has also been interfaced with sensors that measure dissolved oxygen, pH, in vivo chlorophyll fluorescence, turbidity, photosynthetically active radiation (PAR) and light transmission. Specific sensors used for measuring each parameter are listed in Table 10.

A CTD cast is conducted at each monitoring station. Each time the CTD is turned on, data is recorded internally (minimum sampling rate is eight scans per second). This cast is assigned a cast number and time. For each cast, the station name, cast number, and cast start time are recorded in the field log (Figure 6). This information is needed for CTD data processing. Additional comments are recorded in the log to provide any ancillary information about instrument operations, the purpose or condition of the station and cast—such as a duplicate cast—or to note any problems that may affect the CTD data.

The sensors on the CTD are equilibrated with in-situ conditions. The CTD is turned on, lowered into the water until the entire unit is submerged, and held stationary for 1 minute. This time is needed for the sensors to equilibrate with the environment, although the sensor response is generally within seconds of turning on the instrument. The CTD is then lowered to 1-2 meters

above the bottom at a rate no faster than 0.5 m/sec., held near the bottom for 2 minutes, raised to the surface and turned off.

The CTD used during this program has a pump attached to give the conductivity and dissolved oxygen sensors a continuous flush of sample water. The advantages to lowering the CTD at this rate are:

- The sensors have time to respond to changes in the water column more accurately.
- The resultant water column hydrographic structure will have higher resolution, especially in the upper layers where steep gradients may exist.
- Measurement errors due to rapid sampling and steep parameter gradients such as rapid changes in temperature are reduced.

Water samples to verify CTD sensor performance are collected on every survey, as discussed in the *Quality Control Section*. Samples such as salinity, chlorophyll *a*, and DO are collected to represent the range of water characteristics sampled in a given survey. Water sample collection is discussed in the next section.

Principles of CTD and sensor operations are described in manufacturer operating manuals, referenced in Appendix E. 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.

8.1.2 Water sample collection

At each station, water samples are collected for nutrients and chlorophyll *a*. Dissolved oxygen and salinity samples are collected at a select number of stations for verification of correct CTD sensor operation. Nutrient, chlorophyll *a*, salinity and dissolved oxygen water samples are collected using 1.2 liter Niskin™ water bottles, attached to a rosette. The bottle lids are fixed in an open position on both ends while lowered, and at desired depths, the rosette arms are triggered to release the lids, closing the bottles at pre-determined depths. More detailed information on water sample collection can be found in Tables 6 and 10.

8.1.3 Field observations and weather and conditions

Photos are taken during each flight or survey to record observations and events. These photos are used to document each sampling event and to create reports, procedures, and other documents. Technicians also make observations useful for interpreting data and related water conditions. These observations include:

- Secchi disk depth.
- Water color.
- Debris.
- Sightings of fronts, eddies and other surface current features.
- Plankton blooms and presence of algal mats.
- Waves and wave height.

A Secchi disk is used to measure light attenuation in the photosynthetically active region of the water column (euphotic zone).

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

- Wind speed and direction.
- Cloud cover (%) and cloud type.
- Presence of direct sunlight.
- General weather condition (overcast, cool, rainy, foggy, sunny, warm).
- Recent past weather conditions.

These data are captured in field logs and transferred to the data management system along with other field information, as described in the Data Management Procedures Section.

8.2 Containers, preservation methods, holding times

Information on containers, preservation methods and holding times can be found in Table 10.

8.3 Invasive species evaluation

We use a floatplane and dedicated boat kept at a saltwater marina, with little to no opportunity for contact with invasive species. Therefore, we have low risk of transporting invasive species from one water body to another. Marine waters monitoring staff make every effort to minimize the spread of aquatic organisms by following protocols set in Standard Operating Procedures to Minimize the Spread of Invasive Species, Ecology's SOP No. EAP070. This document is at [Ecology QA Website](#).

8.4 Equipment decontamination

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

8.5 Sample ID

All collected water samples are labeled with station, depth, and sample identification numbers based on bottle numbers, and these are recorded in the field log. Each sample is automatically given a unique identification number once loaded to the database. This number is transferred to analyses logs (for internal lab samples) or chain of custody forms sent to external labs. All sample bottles are reconciled against forms to verify completeness as samples move through the analytical process, described in the *Quality Control* section of this QAMP.

8.6 Chain-of-custody, if required

During sample collection, a chain of custody form is generated for samples, based on field logs. Chain of custody logs are delivered to the lab with the corresponding samples for management of sample counts, scheduling, and tracking analysis. Once the samples are delivered, lab personnel log in each sample and assign a lab number to each, using the sample label number and date. Each laboratory sample number must correspond to a particular date, station, and depth. Examples of chain of custody logs sent to each laboratory are included in Appendix D.

When data results are received from labs, 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.

8.6.1 Lab Notification

When samples are ready for delivery, external laboratories are contacted to schedule delivery. Advance notice is given so that transfer is successful and samples are kept in optimal storage conditions at all times during transport and transfer.

8.7 Field log requirements

Most of the parameters measured in the water column are either recorded internally within the CTD's data logger or collected as water samples and analyzed at the laboratory. Information on CTD casts and water samples are recorded in a digital field log. Information such as station ID, secchi depth, date, time, weather, and environmental conditions, field observations, tidal stage and height, samples collected, sample bottle numbers, QC sample identities, latitude and longitude of the station, technician names, comments, and CTD cast information are digitally recorded in the field log form (Figure 5 and Appendix D, Figure 1). The field log form also includes CTD information for data processing such as cast start time, file names, replicate cast number, instrument information and survey ID. In addition, any changes or deviations from the sampling plan or unusual circumstances that might affect interpretation of results are recorded.

Collection data sheets are also generated on each survey to record collected samples to be sent to the lab (Appendix D, Figure 2). A paper log is brought along on every survey to use as a backup if the electronic form or device should fail. Digital copies of the field and sample logs are stored for future reference on a shared, secure, frequently backed up network server. Photos are taken during each flight or survey to record observations and events. These photos are used to document each sampling event and for the creation of reports, procedures and other documents. Examples of field log forms and sample logs are included in Appendix D.

Figure 5. Field log documentation using a portable tablet.



Field notebooks created specifically for each flight or sampling survey are used on every event as a reference tool for technicians. Documents included in the field notebook are backup paper logs, maps, checklists, station and sampling plans, various SOPs and technical notes, a weather dictionary, and safety and contact information (Appendix D). The field notebook contains all the resources needed for a field survey, including pre-and post-field procedures.

8.8 Other activities and information

8.8.1 Sampling vessel

Long-term station monitoring is conducted by floatplane or research vessels, such as Ecology's boat, R/V Skookum, (primarily used for backup operations). Using a floatplane for sampling allows coverage of a large geographic area in a short period of time. Surveys are conducted from a DeHavilland Beaver floatplane that can accommodate the sampling gear, pilot, technician and an assistant/observer. Samples are collected using a portable winch to lower and retrieve instruments and water sampling equipment through a floor-mounted observation hatch in the rear of the passenger compartment. These surveys are referred to as marine flight surveys. Sampling from a vessel allows for sampling of a smaller geographic area and can accommodate the boat operator and up to three technicians, assistants, or observers. Samples are collected using a winch attached to the vessel to lower and retrieve instruments and water sampling equipment.

8.8.2 Navigation

A GPS navigation system is used to position the aircraft or boat. Each station is located at specific latitude and longitude coordinates. The GPS allows for sampling on these coordinates and enables stations to be re-occupied to within approximately ± 500 meters. This is the recommended procedure found in the original PSEP protocols and is the preferred method of navigation for the long-term monitoring component. Due to the risky nature of sampling on open water, the vessel operator is responsible for understanding navigation markers and hazards. However, all technicians are required to be familiar with navigational markers, signs, safety, and

communication protocols. Detailed navigational protocols and operational theory of GPS can be found in PSEP, 1998.

8.8.3 Scientific party

A crew of two (the floatplane pilot or certified boat operator and a trained technician) are required to conduct a marine flight or research vessel survey. The vessel operator must be trained in boat operation, maintenance, and safety procedures before conducting surveys. The technician is responsible for following pre-and post-survey procedures (Appendices D and E), correctly operating all instruments and equipment during sampling, processing and checking data, transferring field data to data storage, and complying with safety procedures. A second technician or volunteer, if along, will assist the lead technician with loading, sample bottle tracking, field logs, taking photos, and making observations.

8.8.3 Personnel responsibilities

The PI or crew leader for each survey conducted during this program is the designated safety officer for that survey. The safety officer will have the following responsibilities:

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

The pilot during marine flight surveys and boat operators during cruises are authorized to cancel a survey, should conditions warrant.

Technicians are required to read and follow all appropriate guidelines in the EAP Field Operations Safety Manual for Specialized Work - Marine Flights section and all other applicable sections of this manual (Appendix E). Required safety notifications and plans are generated for every sampling survey, according to protocols in the EAP Safety Manual. (Appendix E).

Technicians are also required to read and follow Ecology's Chemical Hygiene Plan.

8.9 Safety Protocols

Collecting water samples aboard a floatplane or research vessel poses many potential safety hazards to the field crew, including adverse flying conditions, falling overboard, handling heavy gear, being struck by heavy equipment, coming into contact with hazardous materials (NaI/NaOH-azide), fatigue, and exposure to extreme temperatures and sunlight. To ensure their safety, all crew members are required to wear the following safety gear at all times while collecting samples:

- Standard U.S. Coast Guard-approved personal flotation device (PFD).

- Appropriate footwear.
- Protective gloves.
- Temperature-appropriate clothing.
- Sunscreen.

All equipment is secured prior to transit or take-off at each station. A corrosive chemical is used during the water column task. This chemical is alkaline (NaOH-NaI-azide) and is used for dissolved oxygen sample preservation. It is stored in secondary containment at all times. Materials for managing spills are brought along. All samples fixed with this reagent are stored in a secured container.

The pilot and the field staff will communicate before initiating a marine flight. Weather conditions, personal health, and other considerations are taken into account. For instance, on windy days when there may be considerable wind waves, swell or vessel drift, a survey may be postponed. These factors must be considered prior to sampling. As a general rule, if it is expected that out of ten stations, more than three will be missed, the survey is postponed until the following day.

Marine flights will last about eight hours. One break is taken mid-day, unless it is unfeasible due to time or location constraints. Marine flights will not be conducted under adverse flying conditions (fog, storms) and must abide by all visible flight regulations (VFR).

Foul weather gear should always be available, in case conditions change. All crew members are responsible for their own clothing and gear. First aid kits are available on all vessels.

8.9.1 Safety Equipment and Emergency Procedures

Safety equipment includes:

- Inflatable PFDs (for marine flights).
- Standard Coast Guard-approved PFDs and survival suits (for research voyages).
- Ship-to-shore (VHF) radio.
- First aid kit.
- Fire extinguisher.
- List of emergency frequencies and phone numbers.

Emergency procedures require the field staff to have current CPR training and knowledge of agency procedures for emergencies (Ecology, 2012).

8.9.2 Emergency Contacts

All personnel are familiar with the emergency contact list that is carried in the field during every survey. The list includes VHF radio frequencies for offshore emergencies and a list of on-shore facilities (Appendix D). This list will serve as the field emergency contact list.

9.0 Measurement Methods

9.1 Field procedures table/field analysis table

As discussed in the *Sampling Procedures* section, MMU staff make marine water column measurements, using various combinations of sensors from Sea-Bird Electronics, Inc. and WET Labs, Inc. Manufacturer specifications and model numbers for the instruments and associated sensors are shown in Table 11.

Table 11. Instrument measurement methods, expected range of results, lowest values.

Measurement - Field	Manufacturer (Model Number)	Mfg Method	Expected Range of Results	Lowest Value
Chlorophyll Fluorescence	WET Labs, Inc. (ECOFLNTU)	Flat-face optical sensor, 700 nm wavelength	0 - 50 µg/l	0.1 µg/l Chl
Conductivity	Sea-Bird Electronics (SBE4)	Cylindrical, flow-through, borosilicate glass cell with 3 internal platinum electrodes, Wein bridge	0.02 - 35.00 PSU	0.0001 PSU
Density	<i>dependant on T,C</i>	<i>dependant on T,C</i>	0.00 - 26.00 s _t	0.1 s _t
Dissolved Oxygen	Sea-Bird Electronics (SBE43)	Clark cell polarographic electrode with platinum membrane	0.00 - 15.00 mg/L	0.05 mg/L
Light Transmission	WET Labs, Inc. (C-Star)	Photoelectric beam transmission sensor; wavelength 650 nm; pathlength 25 cm	0 - 100%	0.01%
PAR (Photosynthetically Active Radiation)	Biospherical Instruments, Inc. (QSP-2200)	PAR sensor with silicon photovoltaic detector measuring quantum response in 400-700 nm spectrum	1 - 4000 µmol/m ² ·sec	1 µmol/m ² ·sec
pH	Sea-Bird Electronics (SBE18)	Pressure-balanced glass-electrode with Ag/AgCl reference	6.0 - 9.0 pH	0.1 pH
Pressure	Sea-Bird Electronics (SBE29)	GE Druck strain-gauge pressure sensor	0.00 - 220.00 db	0.1 db
Temperature	Sea-Bird Electronics (SBE3)	Pressure-protected thermistor	3.00 - 25.00 °C	0.01 °C
Turbidity	WET Labs, Inc. (ECOFLNTU)	Optical scattering sensor, flat-face; wavelength 700 nm	0.00 - 25.00 NTU	0.1 NTU

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

9.2 Lab procedures table.

Nutrient and salinity samples are analyzed at University of Washington's Marine Chemistry Laboratory in Seattle, Washington using various analytical methods described in Table 12. Dissolved oxygen and chlorophyll *a* samples are analyzed at Ecology's Marine Laboratory using analytical methods described in Table 12. Information and references for specific analytical procedures are provided in Appendix E. QA/QC protocols are discussed in the *Quality Control* section of this plan. More details on laboratory procedures are described in the Manchester Laboratory User's Manual (Ecology, 2008), recommended PSEP protocols (PSEP, 1990), and the SOP Marine Waters Data Quality Assurance and Quality Control, Bos (2014a). Program QA/QC objectives and procedures are briefly described in the QA section of this report.

Table 12. Lab measurement methods, expected range of results and reporting limits for marine data.

Measurement - Lab Analyte	Lab	Analytical Method	Expected Range of Results	Reporting Limit
*Alkalinity				
*Dissolved Inorganic Carbon				
Dissolved oxygen	ML	Carpenter, 1966	0.00 - 15.00 mg/L	0.01 mg/L
Marine Nitrate	MCL	Armstrong et al., 1967	0.00 - 40.00 μ M	0.15 μ M
Marine Nitrite	MCL	Armstrong et al., 1967	0.00 - 2.00 μ M	0.01 μ M
Marine Ammonium	MCL	Slawyk and MacIsaac, 1972	0.00 - 10.00 μ M	0.05 μ M
Marine Orthophosphate	MCL	Bernhardt & Wilhelms, 1967	0.00 - 4.00 μ M	0.02 μ M
Marine Silicate	MCL	Armstrong et al., 1967	0.00 - 200.00 μ M	0.21 μ M
Chlorophyll <i>a</i>	ML	EPA, 1997	0.00 - 60.00 μ g/L	0.01 mg/L
Salinity	MCL	Grasshoff et al., 1999	0.00 - 36.00 PSU	0.01 PSU

ML - Ecology's Marine Laboratory

MCL - UW's Marine Chemistry Laboratory

MEL - Ecology's Manchester Environmental Laboratory

9.2.1 Analyte

Analytes are listed in Table 12.

9.2.2 Matrix

All samples collected are in a seawater matrix.

9.2.3 Number of samples

The number of samples collected per sampling event depends on sites sampled per survey, the depth of each site, and the quality control samples collected. Each year, these could change

slightly, depending on core and rotational stations added to the regional sampling plans. During annual planning, a table is generated with these details. An example of this table is included in Appendix D, Table 4.

9.2.4 Expected range of results

Expected ranges for analytical results are listed in Table 12.

9.2.5 Analytical method

Analytical methods are listed in Table 12.

9.2.6 Sensitivity/Method Detection Limit (MDL)

Sensitivity is reported as “Reporting Limit” in Table 12.

9.3 Sample preparation method(s)

Sample preparation methods are listed in standard operating procedures for lab analyses or in analytical methods. For analytes determined by Ecology’s Marine Lab, the following SOPs are employed:

- EAP026 Standard Operating Procedure for Chlorophyll *a* Analysis
- EAP027 Standard Operating Procedure for Seawater Dissolved Oxygen Analysis
- EAP028 Standard Operating Procedure for Reagent Preparation

For analytes determined by the UW Marine Chemistry Lab, methods used for sample preparation are listed in Table 12 and can also be found in Grasshoff (1999).

9.4 Lab(s) accredited for method(s)

Ecology’s Marine Lab and UW’s Marine Chemistry Lab are accredited for specific analytes assigned to each lab in Table 12.

10.0 Quality Control (QC) Procedures

High data quality is mandatory for Ecology's Long-Term Monitoring Program and ensures that trends accurately reflect true environmental change. We routinely perform data quality assurance (QA), data quality controls (QC), and data group reviews to ensure that our data meet highest quality standards. Data quality codes are applied to the data set, allowing users to decide the appropriate level of quality for specific analyses.

The ongoing effort to provide high quality data occurs in many steps before, during, and after data collection. QA/QC procedures include the following activities:

- Meeting QA/QC objectives.
- Training personnel.
- Calibrating equipment and maintaining equipment.
- Conducting repetitive sensor performance assessment or verification.
- Analytical laboratory and field data QA/QC procedures.
- Performing proper sample custody.
- Performing proper data and information management.
- Verifying and validating data through routine data review.
- Assessing data usability (method).
- Conducting audits.

The first six activities are discussed at length in this section of the plan. Data management is discussed in the next section. The last three are discussed in later sections.

This plan is conducted using any current and available oceanographic data QA/QC standards. Yet the current practices and technologies for oceanographic sampling and marine monitoring continue to evolve. Different types of data (sensor, discrete laboratory sample analyses, field observations) require unique data QC techniques. As technology changes, steps in the QC process change also. Therefore, the current routines used for QA/QC activities for data review and assessment are published and updated every 3 years in a standard operating procedure (SOP). Specific routines and information for marine water column data quality control procedures can be found in Ecology's SOP No. EAP088 *Standard Operating Procedure for Marine Waters Data Quality Assurance and Quality Control*, Bos, 2015.

10.1 Meeting data and measurement quality 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. (US IOOS, 2012) For this reason, the MWM group has implemented multiple levels of QA to test performance and operation of sensors before, during, and after deployment. The MWM group engages in routine, frequent quality assessments to determine if measurement procedures are functioning as expected and generating high quality data. Technicians routinely collect a variety of quality control samples and conduct a variety of evaluations to test whether quality objectives are being met in the field and in the lab.

10.1.1 Tables of field and lab QC required

Tables 13 and 14 identify quality objectives for marine waters data and steps taken to meet these objectives. Tables 15 and 17 include types and numbers of QC samples collected for each

sampling survey. The Ecology QA Glossary included in Appendix F contains definitions of the various types of QC samples, including:

- Blanks, both lab and field
- Duplicates, both lab and field
- “Standards” or Standard Reference Materials (SRM)
- Lab Control Samples (LCS)
- “Blind” SRMs submitted to the laboratory

Table 13. A summary of quality control steps for field measurements.

Field Measurement	Precision (relative standard deviation, %RSD)	Accuracy (% from true value)	Manufacturer Calibration Report Reviewed	Pre-deployment Performance Assessment via lab seawater bath	In Field Performance Assessment	Preliminary Processing and Flagging of Raw Data	Graphical and Statistical Data Review and Flagging	Adjustment Based Performance Assessments	Annual Review and Final Data Assessments
Conductivity	10%	5%	✓	✓	✓	✓	✓		✓
Density	10%	5%	✓	✓	✓	✓	✓		✓
Dissolved Oxygen	5%	5%	✓	✓	✓	✓	✓	✓	✓
Fluorescence	10%	5%	✓		✓	✓	✓	✓	✓
Light Transmission	10%	5%	✓	✓	✓	✓	✓	□	✓
PAR	5%	5%	✓	□	✓	✓	□		✓
pH	10%	10%	✓	✓	✓	✓	✓	□	✓
Pressure	5%	1%	✓	✓	✓	✓	✓		✓
Salinity	10%	5%	✓	✓	✓	✓	✓		✓
Temperature	1%	1%	✓	✓	✓	✓	✓		✓
Turbidity	10%	5%	✓	□	✓	✓	□		✓

Table 14. A summary of quality control steps for lab measurements.

Lab Measurement	Precision (relative standard deviation, %RSD)	Accuracy (% from true value)	Instrument Control Check Using Blanks	Laboratory Standards Check	Laboratory Control Samples	Replicate Analysis	Method Detection Limits Check	Preliminary Review and Flagging of Raw Data	Graphical and Statistical Data Review and Flagging	Annual Review Assessments
Chlorophyll <i>a</i>	10%	NA	✓	✓		✓	✓	✓	✓	✓
Dissolved Oxygen	5%	NA	✓	✓	□	✓	✓	✓	✓	✓
Nitrate	10%	5%	✓	✓	✓	✓	✓	✓	✓	✓
Nitrite	10%	5%	✓	✓	✓	✓	✓	✓	✓	✓
Ammonium	10%	5%	✓	✓	✓	✓	✓	✓	✓	✓
Ortho-phosphate	10%	5%	✓	✓	✓	✓	✓	✓	✓	✓
Silicate	5%	5%	✓	✓	✓	✓	✓	✓	✓	✓
Salinity	10%	5%	✓	✓	□	✓	✓	✓	□	✓

All QC samples will have MQOs (evaluation criteria) associated with them. These are described in Section 6.2. These criteria must be met to obtain fully usable data.

Following quality assessment, all data are given a quality description (QC code) and released for public use or removed from the data set. A quality flag is given to each data point in order to communicate any specific reason for the QC code. Also, quality assessment allows the marine waters group to describe and quantify the accuracy and expected error associated with all marine data generated via lab analysis or through sensor operation. At various stages of assessment, data are given a QA level description to denote the status of data in the QC and review process. Descriptions of all QC codes, flags, and level of assessment can be found in the SOP “Marine Waters Data Quality Assurance and Quality Control” (Bos, 2015).

Tables 4 and 5 list criteria for quality objectives specified for marine water column variables, including precision, accuracy, and reporting limits. The basic premise of analytical procedures used to test these objectives are discussed in the next sections. More specific details on QA/QC procedures are in Ecology’s SOP No. 088, *Standard Operating Procedure for Marine Waters Data Quality Assurance and Quality Control*, (Bos, 2015). The tests performed for these assessments may change with advancing technology in sensor or laboratory methods. Thus, an SOP on conducting quality assessment of long-term marine water column data is updated every 3 years.

The overall QA/QC objectives may change, depending on the monitoring plan, study design, or advancing technology in sensor or laboratory methods. Any changes are noted in annual updates to be published as an addendum to this plan.

10.2 Training of personnel

All personnel who conduct any field activities receive training on CTD use and calibration, sample handling, program QA/QC, and safety. Each staff person is required to be familiar with this QAMP and field procedures described in SOPs. All staff are given demonstrations of field procedures before they perform field activities. An experienced senior technician accompanies trainees on their first few field trips, to verify that procedures are understood and followed. Ecology requires sampler certification. A training checklist is used to guide and certify the training of technicians, ensuring proficiency in all data collection and field and laboratory procedures. When revisions in procedures are made, staff are informed and the training checklist is updated to assure compliance with program procedures. Ecology management approves the final certification of MWM technicians for various procedures.

Periodic field audits are conducted by the monitoring coordinator or senior staff to ensure consistent sampling performance by staff. Cross-checks between technicians occur frequently for both field and lab procedures. Results from these checks are discussed with the team and appropriate updates or changes are implemented.

An annual field and lab review is required for all staff. Safety and procedures are discussed and reviewed to check methods and implement changes and improvements.

10.3 Instrument calibration

The primary instrument used for Marine Water Column Monitoring is a Sea-Bird Electronics CTD package. The CTD is a system composed of multiple specialized sensors that will give accurate and precise results when properly calibrated and maintained. Maintenance and calibration procedures are fully described in various operating manuals and application notes for the specific sensors used. A full list of sensors is included in Table 10. References for specific manuals and application notes for each sensor are included in Appendix E.

High quality, controlled manufacturer calibrations help 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. A list of all manuals and application notes relevant to the marine water column program is found in Appendix E. Calibrations are performed at the factory for all sensors on an annual basis, with servicing and repairs occurring as needed. With each calibration, the manufacturer generates a new set of calibration coefficients. 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. The most recent calibration coefficients are applied to the data during processing prior to storage in the database.

The CTD unit is calibrated according to the schedule in Table 15. In addition, certain sensors are validated more frequently. The calibration and maintenance schedule also helps track age and behavior of sensors over each instrument's operational lifetime. If performance checks and data review indicate that instrument performance may be compromised from original factory state, the problem is investigated and resolved, and instruments are returned to the manufacturer for diagnostics and repair, as needed.

All calibration/validation data are recorded in separate sensor forms (Appendix D) and archived in the data management file system. Calibration and sensor performance verification results are maintained in the database.

Table 15. CTD calibration and maintenance schedule.

Sensor	In-House Calibration or Performance Check	Annual Factory Calibrations
Conductivity ³	X	X
Temperature		X
Pressure		X
Dissolved Oxygen ^{2,3}	X	X
pH ^{1,4}	X	X
Transmissometer ¹	X	X
Fluorescence ³	X	X
Turbidity		X
Photosynthetically Active Radiation (PAR)		X

¹ Bi-monthly calibration.

² Monthly performance check via lab bath.

³ Performance check using in-situ samples.

⁴ During factory calibrations, pH sensor is checked for internal electrolyte and electrical connections. Probe to be replaced annually.

10.4 Field QC

CTD QA/QC procedures

Pre-survey performance tests of instruments are conducted and compared to expected value ranges determined by constant, sensor-specific performance testing and to published specifications. Technicians test instrument packages under controlled conditions prior to any field survey to ensure proper operations. Technicians take sensor performance readings (voltage and frequency readings) during flights and boat surveys, before and after every sensor deployment (cast) to ensure reasonable operation of all sensors. Examples of typical readings are shown in Table 16. These measurements are reviewed and compared to the range (between 5th and 95th percentiles) of all good test results for each sensor. If a sensor malfunctions, the

problem is immediately recognized through the use of these sensor performance readings. If a problem is detected and verified in the field using plotting tools, then data collection is suspended. Once the problem is resolved and the sensor repaired or replaced, data collection can resume.

Table 16. Raw CTD voltage readings from one month used as a coarse QA in the field prior to every cast.

The pH sensor is soaked in pH 8 buffer for reading. No other sensors are controlled using standard reference materials for this test.

Voltage Channel	1	2	3	4	5	6	7	8	9	10
Voltage Description	CTD Alkaline Batteries/ 5.0161	CTD Lithium Battery/ 3.873	Pressure	Pressure Temperature	Dissolved Oxygen	pH	Transmission	Fluorescence	Turbidity	Photo-synthetically Active Radiation
Sensor SN	2538854-0381	2538854-0381	290559	290559	430049	180530	CST-850PR	FLNTURT-299	FLNTURT-299	20351
Month	March-2013	March-2013	March-2013	March-2013	March-2013	March-2013	March-2013	March-2013	March-2013	March-2013
Count	772	772	772	772	772	772	772	772	722	722
Average	2.406	1.317	4.408	1.452	2.981	2.909	2.948	0.091	0.375	2.789
Min	2.166	1.278	4.399	1.269	2.267	2.128	0.337	0.055	0.243	1.645
Max	2.649	1.364	4.422	1.567	3.295	2.987	4.598	0.18	0.603	3.423

Pressure sensor measurements determine the daily atmospheric pressure offset. Pressure offsets are determined by recording pressure values before lowering and after raising the CTD in water. This offset is used to process during data processing to generate the most accurate readings of in-water pressure.

The remaining sensors are checked using standard procedures during laboratory and factory calibrations as recommended by the manufacturer.

10.4.1 CTD comparison samples

Independent samples for CTD comparison are collected in the field and are used to indicate possible sensor malfunction or drift. Verification samples for salinity measurements and reference samples for dissolved oxygen and chlorophyll *a* fluorescence are collected during each marine flight or survey to compare with sensor values and verify CTD sensor performance. Reference samples are also used to adjust data as appropriate, according to methods documented in Ecology SOP No. 088.

Water samples, including dissolved oxygen (DO) are collected at stations where there is little to no vessel drift to minimize effects of rapidly changing horizontal water masses. DO samples are not collected from areas with rapidly changing vertical oxygen gradients due to stratification, upwelling, tide or meteorological fronts. DO Samples are collected from near bottom depths at more stable sites, and from a variety of sites with diverse oxygen conditions in order to capture the natural range of oxygen levels. Chlorophyll *a* samples are collected from 0, 10 and 30 meters to capture a variety of levels typically observed in the upper water column where light is

present (euphotic zone). Salinity samples are collected at a few various locations throughout the day to cover a range of expected salinities.

Should the CTD values differ substantially from the analyzed water samples, CTD data are "flagged" until differences are resolved.

10.4.2 CTD field replicates

Due to the nature of marine water column sampling via a Lagrangian approach—that is, drifting with a water parcel rather than holding one static position—collection of replicate CTD casts in the field does not provide a good test of precision. At some sites, currents and winds can cause the vessel to drift a significant distance. Along with rapidly changing water conditions, replicate casts collected one after another provide a measure of field variability in space and time rather than a test of CTD precision and accuracy. For this reason, the MWM group uses independent, in-situ sample collection and lab testing to perform QA of CTD performance.

10.4.3 Field observations

Technicians are trained to constantly check each other's data entry and verify reasonableness and veracity of the data, as part of post-field procedures.

Critical field data such as correct sampling location (latitude and longitude) are best managed while sampling, so technicians are trained to recognize landmarks and proper location and check these before sampling. Time is recorded using GPS or cellular telephone, both considered highly accurate. This is verified during data entry. Tide and current information are added after sampling, and these data are verified by a second technician who confirms all field data entry.

10.4.4 Weather and conditions

Weather observations collected during the flight are used to denote local conditions only, as an aid to reviewing and assessing data. Many of these observations are subjective, depending on the experience and background of the observer. As part of post-field procedures, a technician will independently check data entry and weather observations for reasonableness. Further processing and analysis of weather observations are made, using independent weather data generated by NOAA, local airports and the National Weather Service. More information on this analysis can be found in Ecology SOP No. 089.

10.5 Laboratory QA/QC procedures

10.5.1 Laboratory-based CTD QA/QC procedures

10.5.1.1 Seawater bath assessment of CTDs for quality control (QC)

A pristine, calibrated CTD package, reserved for lab assessments only, is used to test the performance of sensors before and after deployments. The lab and field sensors are run side-by-

side in a semi-controlled seawater bath where environmental effects from currents, advection, and weather are minimal. A side-by-side (paired sample) approach generates a data volume adequate for more statistically robust comparisons of sensors. For dissolved oxygen this type of sampling is referred to as “reference sampling” (Sea-Bird Electronics Application Note 64-2, 2012).

For the seawater bath, a 187-gallon (5' long x 3' wide x 3' high) tank is set up and maintained at Ecology's Marine lab. This tank is used to assess clean, recently factory-calibrated sensors prior to deployment and then again every month during the sampling year. More information on this procedure can be found in “Marine Waters Sensor Performance Assessment - Lab Procedure” (Friedenberg et al., 2013).

For the laboratory bath procedure, a reference CTD-DO (SBE 37-SMP-IDO) is used to evaluate the performance of field instruments. Every 3 months, 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 an SBE 43 dissolved oxygen sensor 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 how field sensors perform and whether measurement quality objectives for accuracy and precision are met.

For dissolved oxygen, a sensor passes the performance check if values fall within 2% of the expected value (i.e., the paired bath measurement values of the assessed instrument are 98-102% of the reference instrument measurements). Any instrument that does not pass performance checks is not deployed and is removed from the instrument pool for additional diagnostics. The instrument-to-instrument comparison ratio is confirmed by laboratory analysis (Winkler DO replicates). The instrument should fall within 5% of the expected result, based on ongoing sensor control methods. The Carpenter method for DO titrations is used to determine the dissolved oxygen concentration in collected reference samples (Bos, J., 2007). Verification DO samples are analyzed by staff in Ecology's Marine Laboratory.

For pressure, performance is verified in the bath by confirming whether values are near expected pressure values, given the depth of the bath water, and whether there are continuous, stable measurements and general agreement with the reference instrument held at the same depth within the bath.

For salinity, which is derived from the CTD's conductivity measurements, performance is verified based on agreement (difference <0.2%) between the reference CTD and the assessed CTD. In general, sensors are expected 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, sensor performance is based on agreement (difference <0.2%) between the reference CTD and the assessed CTD.

10.5.2 Water sample QA/QC procedures

10.5.2.1 Replicate sample collection

Replicate samples are collected during every long-term monitoring survey to help determine field and sampling variability. One site per each survey of 10 sites is sampled to conduct a quantitative determination of homogeneity of conditions, along with precision and bias of sampling methods. Parameters to be replicated include dissolved oxygen, nutrients, and chlorophyll *a*.

10.5.2.2 Analytical replicates

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

10.5.2.3 Laboratory control samples

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

10.5.2.4 Laboratory blanks

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

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

Table 17. Quality assurance/quality control procedures for water column 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				
Ammonia (NH ₄)	5 point standardization	2 - 3	2	2
Nitrate (NO ₃)	5 point standardization	2 - 3	2	2
Nitrite (NO ₂)	5 point standardization	2 - 3	2	2
Orthophosphate (PO ₄)	5 point standardization	2 - 3	2	2
Silicate (SiO ₄)	5 point standardization	2 - 3	2	2
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
<i>~ Nutrients, dissolved oxygen, and chlorophyll a are replicated in the field.</i>				
CTD Sensors				
pH (electrode sensor)	5 point calibration	NA	NA	NA
Light Transmission	2 point calibration (high & low)	NA	NA	NA
Dissolved oxygen (Clark cell - membrane)	Standardization – full saturation	NA	NA	NA

10.5.3 Lab QC documentation

Quality control procedures for the UW's Marine Chemistry Laboratory are documented and followed per standard seawater analysis protocols (UNESCO, 1994). The laboratory can assess laboratory bias by using standards, replicates, and laboratory splits to analyze error and MDLs during analyses. 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.

Full quality control procedures for Ecology's Marine Laboratory are documented in Bos 2012, 2010a, 2008, 2007 and 2010b. 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 QAMP.

10.6 Corrective action processes

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

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

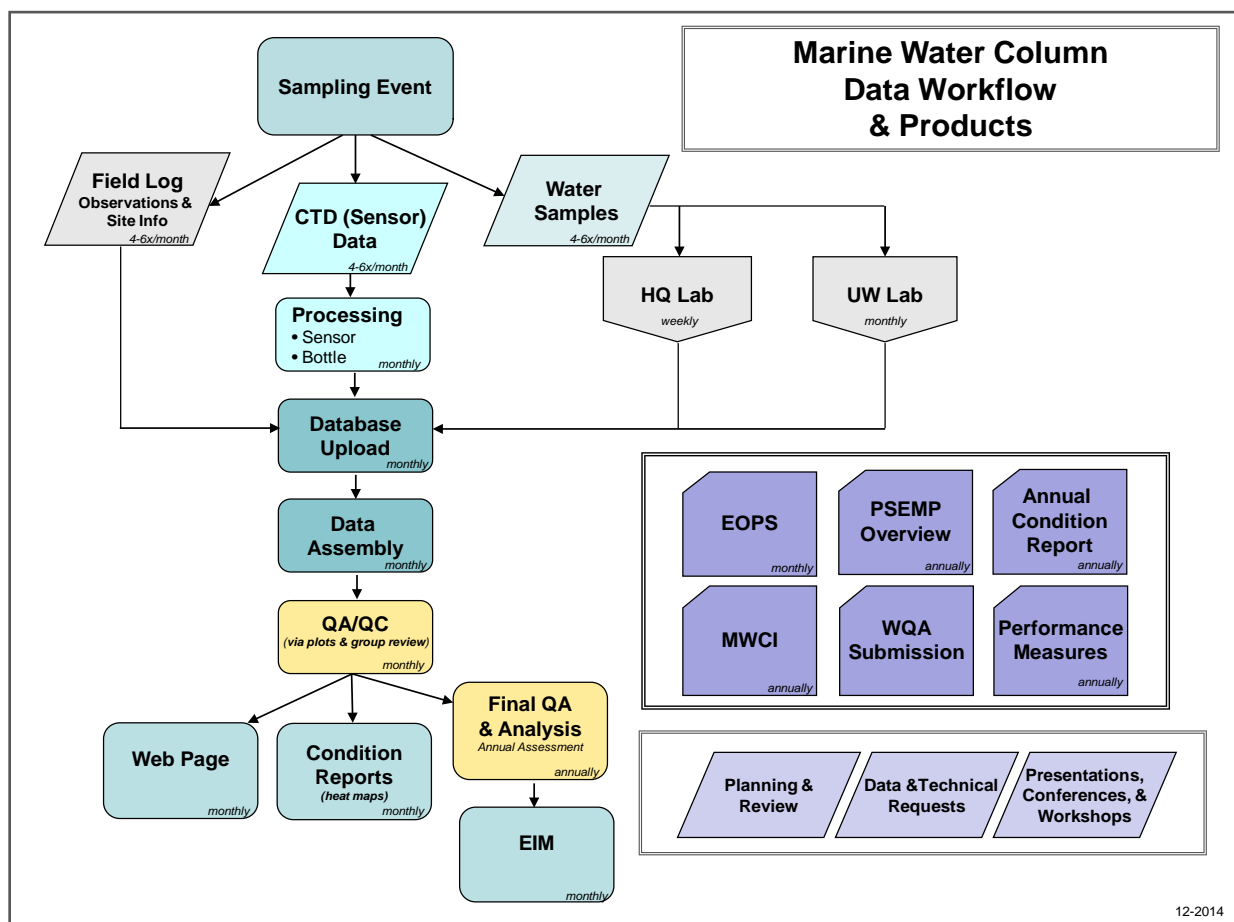
11.0 Data Management Procedures

Data and information management are critical to maintaining an efficient, organized, long-term monitoring system capable of generating high-quality, up-to-date, informative products for managers and scientists. Data used for analysis and reporting, and distributed to the public must pass all QA/QC tests. The MWM group has invested considerable resources in maintaining and updating data processing and storage structures to facilitate rapid distribution of high-quality monitoring data and products. 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).

Figure 6 shows the overall organization of the data workflow and products generated by the Marine Waters group. At many levels, it is essential for information and products to be thoughtfully organized for efficient and reliable output. The MWM group uses well-managed information and file systems to make this possible.

Figure 6. Marine waters data workflow and data products.



11.1 Data recording/reporting requirements

11.1.1 Field log data and observations

Field data and observations are recorded in electronic field logs (Appendix D) during sampling events. Upon return from the field, a second technician reviews field logs for correctness and completeness and then uploads to the marine waters EAPMW database. If errors are found, the technician confirms with the original sampling team and then corrects as possible. As a backup to the electronic field log, a blank, printed version is brought along on every sampling event and used if the field tablet or laptop fails. After sampling is completed, information from the printed version can be checked and entered into the electronic log in the office and loaded to the database. A new log is completed at every station, including those that are rejected. All entries are independently verified for accuracy by another individual on the project team. The digital forms are backed up onto a secure, network server after verification is complete and data are uploaded to the database.

11.1.2 CTD data

Processing and managing all sensor data involves 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 using an SOP that is updated every 3 years with any changes and improvements. This information can be found in the Standard Operating Procedure for Marine Waters Data Processing (Albertson and Bos, 2015).

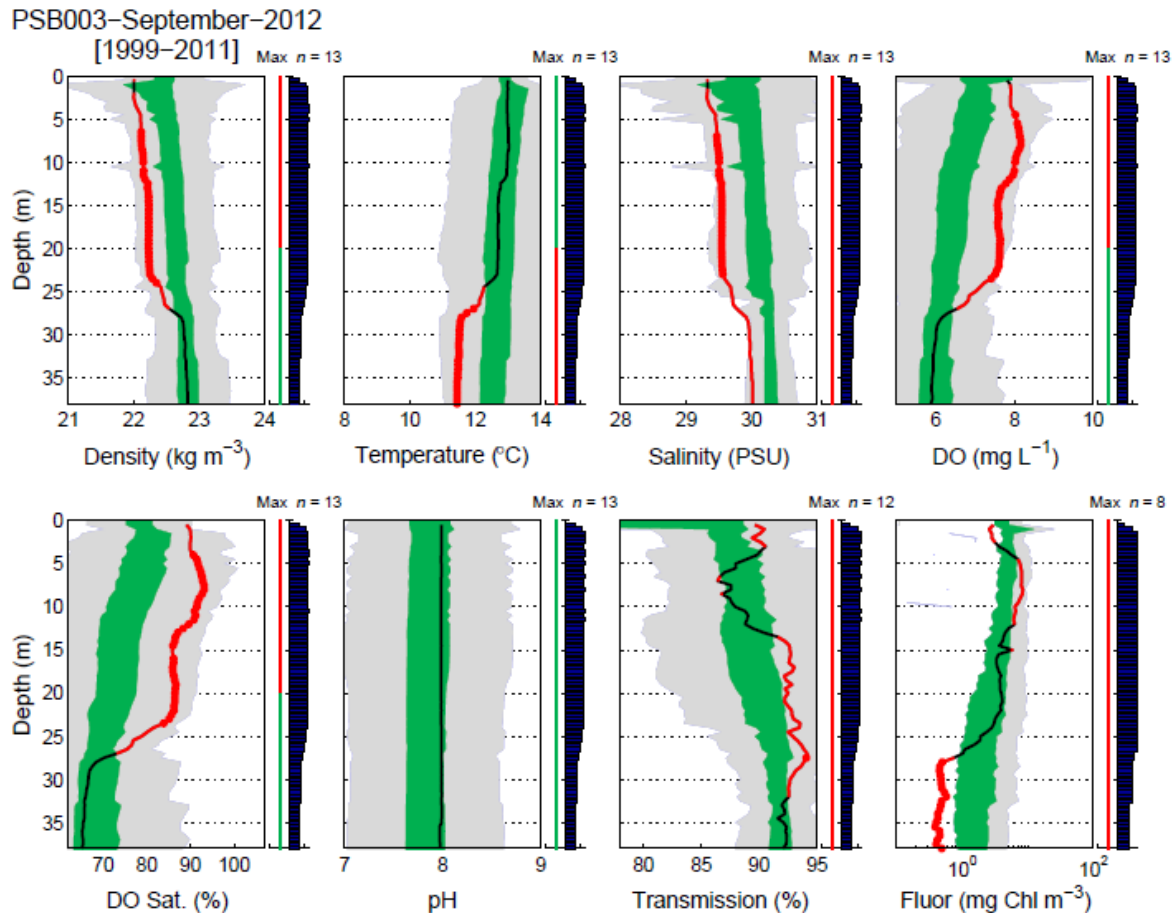
At a descriptive level, CTD data are downloaded in the field, immediately after collection, and are stored on a field laptop. Raw (unprocessed) data files are named transparently with the date and station name where collected. Staff transfer data files to a secure network drive when they return from the field. Data processing of the raw electronic data is automatically performed using MatLab software scripts based on or using recommended routines designed by Sea-Bird Electronics, which incorporate standard oceanographic methods (UNESCO, 1994). The recommended data processing procedures, including calculation of derived variables, are described in manuals referenced in Appendix E.

Once CTD data are processed, they are automatically loaded to the EAPMW database, where QA/QC assessments are then performed. These data are plotted in standardized templates, including vertical profile plots of all sensor data, in statistical context of historical data ranges, then reviewed and given a final quality assessment. Each data result is given a final QC code based on passing or failing QA/QC assessment.

11.1.3 Statistical analyses

Site-specific statistical evaluation of water column data is conducted every month by the marine waters monitoring group. The interquartile ranges of historical results for each station and each depth are calculated and compared to the current monthly data. An example of this type of plot is shown in Figure 7. Data significantly higher or lower than the historical ranges are automatically flagged and reviewed. Reports on monthly anomalies in water properties through the entire station network are then generated and posted to the [website](#) by the senior oceanographer. To determine significant trends, data sets are de-seasonalized using site-specific historical monthly data based on the data from 1999 to the present. Heat maps are used to describe the volume of data and to communicate long-term monitoring results.

Figure 7. Site-specific monthly data plotted in the context of interquartile ranges based on historical results, grouped by station and month.



Further analysis to detect significant changes in water quality is performed via mathematical and other statistical analysis of the data. Non-parametric tests of the data are predominantly used to further interpret oceanographic influences and processes as data. Non-parametric analysis is used as water quality parameters collected at random do not display a normal frequency distribution (Janzen, 1992). The data set may include some of the following attributes which must be considered when conducting statistical analysis:

- Missing data.
- Values that exceed laboratory detection limits (data at or below detection limits).
- Weather events that cause anomalous values.
- Laboratory method changes.
- Field data collection method changes.
- Personnel changes.
- Equipment malfunctions.

The MWM group evaluates trends for the year 1999 and beyond, when laboratory methods and field collection methods consistent with standard oceanographic procedures were implemented with method changes thoroughly tested and evaluated prior to implementation. Since 1999, no significant method changes have impacted data trends.

11.2 Laboratory data package requirements

Laboratory reports and results for marine water sample analysis performed by external labs are typically sent as files attached to email. These are reconciled and reviewed for completeness and correctness. They are then loaded into the EAPMW data management system. Laboratory results generated by the internal Marine Lab are entered into digital forms and stored on a secure network server. All digital files are stored “raw” in folders organized by monitoring year. All laboratory results are reviewed, loaded to the EAPMW database and further assessed, using QA/QC procedures. All data are given QC codes when finalized.

All data from labs include:

- Raw data results for all parameters measured at each station in electronic format.
- QA sample results.
- A narrative or report with methods used, any problems with the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers.
- All associated QC results. This includes results for all required field and analytical (laboratory) control replicates, laboratory control (check) samples, reference materials or standards, method blanks (Table 14).
- Any qualification of the results.

Manchester Environmental Laboratory, UW Marine Chemistry Laboratory, and Ecology’s Marine Laboratory provide verified data packages for all data analyzed. Laboratories and contractors submit interim data packages including information for data verification to the monitoring coordinator.

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

11.3 Electronic transfer requirements

All data is generated electronically and transferred in the form of various files such as spreadsheets, database forms and recorded instrument files converted to simple text formats. All data are transferred to a secure, shared network server within 24 hours of receipt or generation. Long-term marine monitoring information is organized in annual folders with subfolders 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.

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

Specific analyses conducted on field and lab data results 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 final data results. Performance assessment measures are calculated annually and stored within the appropriate program or project files and reported to the state's Office of Financial Management.

11.3.2 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](#). 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.

11.4 Acceptance criteria for existing data

After initial data processing and QA/QC activities confirm that all instrument operations, laboratory analyses, and field information collection were performed without error or failure, data are accepted for use.

11.5 EIM/STORET data upload procedures

The Marine Waters Monitoring database (EAPMW) is a SQL server database, connected to Ecology's EIM data system. Data generated by the program are stored on EAPMW, then transferred to EIM. The data is considered provisional until all QA/QC activities have been completed successfully. All data that pass QA/QC are finalized and stored in EIM for subsequent transfer to STORET.

12.0 Audits and Reports

12.1 Number, frequency, type, and schedule of audits

Data audits are conducted every month, on incoming sample data once they have been processed and uploaded to the EAPMW database. Annual audits are conducted for every sampling year, once data have been completely reviewed and quality control and assessment activities are completed. These audits occur 4-6 months after the sampling year is completed.

MWM technicians track and reconcile the status of samples being analyzed by the laboratories, being particularly alert to any significant QC problems that 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.

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. This accreditation process includes performance testing and periodic lab assessments. No additional audits are envisioned.

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

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

The results of QA/QC and audits, including performance assessment of all measurement systems, significant QA problems, and recommended solutions, are available when data is finalized after the sampling year is complete.

12.2 Responsible personnel

The marine monitoring coordinator conducts audits of all data and works with field and lab technicians to complete audits. The senior oceanographer participates in checking finalized data available to the public.

12.3 Frequency and distribution of report

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

12.3.1 Monthly data summaries

Monthly data summaries are produced to check for initial QA/QC issues such as:

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

Monthly condition reports are generated during data reviews and posted on the MWM group [website](#) at the “Water Column” page by the senior oceanographer. These summaries give information, one month post-data collection on Puget Sound physical, biochemical, and optical conditions along with weather summaries.

12.3.2 EOPS summaries

Monthly data summaries, in the form of heat map graphics and other products, are reported in a monthly online report titled “Eyes Over Puget Sound” ([EOPS](#)). This report is released two days after the senior oceanographer conducts an EOPS aerial photographic survey, done on the commuter legs of a marine flight. For this product, a summary of Puget Sound conditions for salinity, temperature, dissolved oxygen, water clarity, and fluorescence for the previous month is presented in the temporal context of the past 2 years of observations.

12.3.3 The Marine Waters Condition Index

Marine water quality conditions are considered a key indicator of Puget Sound ecosystem health so the MWM group also reports changes in water quality conditions, using an index. Indicator development began in 2000 (Newton and Mumford, et al.) through coordination with other agencies and partners in PSAMP, now called PSEMP. Ecology’s Marine Water Condition Index (MWCI), developed by Christopher Krembs, improves upon these original efforts. The Puget Sound Partnership (PSP) has adopted Ecology’s MWCI as one of its dashboard indicators. Ecology evaluates the MWCI for coastal bays as well as Puget Sound, using the same methodology.

The MWCI takes advantage of the long-term de-seasonalized data set generated by the marine water column program and uses this information to provide updates on changes in water quality at core stations. Monthly core station data feed the Marine Water Condition Index. More information on the formulation of this index is in the report, [Marine Water Condition Index](#). Current results for core stations in the MWCI can be found at the [Marine Waters website](#).

12.3.4 Annual data assessment and summary

An annual assessment of data, including summaries of key variables in each region and Sound-wide, is generated at the end of every sampling year and available on the web within 4 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.

12.3.5 PSEMP Annual Marine Waters Overview report

The MWM group contributes several monitoring products to the annual Puget Sound Marine Waters Overview. This report is published by NOAA's Northwest Fisheries Science Center for the Puget Sound Ecosystem Monitoring Program's Marine Waters Workgroup. The objective of this report is to collate and distribute physical, chemical, and biological information obtained from various marine monitoring and observing programs in Puget Sound. This report is a joint publication with contributions from over 40 individual authors. It presents data and observations collected during the previous year on topics ranging from large-scale climate variability to local weather, ocean boundary conditions, river inputs, water quality, plankton, bacteria and pathogens, and marine birds (PSEMP, 2013) and can be found at the [PSEMP website](#).

Electronic versions of the data and reports generated from this project are available to the public via Ecology's homepage at the "Ecology for Scientists" site (www.ecy.wa.gov/science/) and the [Marine Waters website](#).

12.4 Responsibility for reports

Given the long-term nature of the marine waters monitoring program, the historical data set is extensive and contains a wealth of information. Analyzing and interpreting data results requires an intensive team approach. The senior oceanographer leads reporting on status and trends on various products and presentation of results. Members of the marine waters monitoring team assist in reports and presentations.

13.0 Data Verification

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

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

13.1 Field data verification, requirements, and responsibilities

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

13.2 Lab data verification

Lab technicians verify sample and data disposition by conducting continual tracking and reconciliation procedures. A second staff person always checks the work of the staff person who primarily collected or generated data results.

13.3 Validation requirements

On an ongoing monthly basis, the MWM group meets and performs a group review of all raw and processed data and data uploaded to the EAPMW database, by reviewing plots and statistical summaries of data. Staff members individually review various data sets, documenting problems and applying QC qualifier codes as necessary. All flagged data is presented, reviewed, and discussed by several MWM group staff members and either removed from the data set or released for public use with a data quality code. Once the sampling year is complete, all reviewed data is re-assessed in the context of the annual summary and then finalized once all QA, QC, and validation is complete.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining whether project objectives have been met

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

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 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.

Staff review sample results following each sampling year to determine need for modifications to the sampling or analysis program. Laboratory and quality assurance experts who are familiar with assessment of data quality are consulted if guidance is needed for assessment. Annual summaries include data quality 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 members examine the data to determine whether they are still usable and whether the quantity is sufficient to meet project objectives.

14.2 Data analysis and presentation methods

MWM oceanographers use methods to reduce, analyze, and present the data. Analytical approaches are chosen based on the assessment needs; these include eutrophication effects, the influence of water mass exchange or nutrient dynamics, and climate influences. Methods used are generally the best available, appropriate practices with common clarity and acceptance, according to relevant statistical and analytical research published in peer-reviewed literature. Descriptions of analytical methods are published with presentation of the analysis.

Data are summarized and displayed using a range of standard scientific graphical methods. Outliers and out-of-range data are reviewed to determine if these are errors or possible real events. During data analysis, especially when based on graphical display, data anomalies may be found which have previously escaped detection. These anomalies are evaluated and resolved. If data are erroneous, they are removed or corrected, and analysis is re-done.

14.3 Treatment of non-detects

A general practice for data management is that results or concentrations between the method detection limit (MDL) and the reporting limit are reported as detected but not quantified, due to the potential for misuse or misinterpretation of low-level data which has relatively high quantitative uncertainty.

For the Long-term Marine Waters Monitoring Program, data results or concentrations of all analytes reported between the MDL and reporting limit are quantified and annotated with a “J” qualifier (estimated concentration); this indicates a higher level of uncertainty in the quantitative value. Statistical evaluations of data whose uncertainties are “high” can lead to erroneous conclusions, especially if the sample populations are limited in size or have high percentages of non-detect data—results where analytes are not present at detectable concentrations.

For lab data, the only sample results considered “detected” are those quantified at concentrations at least three times greater than the corresponding results in the method blank and in the field blank samples. Sample results that are not at least three times greater than the corresponding results in the method blank are qualified with a “U” to indicate “not detected.” Sample results that are not at least three times greater than the corresponding results in the field or reagent blank samples are qualified with a “JB” to indicate “not detected due to contamination of the field or reagent blank”.

14.4 Sampling design evaluation

The sampling design for the Marine Waters Monitoring Program was developed by questions and concerns about the water quality of Puget Sound. Ideally, the sampling plan and data populations needed to assess water quality conditions are determined by required significance level, precision, and analytical and statistical power. Realistically, the ongoing monitoring program is affected by resource availability including budget and staff, and program capabilities and capacity.

The study design for the Long-term Marine Water Monitoring Program and related studies were developed by—and have been peer-reviewed at—the regional and national level under the National Estuary Program. The development and review are discussed in Appendix B.

14.5 Documentation of assessment

Summary statistics are computed for all variables and reported with the final data and analytical results. The senior oceanographer summarizes and reports the final annual assessment via the Marine Waters website, within 6 months of the end of the sampling year.

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16.0 Figures

The List of Figures follows the Table of Contents in this report.

17.0 Tables

The List of Tables follows the Table of Contents in this report.

18.0 Appendices

Appendix A. Glossary, Acronyms, and Abbreviations

Glossary of General Terms

Alkalinity: The negative charge in a seawater solution that can be titrated by a strong acid to lower the pH of the sample to the point where all of the bicarbonate [HCO_3^-] and carbonate [CO_3^{--}] could be converted to carbonic acid [H_2CO_3]. This is called the carbonic acid equivalence point or the carbonic acid endpoint.

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

Anthropogenic: Human-caused.

Beam Attenuation: A decrease in light energy from a beam that is passing through a water sample with a specific pathlength. It is an inherent optical property. The amount of attenuation is primarily dependent upon the wavelength of the propagated light, the concentration of suspended materials and the concentration and composition of both particulate and dissolved absorbing materials.

Calibration: A procedure for comparing the signal from an instrument with known or standard values for turbidity, temperature, pressure, salinity, etc.

Clarity: A qualitative measurement of the ability of water to transmit light. Clarity can be assessed using transmissometer and turbidity sensors.

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

Chlorophyll *a*: Pigment that allows plants, including algae, to convert sunlight into organic compounds in the process of photosynthesis. Chlorophyll *a* is the predominant type found in algae and phytoplankton, and its abundance is a good indicator of the amount of algae biomass present.

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.

CTD: A set of sensors (conductivity-temperature-depth) combined into an instrument package used for collecting continuous water column profile data. The CTD is equipped with sensors to measure additional variables and a pump to draw water through the sensors. Profiles at each station are collected from the sea surface (top bin = 0.5 m) to the sea bottom. The CTD and

sensors are operated and maintained according to manufacturers' recommended protocols, with factory calibration occurring annually.

Dissolved Inorganic Carbon (DIC): The sum of inorganic carbon species in a solution. The inorganic carbon species include carbon dioxide (CO_2), carbonic acid (H_2CO_3), bicarbonate anion (HCO_3^-), and carbonate (CO_3^{2-}).

Dissolved oxygen (DO): The amount of gaseous oxygen (O_2) dissolved in water. Oxygen gets into water by diffusion from the surrounding air, by aeration (rapid movement), and as a product of photosynthesis. DO levels are used as an indicator of water quality.

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

Eutrophication: An ecosystem response to the addition (naturally or artificially) of nutrients and related substances to an aquatic system. Commonly, enriched nutrient levels from human activities such as fertilizer runoff and leaky septic systems can result in high productivity in plankton and algae, ultimately causing negative effects such as hypoxia and altered optical properties.

Fecal coliform: That portion of the coliform group of bacteria that live in waste material or feces of warm-blooded animals and humans. When present in high numbers in a water sample, they may suggest the possible presence of disease-causing organisms. They are used as "indicator" organisms for water quality. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

Fluorometer: An instrument that provides an indication of the concentration of a given material by measuring the amount of fluorescence attributed to the material. For example, a fluorometer provides an excitation beam at a wavelength that is known to cause fluorescent emission from chlorophyll and measures light at a wavelength that matches the chlorophyll emission. As a result, the amount of chlorophyll-containing biomass can be estimated.

Hypoxia: oxygen depletion – a phenomenon where the amount of oxygen gas dissolved in water in an aquatic environment is between 1 and 30%, calculated at the prevailing temperature and salinity. Levels of oxygen this low can be detrimental to aquatic organisms.

Niskin Bottle: Water sampling bottle used to make sub-surface measurements of water. These are plastic tubes (PVC) with spring-loaded end caps, an air-vent valve at one end and a dispensing stopcock at the other.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water

pollution that does not meet the legal definition of “point source” in section 502(14) of the Clean Water Act.

Nutrient: A substance such as nitrate, nitrite, silicate, ammonium and phosphate. These compounds are used by organisms to live and grow.

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

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

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

Photosynthetically Active Radiation (PAR): Wavelengths—roughly 400–700 nanometers—of incoming sunlight that can be absorbed by plants for photosynthesis.

Phytoplankton: Free-floating flora that convert inorganic compounds into complex organic compounds. This process of primary productivity supports the pelagic food-chain. Phytoplankton vary in size from less than 1 to several hundred μm .

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

Salinity: Salinity is the total amount of dissolved material in grams in one kilogram of sea water. Samples are collected to calibrate and check conductivity measurements made by the CTD.

Secchi Disk: Measures transparency of the water using an 8-inch diameter white disk attached to a rope. The rope is marked at 0.5 meter intervals for easy determination of depth.

Secchi Depth: Depth in the water at which the disk is no longer visible. It is usually the average between the depth at which the disk is no longer visible when it is lowered into the water and the depth at which it is again visible as the disk is raised. The secchi depth can be used to calculate the amount of colored substances (i.e., phytoplankton, algae, and detritus) in the water. Changes can be caused by sediment runoff from land or increased phytoplankton populations. Changes in secchi depth over time are used as an indicator of water quality.

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

Transmissivity: (light transmission) A measure of light scattering and absorption through the water column, reported as a percent or ratio of light received relative to light originally transmitted. Light transmission is used as an indicator of water quality, indicating water clarity and providing information on light absorption and light scattering (beam attenuation).

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

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

90th percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90th percentile value is a statistically derived estimate of the division between 90% of samples, which should be less than the value, and 10% of samples, which are expected to exceed the value.

Acronyms and Abbreviations

Chla	Chlorophyll <i>a</i>
CTD	Conductivity-Temperature-Depth (Instrument)
CWA	Clean Water Act
DIC	Dissolved Inorganic Carbon
DO	Dissolved Oxygen
EAP	Ecology's Environmental Assessment Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
GMT	Greenwich Mean Time (equivalent to Coordinated Universal Time – UTC)
GPS	Global Positioning System
JEMS	Joint Effort to Monitor the Strait
MEL	Manchester Environmental Laboratory
MMU	Marine Monitoring Unit
MQO	Measurement quality objective
MMU	Marine Monitoring Unit
MWM	Marine Waters Monitoring
NEP	National Estuary Program (EPA)
NOAA	National Oceanic and Atmospheric Administration
QA	Quality assurance
QC	Quality control
PDT	Pacific Daylight Time
PST	Pacific Standard Time
PSAMP	Puget Sound Assessment and Monitoring Program
PSEMP	Puget Sound Ecosystem Monitoring Program
PSAT	Puget Sound Action Team
PSEP	Puget Sound Estuary Program
PSP	Puget Sound Partnership
PSWQA	Puget Sound Water Quality Authority

RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
UW	University of Washington
WAC	Washington Administrative Code
WRIA	Water Resources Inventory Area

Units of Measurement

°C	degrees centigrade
ft	feet
g	gram, a unit of mass
m	meter
mEq/L	milliequivalent per liter, a unit of alkalinity
mg	milligram
mg/L	milligrams per liter (parts per million)
mL	milliliters
mm	millimeter
NTU	nephelometric turbidity units
psu	practical salinity units
µg/L	micrograms per liter (parts per billion)
µM	micromolar (a chemistry unit)
µmol/Kg	micromoles per kilogram, a unit of dissolved inorganic carbon
umhos/cm	micromhos per centimeter
µS/cm	microsiemens per centimeter, a unit of conductivity
µm/m ² /sec	micromoles per square meter per second, a unit of PAR

Appendix B. Puget Sound Assessment and Monitoring Program (PSAMP) Water Column Monitoring Historical Background

Appendix B-1. National Estuary Program: Inception of the Puget Sound Estuary Program (PSEP) and the Puget Sound Ambient Monitoring Program (PSAMP) Task: Water Column Monitoring in Puget Sound

The National Estuary Program (NEP) was established under Section 320 of the 1987 Clean Water Act (CWA) Amendments as a U.S. Environmental Protection Agency (EPA) place-based program to protect and restore the water quality and ecological integrity of estuaries of national significance. Section 320 of the CWA calls for each NEP to develop and implement a Comprehensive Conservation and Management Plan (CCMP). The CCMP is a long-term plan that contains specific targeted actions designed to address water quality, habitat, and living resources challenges in its estuarine watershed.

Each NEP has a Management Conference (MC) made up of diverse stakeholders including citizens, local, state, and Federal agencies, as well as with non-profit and private sector entities. Using a consensus-building approach and collaborative decision-making process, each MC works closely together to implement the CCMP. The MC ensures that the CCMP is uniquely tailored to the local environmental conditions, is based on local input, and supports local priorities.

Currently there are 28 estuaries located along the Atlantic, Gulf, and Pacific coasts and in Puerto Rico that have been designated as estuaries of national significance. Each NEP focuses its work within a particular place or boundary called a study area which includes the estuary, and surrounding watershed.

In 1988, state and federal agencies embarked on a comprehensive Puget Sound environmental protection campaign, the Puget Sound Water Quality Management Plan (Puget Sound Water Quality Authority, 1988). As a result, a monitoring program that expanded existing Puget Sound monitoring efforts was implemented. Its primary goal was to coordinate the collection of information on parts of the Sound ecosystem that might be affected by pollution. In 1987-88, the Puget Sound Ambient Monitoring Program (PSAMP) was developed by a regional group of professional environmental scientists from the Pacific Northwest, known as the Monitoring Management Committee (MMC). A plan was designed to guide comprehensive long-term monitoring in Puget Sound (MMC, 1988a), and to measure ambient (background) conditions in Puget Sound, as well as to measure the cumulative effects of contamination and habitat degradation from human activities. To encourage cooperation with existing programs, the MMC recommended that monitoring tasks be assigned to appropriate state agencies. Ecology's Environmental Assessment Program (EAP, formerly Ambient Monitoring Section - AMS) was assigned the marine water column monitoring task of PSAMP, as well as the marine sediment and freshwater monitoring tasks.

Appendix B-2. 1995 PSAMP Marine Water Column Review Results

PUGET SOUND AMBIENT MONITORING PROGRAM MARINE WATER COLUMN QUESTIONS, ISSUES, AND RECOMMENDATIONS by **Jan Newton, Washington State Department of Ecology**

TABLE OF CONTENTS:

Introduction.....	1
Historical Background.....	2
Results of Ecology's PSAMP Marine Water Monitoring	3
Long-term monitoring.....	4
Seasonal/focused monitoring.....	7
Original PSAMP Objectives and Sampling Directives.....	8
Objectives.....	8
Sampling directives.....	9
Proposed PSAMP Marine Water Objectives and Assessment Questions.....	9
Issues and Recommendations.....	15
Realities.....	15
Refinements.....	16
Improvements.....	20
Gaps.....	22
Summary.....	26
Literature Cited.....	27

ABSTRACT--

There are many aspects of Ecology's Marine Water Monitoring Program that are providing insightful information and preserving a comprehensive time-series of water-column data. There are also areas within the program that need refinement (e.g. station location, and how parameters are measured), areas where efforts must be improved (e.g., analyzing historical data, and assessing/integrating the sampling for fecal coliform bacteria and harmful phytoplankton between Health, Ecology and others), and areas where sampling does not exist (e.g., chemical contamination of the water column, circulation, and food-web information) and that need consideration on whether omission of this information is of enough importance to PSAMP to warrant changes. Issues of staffing level, shiptime and equipment need to be considered up front when reviewing this program.

INTRODUCTION

This question-issue-recommendation (QIR) document was written to facilitate a 5-year review of the Puget Sound Ambient Monitoring Program (PSAMP). It is being sent to the formal review panel members as well as solicited peer reviewers in order to assess the present status of the Marine Water Monitoring Program of the Washington State Department of Ecology and its contribution to the PSAMP.

The format of this document is fourfold: 1) to provide background information on past and present monitoring of Puget Sound marine waters; 2) to summarize key results from the last five years of Ecology's marine water monitoring under the PSAMP; 3) to present proposed objectives for the continuation of marine water monitoring under the PSAMP; and 4) to identify issues that need evaluation and outline recommendations. In order to present these topics, additional documents are enclosed that will be referenced.

Note that as used in PSAMP, "Puget Sound" refers to a wider geographical area than its actual definition, i.e., as on navigational charts. As originally conceived, the PSAMP monitors all waters south of Admiralty Inlet and the U.S. waters of the Strait of Juan de Fuca, the San Juan Island basin, and the Strait of Georgia. In this document, "Puget Sound" refers to this broader geographical region.

HISTORICAL BACKGROUND

Long-term time-series of Puget Sound water column parameters have been recorded by academic or governmental scientists for discrete historical periods. The most notable records were obtained by: 1) the University of Washington (UW), Department (then) of Oceanography from 1932 to 1942 and from 1948 to 1966; 2) the Washington Department of Fisheries, Point Whitney Laboratory from 1952 to ~1970; and 3) the Fisheries Research Board of Canada from 1932 to ~1970.

Monitoring the marine water quality of Puget Sound has been a mandate of the Washington State Department of Ecology (or its predecessor agencies) since 1967, in response to the Clean Water Act. Ecology's mandate for marine water monitoring is statewide and, thus, includes the Pacific coastal estuaries, Grays Harbor and Willapa Bay. Ecology's monitoring has not included the waters of the open Pacific Ocean coast, nor of the intertidal to nearshore environment, primarily due to logistical and financial constraints.

Upon the creation of the PSAMP, Ecology's marine water monitoring in Puget Sound has fulfilled the elements of the Marine Water Column Task (MMC, 1988; a.k.a. "Red Book"). The objectives detailed in the PSAMP Red Book for the Marine Water Column task were numerous and diverse, but can be condensed to the topics listed in Table 1. It should be noted that some of these monitoring objectives were not described for implementation (e.g., characterize the movement of water in Puget Sound), and some have not been funded (e.g., estimate phytoplankton production via solstice monitoring). The data identified (MMC, 1988) to be collected as part of the PSAMP Marine Water Column task are also listed in Table 1.

Because Ecology's marine water monitoring was already implemented, the genesis of the PSAMP in 1989 brought about only modification to Ecology's long-term sampling design and some coordination with other PSAMP tasks. Primary changes to Ecology's marine water monitoring design were to reduce the number of stations monitored, to locate long-term stations exclusively at mid-basin and mid-bay sites, and to conduct more comprehensive sampling (e.g., take full water column CTD profiles, include November through March sampling). Sixteen core and 30 rotating stations were identified (Figure 1) for monthly time-series occupation. One third

of the rotating stations were to be occupied each of three years. Core stations were located in each of the major basins as well as in bays near urban centers (Table 2). For 75% of the core stations Ecology had data records ranging from 7 to 13 consecutive years prior to 1989. Another change to Ecology's marine water monitoring was the addition of seasonal monitoring that was focused on individual estuaries. During these short-term (1-3 year) projects, sampling was conducted on finer spatial and, in some cases, temporal scales. The term "seasonal" monitoring was applied; most of these projects were conducted over the phytoplankton growth season (i.e. March to October). Ecology planned for seasonal monitoring projects in two estuaries each year.

A Marine Water Column Ambient Monitoring implementation and quality assurance plan for the PSAMP was drafted by Ecology (Janzen, 1992; available upon request). This plan outlined procedures for each of the three strategies identified in the Red Book for the marine water column: 1) long-term monitoring; 2) seasonal monitoring; and 3) solstice monitoring. From 1990 to 1991, only the first strategy was funded and implemented; from 1992 onward, the first two strategies have been funded and implemented.

Since wateryear (WY) 1992, an annual implementation plan update for the long-term monitoring component has been written as an addendum to the Janzen (1992) plan. Ecology conducts monitoring on a wateryear basis, wherein sampling runs 1 October through 30 September of named year. The WY 1995 implementation plan (Newton, 1995a), enclosed, details the most recent description of the long-term marine water monitoring component.

Each year, proposals for seasonal monitoring projects are presented to and approved by the PSAMP steering committee. Under new leadership, the seasonal monitoring projects have evolved from intensive sampling surveys of water quality patterns in a particular estuary to hypothesis-driven investigations of a particular water quality issue in a localized area. The 1995 Hood Canal focused project proposal (Newton, 1995b) is enclosed as an example of this latter type of project (now dubbed "focused" project). Starting in 1995, the proposals for focused projects have been drafted as formal Ecology quality assurance project plans and circulated for review. This reflects effort to integrate Ecology's marine water monitoring with other complementary Ecology programs.

RESULTS OF ECOLOGY'S PSAMP MARINE WATER MONITORING

A basic description of the present status of Ecology's Marine Water Monitoring Program, including goals, objectives, sampling design, and parameters was outlined in the PSAMP Marine Water Column briefing paper (Newton et al., 1995b), presented and distributed at the PSAMP Review Workshop I (enclosed for peer reviewers). The intent behind the two monitoring strategies, discussed in the briefing paper, can be summarized as: 1) a long-term time-series recording baseline conditions in order to identify temporal changes and establish spatial patterns; and 2) short-term hypothesis-driven focused projects designed to assess water quality problems at a particular site.

Results from long-term marine water monitoring have been summarized and published by Ecology for each wateryear since 1990 (as shown in Table 2 of the briefing paper). Refer to the enclosed WY 1993 report (Newton et al., 1994) for sampling, analytical and quality control

methods, results and a discussion of significant findings from the long-term marine water monitoring component.

A summary of the geographical focus for the long-term monitoring during WYs 1990-1995 is depicted in Table 3, along with identification of urban and freshwater influences at each station. Note that the "area represented" listed in Table 3 is an estimate, conservatively based on analysis of Collias et al. (1974) transect data and assignment to one of three categories: 4, 2 and 0.5 nautical miles. The original PSAMP sampling strategy (MMC, 1988) called for one third of the rotating stations to be visited each year according to a three-year rotation covering north, central and south Sound stations. The rotating stations listed under each wateryear in Table 3 do not show this pattern primarily because of logistical constraints. As described in Newton (1995a), Ecology conducts long-term sampling from a seaplane via four flights per month, one each week to north (#2), central (#3), and south Puget Sound (#4), and the coast (#1). It has not been possible to arrange three flight paths that cover all core stations plus a highly regional concentration of rotating stations, as originally proposed.

Beginning in 1992, Ecology has conducted two seasonal/focused monitoring projects each year. A summary of these projects is shown in Table 4. Results from the 1992 Budd Inlet project (Eisner et al., 1994) and from the 1994-5 Hood Canal project (Newton, 1995b) are enclosed. Further information on the 1994 Hood Canal project is in Newton et al., (*in press*), available upon request.

Additional products from the Marine Water Monitoring Program were outlined in Table 3 of the briefing paper. At the recent Puget Sound Water Quality Authority sponsored Puget Sound Research Conference '95, four papers and two posters were contributed by Ecology's Marine Water Monitoring Program staff. One of the papers (Newton, *in press*), documenting sea-surface temperature and salinity response from El Niño-Southern Oscillation (ENSO) influenced local weather, is enclosed. This paper stands as an example of more intensive analysis possible from the long-term monitoring data collected under the current Marine Water Monitoring Program.

For the purpose of this review, provided here is a synthesis and overview of results from the last five years of marine water monitoring (WY 1990 to 1994). Briefly summarized results were provided in the briefing paper (Newton et al., 1995b). The format of this synthesis is to look more specifically at the 5-year data record and at results that may influence decisions about the future of the Marine Water Monitoring Program and its contribution to the PSAMP.

Long-term monitoring

Hydrography: The monthly hydrographic conditions for each of the long-term marine monitoring stations are plotted and summarized in each annual wateryear report. Beginning in WY 1993, stations were ranked according to the intensity of density stratification observed (Newton et al., 1994). Recent evaluation of the salinity and temperature from monitoring stations in 1991 (non ENSO), 1992 (moderate ENSO), and 1993 (weak ENSO) showed that variation in weather conditions (air temperature and precipitation) in these three years were reflected in the salinity and temperatures throughout Puget Sound and Georgia Strait, even down to 30 m depth (Newton, *in press*).

Thirty percent of the Puget Sound stations for which sampling is complete (14 of 46) show a sea-surface salinity (SSS) <25 ppt during 10% or more of the observations (Table 3). Only one station, SKG003, showed this condition for more than 50% of the observations. This implies that freshwater influence, while significant in some cases (SSS <5 ppt have been recorded), is highly seasonal in Puget Sound. In most cases where SSS <25 ppt was observed, a major river is proximate (Table 3). For SAR003, PNN001, and ADM003, low salinity is due to a more remote influence of multiple rivers in Whidbey Basin. For OAK004, CSE002, and ELD002, the low salinity influence is from creeks.

Water quality attributes of the long-term monitoring stations during WYs 1990 through 1994 were summarized by highlighting occurrences of high fecal coliform bacteria (FCB) counts (Table 5), high dissolved ammonium-N concentrations (Table 6), consecutive months with below reporting limit (i.e. BRL of 0.01 mg/L) nitrate+nitrite-N concentrations (Table 7), and low dissolved oxygen (DO) concentrations (Table 8). Several patterns emerge from this data presentation. Visually, the first two water quality attributes, high FCB and high ammonium-N, tended to have a similar geographic occurrence pattern, being associated with urban centers and freshwater influence and primarily concentrated in South Puget Sound, and near Seattle, Bremerton and Bellingham. The latter two water quality attributes, consecutive BRL nitrate+nitrite-N and low DO, had different patterns from this and were somewhat similar to each other. Notably, both attributes had occurrences in Hood Canal and Whidbey Basin. Although consecutive BRL nitrate+nitrite-N concentrations were evident at South Puget Sound monitoring stations, low DO concentrations were not; but refer to the *Seasonal Monitoring* section regarding intra-bay DO variation.

FCB: High fecal coliform bacteria (FCB) counts were associated with stations having urban and freshwater influences; however, this was not exclusively so (Table 9). High FCB counts were seen near all of the "big" urban centers, but not all of the near-urban stations show consistent freshwater influence, notably, SIN001, PSB003, BML001, ELD002, TOT001, and NRR001. High FCB counts at both SIN001 and PSB003 may have been influenced by nearby WWTP discharges (Bremerton, Metro, respectively); the four south Puget Sound stations are probably influenced more by smaller or non-point FCB sources. It is also probable that runoff caused by a high rainfall event could contribute FCB without reducing SSS to <25 ppt. Rainfall can affect FCB by washing animal wastes, failing on-site sewage systems, and other more subtle non-point sources into stormwater runoff (Woolrich and Garrett, 1995). Occurrences of high FCB counts at stations away from urban centers were also seen, e.g., at NSQ001, SKG003, ADM003 and a few South Puget Sound stations. It should be noted that wood processing plants (e.g., at Shelton) may contribute positive results from the bacterium *Klebsiella*, a fecal coliform that can persist in lumber and pulp mills. Lastly, some stations with freshwater influence, e.g. HCB stations, SAR003 and PNN001, did not show high FCB counts. These stations presumably do not have major sources of FCB contamination, or are too far from the source (FCB viable in seawater only ~52 h; Lessard and Sieburth, 1983), or have highly episodic, thus easily missed, inputs. In summary, although trends were observed in the FCB data, prediction of high FCB counts from station attributes was quite low. For example, a regression of the % observations of FCB counts >14 org/100 mL against % observations of SSS <25 ppt for WY 1990 through 1994 yielded a r^2 of 0.004. Sources of random variation undoubtedly include the low viability of FCB in seawater,

low-frequency (monthly) sampling, patchiness of contamination, possibly episodic inputs, and uncertainties with the analysis (e.g., non-sewage indicators). Sources of non-random variation include the necessity of both a FCB supply (e.g., human sewage, agricultural wastes) and a transport mechanism into the marine water (e.g., riverine transport, WWTP outfall, rain runoff).

Nutrients: Ammonium-N, as a preferred N source for phytoplankton, is usually found at low concentrations in marine systems. Thus, high ammonium-N concentrations are often indicative of anthropogenic nutrient loading. The cut-offs of 0.07 and 0.14 mg/L (5 μ M and 10 μ M) used in Table 6 were arbitrarily chosen, based relative to the maximum Admiralty Inlet source water concentration of about 0.03 mg/L (\sim 2 μ M). As shown in Table 9, most (65%) of the occurrences of high dissolved ammonium-N are from stations with high FCB counts also, substantiating the association of such high ammonium-N concentrations with anthropogenic input. The high ammonium-N stations without observed high FCB counts, particularly CSE001, EAS001 and DYE004, also may indicate anthropogenic additions of nutrients since these three locations all have experienced recent increases in human development of the nearby land. A PSWQA-sponsored project by the Orcas Watershed Education Alliance (OWEA, 1995) has recently presented evidence of a source of anthropogenic fecal contamination into Eastsound via the village's storm water system. High ammonium-N may have persisted longer than FCB at the Ecology mid-bay station.

Because nutrients naturally occur in seawater and are also naturally used up by phytoplankton in a temperate seasonal cycle wherein the water-column stratifies, stations with low nitrate+nitrite-N cannot be linked definitively to a human-influence on water quality. In addition, as has been well-established (cf. Hecky and Killam, 1988), BRL nitrate+nitrite-N concentrations do not necessarily imply nutrient-limitation of phytoplankton growth, since source and uptake rates may be rapid and of equal magnitude. Nonetheless, stations with a persistence of BRL surface water nutrient concentrations do indicate where human-induced eutrophication may produce increased organic production and thus, deep-water oxygen demand. As shown in Table 7, this potential exists in many south Puget Sound embayments (most notably Budd Inlet and Oakland Bay), in Hood Canal (especially southern), and in the Whidbey Basin waters (Saratoga Passage, Possession Sound and Penn Cove). In these areas, it is important to assess whether nutrient addition increases primary production, as was shown during the 1994 Hood Canal project (Figure 3) to be true for Hood Canal but not for the Puget Sound main basin (in the vicinity of ADM003). This is of special concern because the South Puget Sound region, in particular, is expected to encounter some of the most rapid population growth in the region over the next 20 years (B. Backous, Ecology, pers. comm.), and yet these waters are poorly flushed.

Looking at patterns of BRL concentrations of nutrients (nitrate+nitrite-N, ammonium-N and orthophosphate-P) for all stations monitored during WY 1993, including data from the two coastal estuaries, Grays Harbor and Willapa Bay (Table 10), reveals information about Puget Sound nutrient dynamics and relative nutrient availability. Two striking patterns emerge. One is that there is a low percentage of BRL orthophosphate-P occurrences in Puget Sound (8%), and in every instance except one (PSS019 in May 1993), these were accompanied by BRL concentrations of nitrate+nitrite-N, and ammonium-N. The pattern is quite different in the coastal estuaries where occurrences of BRL orthophosphate-P are much more common (30%) and are frequently associated with detectable nitrogenous nutrients, even ammonium-N (Table

10). This indicates an increased influence of freshwater on the coastal estuaries over that observed for Puget Sound. Generally, phosphorous limits phytoplankton growth in freshwater systems, whereas nitrogen does in marine systems. Estuaries, as intermediates, can show limitation by either macro-nutrient, at times. Such a case is not suggested for Puget Sound phytoplankton, as it may be for the coastal estuarine phytoplankton: in the 15 observations of BRL orthophosphate-P in Puget Sound, only one (7%) had detectable nitrogen; in the 14 observations of BRL orthophosphate-P in the coastal estuaries, nine (64%) had detectable nitrogen. Although phosphorous limitation of phytoplankton growth is not indicated in Puget Sound, the influence of specific nutrients and their relative availability on species succession and dominance, however, is not established.

The second pattern seen in Table 10 regarding nutrients in Puget Sound is that occurrences of BRL nitrate+nitrite-N and orthophosphate-P occur primarily in April through September, reflecting the phytoplankton growth season. In contrast, BRL ammonium-N concentrations can be observed year-round, indicating consistent usage of this less plentiful preferred nutrient by phytoplankton. Notable exceptions, where surface BRL ammonium-N concentrations are not found in winter months, are Bellingham Bay, Sinclair Inlet, Commencement Bay, Budd Inlet, and Oakland Bay, all bays where high ammonium-N concentrations were observed (Table 6) and where anthropogenic eutrophication is likely occurring. Note the lack of sampling at the coast during winter, due to inclement flying weather (Table 10).

DO: Eutrophication (= nutrient input, *sensu* Edmonson, 1991) will lead to bottom-water low DO conditions only if mixing processes that ventilate the water column are weaker than oxygen-binding processes, such as respiration and organic degradation. Because much of Puget Sound has deep basins, strong tides, bathymetric sills and dynamic weather, this situation is naturally observed in only a few places. Any discussion of DO in Puget Sound needs to be prefaced with the fact that the Pacific Ocean waters entering the Strait of Juan de Fuca and Puget Sound in late summer are recently upwelled deep oceanic waters with naturally low DO concentrations. Thus, in terms of avoiding low DO conditions, Puget Sound is at a natural advantage, due to its high degree of mixing and large volume, but also at a natural disadvantage, because its oceanic source waters have naturally low DO. Data from ADM002 during WYs 1990-1994 show this seasonal DO minimum signal, with DO concentrations at 30 m ranging from 4.9 to 5.3 mg/L, observed usually in September or October of each year (Table 8). The seasonal range at 30 m for ADM002 was 4.9 to 9.7 mg/L, typically minimum in September and maximum in May. (Note that the ADM002 data in Table 8 show zero low DO occurrences for WY 1992 and two for WY 1993 because the DO minimum for WY 1992 occurred late, in October 1993, thus during WY 1993. This observation is of interest since 1992 was an ENSO year. The occurrences of low DO at Port Angeles Harbor (PAH008) are of similar timing and magnitude as those at ADM002, indicating this station receives oceanic input via Strait of Juan de Fuca waters. The oceanic low DO signal is presumably mixed away in the Puget Sound waters south of the sill at Admiralty Inlet, as evidenced by the DO concentrations at ADM001 and ADM003 that were always observed above 5.0 mg/L for the same 5-y period (Table 8). The 30-m DO concentration south of Admiralty Inlet sill, at ADM001, is typically higher by about 1 mg/L than the DO north of the sill (oceanward), at ADM002 during the late summer, further evidence that the oceanic signal is obscured from turbulent mixing at the sill.

Aside from the oceanic-influenced sites, areas with low DO concentrations in Puget Sound, as shown by the long-term monitoring stations (Table 8), are few: Eastsound (Orcas Island), Saratoga Passage/Possession Sound, Penn Cove, Budd Inlet, southern Hood Canal. However, as presented in the *Seasonal/focused monitoring* section, this may be an underestimate since many of the long-term monitoring stations do not represent DO conditions throughout the bay/inlet. The influence of natural versus anthropogenic processes in producing the observed low DO conditions is somewhat difficult to assess. Comparisons with historical data are highly useful, although the degree of anthropogenic influence in data even from the 1930's is not quantifiable. Budd Inlet and, apparently, Eastsound have anthropogenic nitrogen sources (Eisner et al., 1994; OWEA, 1995), and a high probability that these influence the low DO observed there. There is evidence of historical differences in the DO of Hood Canal based on data from 40 y ago (Collias et al., 1974 data), although further investigation is necessary (Newton et al., *in press*). To some extent, increases in low DO intensity over time are indicated for Saratoga and Possession Sound (see Newton et al., 1994). There has not been adequate investigation of low DO concentrations at three Whidbey Basin sites; however, due to extensive industry and development nearby, anthropogenic influence on DO cannot be ruled out.

All of the sites with low DO (excluding ADM002 and PAH008) also exhibit consecutive months with BRL nitrate+nitrite-N concentrations (Tables 7 and 8; unfortunately, nutrients were not obtained at EAS001 during the years low DO was observed). The coincidence of these observations emphasizes the importance of water column stratification in facilitating low DO conditions. In Table 11, all of the stations monitored during WY 1993 were analyzed and ranked for the degree of density stratification throughout the water-column (see Newton et al., 1994 for details). ADM002 aside, all of the stations exhibiting low DO during WY 1993 also showed persistent stratification throughout the year.

Stratification: A recent agenda of the Marine Water Monitoring Program has been to categorize various regions in Puget Sound according to stratification intensity (cf. Newton et al., 1994). Because stratification is so highly correlated with water quality concerns, assessing stratification patterns throughout Puget Sound as well as understanding the forcing functions that affect stratification are important. Two forcing functions for stratification are freshwater input from rivers and weather conditions (air temperature, precipitation, wind). The Marine Water Monitoring Program has begun to address both of these. Local weather anomalies associated with the 1992 and 1993 ENSOs were reflected in the salinity and temperature of Puget Sound monitoring stations (Newton, *in press*). A longer record should be analyzed to ascertain if a consistent ENSO signal is seen. Effects of air temperature, precipitation, and flow on salinity and temperature in Budd Inlet during 1992 through 1994 have been analyzed by regression analysis (Eisner, *in prep.*) with the assistance of a student intern's (K. Kaplan, The Evergreen State College, TESC) time. Salinity was most affected by flow ($r^2 = 0.51$), whereas water temperature was significantly affected by air temperature ($r^2 = 0.64$). Stratification in Budd Inlet was most affected by salinity, as has been observed in many other Puget Sound embayments (though not always in Sinclair Inlet, Albertson et al., *in press*). This fact is why freshwater diversions are of high concern to water quality, in addition to how circulation and flushing may be affected (cf. Copping et al., 1994).

Turbidity: Freshwater diversions are also of concern for how structures and/or holdings affect the suspended particulate load of the freshwater input into Puget Sound. Other watershed developments and paving can also alter particulate loads. Light attenuation in marine systems is from both sedimentary particles and from living cells, e.g., phytoplankton. To examine the relative contribution of both particles types in determining light attenuation, monthly values of the light extinction coefficient, k , were calculated from Secchi disk data for all monitoring stations in WY 1993 and regressed versus the 0.5-m chlorophyll a concentration (cf. Appendix D in Newton et al., 1994). Results varied, as might be expected, according to degree of freshwater input (e.g., r^2 for Sinclair Inlet = 0.64; r^2 for Saratoga Passage = 0.03). Outlier months (with very high k values) were sometimes seen, frequently in winter and spring months, presumably corresponding with high precipitation/flow events and high sedimentary contributions. Ecology is presently obtaining historical weather data so correlations with weather can be identified.

Additional analyses of the long-term data set to be conducted include: assessing trends in euphotic zone depths, as indicated by the long Secchi disk data record; assessing trends in nutrient ratios (N:P); assessing whether nitrate vs. temperature regressions can indicate eutrophication; longer analyses (1973-present) of water column parameters at Ecology monitoring stations; etc. Long-term analysis of chlorophyll a data is not recommended since prior to 1994, filters were stored in air, not acetone, causing a pigment degradation of up to 22% (Eisner, 1994a). Concerns with DO and nutrient data also need to be resolved (see *Issues and Recommendations* section).

While the present analysis of the long-term monitoring data has revealed many patterns, of concern particularly to this review is what has not been revealed: information on chemical contamination in the water column, the degree of variation on parameters due to tide, time, and weather; the spatial representativeness of the monitoring stations; knowledge of transport/flushing characteristics; and estimates of future water column impacts at specific locations from modeling present-day conditions, currents, and inputs. Information on some of these issues has been obtained through seasonal/focused monitoring (see below). All of these issues will be discussed in the *Issues and Recommendations* section of this document.

Seasonal/focused monitoring

The comprehensive sampling surveys conducted in 1992-1993 provided an excellent assessment of spatial variation. In each of the embayments monitored during these years (Table 4), 15 to 20 stations were occupied as opposed to one, as in the long-term component. In Budd Inlet and Sinclair Inlet, sampling was conducted every two weeks, as opposed to monthly. A high degree of variation, not evident from the long-term monitoring station, was revealed in each of the three embayments. Unfortunately, the sampling, data processing, and data analysis from these projects were highly time and labor intensive. While sampling can be conducted using volunteers and seasonal temporaries, the data processing, data analysis and report writing for these comprehensive studies has progressed more slowly. This has been severely impacted by the low number of full-time staff who run the Marine Water Monitoring Program presently.

The newer focused projects (e.g., 1994 onwards) have been more tenable in terms of narrowing the focus and answering one or two specific questions of water quality concern. This question-

driven format is also useful for in communicating purpose and significance to management and other non-technical people. Identification and quantification of forcing mechanisms and of long-term change are two important categories for questions driving these projects. Refer to Table 4 for preliminary results from these projects.

Useful information was obtained during the seasonal/focused projects that was relevant to each particular location (Table 4). Of further interest are the general observations that were consistent for most of the projects:

- 1) The inner portion of the inlet/bay has different water quality character than the central and outer portions. This result was observed in Budd Inlet, Sinclair Inlet and Sequim Bay. In all cases, the dimensions of the inlet/bay were longer than it was wide and the inner stations had lower DO than the other stations, including the long-term monitoring station (Figure 2A). Substantial differences with distance also were found along the 18-station transect in Hood Canal. In Dyes Inlet, a rounder embayment, conditions were observed to be different on the east vs. west sides.
- 2) Tidal stage can cause great variation in parameters. A 52-h tidal cycle survey was conducted in Budd Inlet (Eisner et al., 1994). Results from that study and from other tidal comparisons in Sinclair Inlet show that parameters such as DO and temperature can vary as much in one day as they do between weeks or months (Figure 2B). This is an important observation since long-term monitoring is conducted without respect to tides. Variation due to tides in Hood Canal was low, due to its high volume and long extent.
- 3) Biological and chemical parameters (e.g., phytoplankton abundance and nutrients) can change rapidly (Eisner et al., 1994). Different pictures emerge when bi-weekly versus monthly data are shown.

In summary, the seasonal/focused projects have provided good insight on the spatial representativeness of the monitoring stations and some information on the degree of variation on parameters due to tide. A particularly bothersome observation during the Sinclair Inlet seasonal monitoring project was that at several times schools of *Aurelia* medusae were seen with highly abnormal numbers (6-7) of gonad rings (C. Mills, Friday Harbor Labs, pers. comm.) drifting in the Sinclair Inlet waters we reported had acceptable water quality in terms of DO, nutrients and fecal coliform bacteria (Albertson et al., *in press*). Sinclair Inlet is a site known to have contaminated sediments, e.g., lead, mercury, copper, silver (Dutch et al., 1992; Llansó, 1995 Sediment QIR paper).

ORIGINAL PSAMP OBJECTIVES AND SAMPLING DIRECTIVES

Objectives

As summarized in the preceding section, Ecology's Marine Water Monitoring Program has provided much insightful information and has established a solid continuation of its comprehensive water-column time-series. The question remains, how well has it addressed the original objectives of the PSAMP (Table 1)? The original PSAMP objectives within each of the categories listed below (from Table 1) are evaluated here. Because the objectives were quite broad for this start-up program, it is difficult to be stringent in this analysis; however, in the

following assessment, some of the issues that will be developed in the *Issues and Recommendations* section are identified.

Long-term trends, spatial and temporal patterns: Spatial and temporal patterns of water quality attributes have been identified (e.g., Tables 5 through 8). Identification of long-term trends from 5 years of data is not possible. Further analysis of Ecology's complete data set should be conducted. Comparison of present data with historical data (e.g., Collias et al., 1974) also should be conducted and has been the concern of both 1995 focused projects (**Issue #8**). Improvements can be made to data presentation, for instance, contouring data from one station through time and comparing plots from stations along the N-S axis of Puget Sound. Unfortunately, the prevalence of missing data during months with inclement weather (cf. Appendix B in Newton et al. 1994) would make contouring difficult at times. Improvements also could be made to the station selection and coverage (**Issue #3**).

Contaminant transport pathways: Has not been addressed (**Issues #11 and 12**).

Water movement: Has not been addressed (**Issues #3 and 11**).

PSAMP integration: Needs improvement (**Issues #6 and 7**).

Management and policy effectiveness/compliance: This is mostly relevant to FCB and harmful phytoplankton monitoring. Ecology data for temperature, salinity, DO, nutrients, pH, and FCB are used annually for establishment of the Federal Clean Water Act Section 303d Water Quality Limited Waterbody Segments for Washington State, and in generating the Statewide Water Quality Assessment, Section 305b Report (Ecology, 1992). Results of seasonal/focused projects are directly applicable to management goals, but translation of this information to management needs to be addressed. Improvements should be made to FCB (**Issue #9**) and harmful phytoplankton (**Issue #10**) monitoring. Continue to direct focused projects to relevant water quality concerns (**Issue #6**).

Assess Puget Sound health: Could be improved by assessing food-web attributes (**Issue #13**), chemical contamination in the water column (**Issue #12**), and flushing ability of Puget Sound (**Issue #11**).

Water column characterization: Physical parameters have been described well for the areas and times sampled. Consideration of tidal and other variation is necessary. Chemical (e.g. nutrients, DO) and biological (e.g., phytoplankton) parameters have not been determined well, primarily due to sampling and analytical limitations (**Issue #5**). Chemical parameters have not been determined at depth (**Issue #4**), where long-term changes could be detected.

Solstice monitoring to measure end-point conditions: Has not been funded or implemented.

Sampling directives

A "report card" was devised to evaluate how well the original PSAMP sampling directives for the Marine Water Column monitoring have been obtained (Table 12). The overall grade for the

monitoring is a “B”. As shown, several specific technical problems have been encountered, some that have been resolved, some that are being resolved, and some that require improvements to sampling design or integration with other PSAMP investigators. These technical problems will be addressed in the *Issues and Recommendations* section.

PROPOSED MARINE WATER OBJECTIVES AND ASSESSMENT QUESTIONS

This section contains the objectives and questions proposed for the PSAMP Marine Water Monitoring, as implemented by Ecology. Before specific issues regarding marine water monitoring can be debated and changes to the marine water monitoring design recommended, it is imperative to have defined the goals of the PSAMP and the objectives of Ecology's Marine Water Monitoring within the PSAMP. Members of the PSAMP Steering Committee have identified six goals for the future of the PSAMP. Each of the Marine Water (MW) objectives is firmly rooted in facilitating achievement of one of these six PSAMP goals and, thus, reflects what relevance Marine Water Monitoring has to the PSAMP. A short narrative below each objective provides elaboration and pertinent details. The assessment questions that follow for the objectives further define the approach to be taken towards meeting that objective. It is anticipated that specific assessment questions may change with time, evolving as more data is obtained and our understanding increased. Also, in some cases, a specific assessment question or marine water objective will be addressed by more than one agency or task. These collaborations are identified. The following convention has been used to specify assessment questions:

** represents that this is a new focus for PSAMP that cannot be addressed by the data currently collected for PSAMP;

* represents that this is only partially being addressed by the types of data currently collected for PSAMP.

PSAMP Goal 1: Determine and evaluate the spatial extent and rate of change of anthropogenic contamination in Puget Sound.

MW Objective 1.1. Determine the extent and rate of change of anthropogenic contamination in the marine waters throughout Puget Sound.

For the marine water column environment, anthropogenic contamination comprises three areas: fecal contamination, loading of excess amounts of nutrients (eutrophication), and chemical contaminants such as toxics, metals, and oils. The occurrence of the first two of these in Puget Sound has been addressed under the current monitoring program and only refinements are required (**Issues #3, 4 and 9**). It is necessary to evaluate, however, whether chemical contamination in the water column, particularly in the surface micro-layer, should be addressed (**Issue #12**). Lastly, but of high importance, in order to assess the impact of any anthropogenic contamination to the marine waters, better knowledge of residence times is necessary (**Issue #11**). Relatively little is known about the flushing capability of Puget Sound, particularly under different freshwater input regimes.

1.1a. What is the spatial extent and rate of change of fecal contamination in Puget Sound marine waters (**Issue #9**)? (Health, Metro)

1.1a.1. Is the fecal coliform bacteria (FCB) methodology used appropriate for indicating sewage contamination, and thus pathogens, in marine waters?

1.1a.2. In Puget Sound, are high FCB concentrations in marine waters predictably associated with rain runoff or do areas of persistent contamination exist?

1.1a.3. Are stations with high FCB concentrations located near freshwater input, indicating this is the major vector for contamination of marine water by FCB, or near urban areas, indicating that urban areas are the highest supply of FCB to the marine water?

1.1a.4. Are the areas with high FCB concentrations in marine waters co-located with areas where contamination is noted on beaches and/or in shellfish? (Health)

1.1b. Where and to what extent does nutrient loading (eutrophication) of Puget Sound marine waters occur? (Ecology FW)

1.1b.1. What is the spatial and temporal variation of the N:P ratio in Puget Sound waters? Where it is radically different than the Redfield ratio, are these areas where nutrient loading can be identified; are these areas with poor water quality conditions?

****1.1c. Are there chemical contaminants in the marine waters in biologically significant concentrations (**Issue #12**)?**

1.1c.1. What is the fate of chemical contaminants entering Puget Sound; are significant concentrations found in the water column?

1.1c.2. Is there evidence from contaminated areas in Puget Sound that chemical contaminants accumulate in the surface micro-layer?

1.1c.3. Is there evidence for impaired growth/reproductive success of biota due to the concentration of chemical contaminants found in the marine waters of Puget Sound?

****1.1d. What is the flushing rate of the water in Puget Sound as well as in various sub-basins, inlets and bays (**Issue #11**); what are residence times for contaminants, both floatable (hydrophobic substances, e.g., oil) and dissolved substances (hydrophilic substances, e.g., atrazine herbicide, nutrients), in these same areas?**

PSAMP Goal 2: Determine and evaluate the state and rate of change of environmental conditions affected by anthropogenic physical alteration of the Puget Sound landscape.

MW Objective 2.1. Document long-term changes to the physical characteristics of the marine waters of Puget Sound caused by anthropogenic physical alterations to the landscape, and identify their effects on the ecosystem.

One of the major anthropogenic physical alterations to the landscape that influences marine waters has been the construction of dams and other diversions to rivers. Puget Sound receives freshwater from numerous rivers; this freshwater input drives estuarine circulation, stratification, as well as contributing particulate matter and dissolved substances. When diverted, not only can the amount of freshwater input be reduced, but, primarily, the timing of the input is drastically altered. Ebbesmeyer and Tangborn (*in press*) presented data from the Skagit River showing the maximum freshwater delivery in un-diverted conditions is approximately 6 months out of phase from that delivered downstream of power-generating diversions. In a temperate (seasonally influenced) region such as Puget Sound, this change could have consequences on the estuarine

circulation. Damming also can reduce the sedimentary load, which influences the light environment of the marine water column. The magnitude and significance of the effects of freshwater diversions on the marine water column are not established. The British Columbia/Washington Marine Science Panel that was convened in order to evaluate marine environmental concerns in the shared U.S.-Canadian waters identified impacts from freshwater diversions as having “high” overall priority (Copping et al., 1994). (Ratings ranged low, medium, high and very high, with only one issue of “very high” priority: habitat loss.)

Other physical alterations to the Puget Sound landscape that may influence water column attributes include: an increase in non-porous surfaces (i.e., paved, built on), which exaggerates storm run-off and can wash surface contaminants into Puget Sound; and logging and road-building, affecting the particulate loading of the freshwater inputs into Puget Sound. Both of these alterations could have major impacts on the amount of suspended particles in Puget Sound.

2.1a. Has the salinity of Puget Sound waters been affected by the alteration of freshwater delivery due to freshwater diversions; is the estuarine salinity-driven circulation affected?

2.1b. Has the light transparency of Puget Sound marine waters changed due to alterations in freshwater sedimentary loads; are the pelagic and near-shore flora affected? (DNR)

PSAMP Goal 3: Determine and evaluate the status and trends of the biota of Puget Sound.

MW Objective 3.1. Assess the status and trends of the planktonic organisms in Puget Sound and their relevance to water quality trends.

Plankton have relatively short lifetimes and are immersed in the marine waters throughout all their lives. These characteristics make planktonic organisms good indicators of water quality conditions (**Issue #13**). There are many types of plankton data with high pertinence to assessing water quality. Phytoplankton, at the base of the food web and directly involved with nutrient and DO cycling, are of obvious importance. Their production rates and sensitivity to nutrient addition has been investigated at a relatively few Puget Sound locations. As anthropogenic nutrient inputs increase with increasing population and development in the region, knowledge of nutrient-sensitive areas is of high importance. Harmful phytoplankton blooms appear to be increasing in prevalence in Puget Sound (Horner, 1994). The introduction of exotic (non-native) species can have major implications throughout the ecosystem, but presently is not monitored for. Zooplankton biomass has shown a long-term decline association with decreased upwelling and increased sea temperatures off California (Roemmich and McGowan, 1995). Whether zooplankton populations in Puget Sound are stable is not known. The influence of pollutants on zooplankton populations is not well known. While chemical contamination in invertebrates, fish, and birds is monitored in the PSAMP, no information is obtained for plankton, a vital link in the food-web. Lastly, while parameters like DO, nutrients, and salinity, can change rapidly, e.g., in response to weather shifts or mixing processes, a food-web will change more slowly, responding to these and other conditions. The structure of the food web produced in a given environment reflects an integration of environmental conditions. When characterizing an environment or assessing its "health", such integrative indicators hold much information.

*3.1a. What is the spatial and temporal variation of phytoplankton biomass, production and species composition; what is the relation of these to nutrients, stratification or other environmental parameters? (**Issues #6, 10, and 15**)

3.1b. What is the spatial and temporal variation of toxic phytoplankton; can blooms be linked to environmental parameters (**Issue #10**)? (Health)

3.1c. Do overwintering zooplankton at reference sites in Puget Sound exhibit long-term trends in population size, gender composition, or species composition; can any of these be related to sea temperature or salinity or other parameters (Issue #13**)?

3.1d. Is there information from food-webs regarding eutrophic environments (Issue #13**)?

PSAMP Goal 4: In the context of discerning anthropogenic influences, determine and evaluate the natural variability of Puget Sound biota and environmental parameters.

MW Objective 4.1. Assess the spatial and temporal (seasonal and long-term) patterns of marine water column environmental parameters.

Puget Sound is an extremely non-homogenous environment. While the complete diversity of Puget Sound cannot easily be characterized, this objective presently is being addressed in the major basins and bays. Challenges to how well this objective is being addressed primarily regard sampling schemes, such as monthly vs. moored sensor data, point vs. transect sampling, and the inclusion of the nearshore environment (**Issues #3 and 14**).

4.1a. What are the spatial and temporal patterns of temperature, salinity, and density stratification in Puget Sound marine waters?

4.1b. What are the spatial and temporal patterns of nutrients, chlorophyll *a*, dissolved oxygen, light transparency and contaminants in Puget Sound marine waters; how do these relate to each other and to density stratification?

MW Objective 4.2. Evaluate the extent to which a particular natural or anthropogenic mechanism affects or could affect key parameters of the marine water column.

Puget Sound waters are an extremely dynamic environment. At a given time, multiple forcing functions and processes simultaneously act on various timescales, from hours to decades. In order to understand what impacts are most important and where, it is imperative to try to separate and quantify effects from various processes.

*4.2a. To what degree do tidal and diel processes affect water column parameters (esp. DO, density, and nutrients) in different areas of Puget Sound? (**Issue #14**)

4.3b. How does circulation and refluxing affect water column parameters in various areas of Puget Sound? (Issue #11**)

4.2c. What is the impact of ENSO and weather conditions on Puget Sound marine water temperature, salinity and other water column parameters?

*4.2d. Where are the areas in Puget Sound where nutrient-addition stimulates phytoplankton growth? (**Issue #6**)

4.2e. In areas where eutrophication is evident (1b), are other marine water parameters affected?

MW Objective 4.3. Discriminate the effects from natural versus anthropogenic mechanisms on marine water column parameters by analysis of historical data or data where natural variation is low.

This discrimination is difficult since, aside from some contaminants (e.g., atrazine), water quality attributes (e.g., ammonium-N) and their influences (e.g., circulation) have natural levels or degrees. However, some discrimination can be made by using the products from the previous two objectives (4.1 and 4.2) and making comparisons across space or time. No monitoring can have significance if the historical record is ignored (**Issue #8**). The utility of historical baseline data in interpreting present-day conditions is quite high. For the PSAMP, it is important to assess historical conditions, as well as to lay firm groundwork for preserving the continuance of a historical record.

4.3a. What are the differences between present-day Puget Sound data from the historical data? (**Issue #8**)

4.3b. Is there evidence from historical data that marine water low DO conditions are getting worse in areas of Puget Sound; are these areas influenced by anthropogenic mechanisms, and if so, which mechanisms (e.g., nutrient/organic loading, decreased circulation)?

4.3b.1 What information do benthic data yield on the severity of low DO concentrations in marine bottom waters? (Ecology Seds.)

4.3b.2 Do tidal/diel cycles influence DO data such that continuous *in situ* sensors are necessary?

4.3c. In areas with similar density stratification, are the seasonal patterns of nutrients, phytoplankton abundance and dissolved oxygen also similar?

4.3d. Are there any change in the bottom-water data from long-term background stations located in the major basins of Puget Sound? (**Issue #3**)

PSAMP Goal 5: Assess the anthropogenic changes in Puget Sound that may cause human health effects.

MW Objective 5.1. Document what environmental conditions are associated with outbreaks of harmful phytoplankton in order to assess whether anthropogenic influence plays a role. (Health, Ecology MW, Sea Grant/Oyster Growers)

Written record of harmful phytoplankton poisoning in the Puget Sound region extends as far back as 1793 (Taylor and Horner, 1994). The occurrence of these blooms appears to be increasing and it is important to assess whether humans play a role. Knowing the occurrence of harmful phytoplankton blooms is important; however, understanding the stimuli for the blooms is particularly useful information (MW Objective 3.1). This information is much more elusive to obtain, in part because so often it is the conditions at the time of the bloom that are well documented, and not the conditions prior to the bloom. Once information on the conditions that stimulate blooms is available, predictive capability may be possible, but, also, only then can the contribution of anthropogenic influence on harmful phytoplankton blooms be assessed. In the PSAMP, this objective shall be shared between Health and Ecology (**Issue #10**). Recently, Ecology's Marine Water Monitoring staff devised a simple water quality sampling design (Newton, 1995c) for volunteering oyster growers partaking in a Washington Sea Grant/Pacific Coast Oyster Growers Association (PCOGA) project on oyster Summer Kill Syndrome. Sampling includes phytoplankton species and environmental parameters; growers were outfitted with sampling equipment at relatively low cost. This sampling design should be considered as a template that could be replicated e.g., to Health's mussel cage samplers, or established citizen groups, in order to increase monitoring coverage and build a significant database. Phytoplankton samples need to be analyzed only if a bloom subsequently develops. Such an approach is the only way to gain predictive information on the stimuli for harmful phytoplankton blooms and then to assess whether anthropogenic influence contributes.

MW Objective 5.2. Document where fecal coliform bacteria levels are high enough to pose human health hazards. (Health, Metro, Ecology MW)

This is also a jointly shared objective. Sampling with respect to where human health hazards may exist has not been an active consideration of Ecology's program. Agency efforts and methodologies need to be assessed (**Issue #9**).

PSAMP Goal 6: Support management and research activities by making high-quality data available.

MW Objective 6.1. Collect, archive, analyze, report and disseminate high-quality marine water column data.

Ecology's Ambient Monitoring Section, in which Marine Water Monitoring resides, has an active in-house database where more than 20 y of marine water monitoring data are recorded and accessed. Refer to Appendix A of the briefing paper (Newton et al., 1995b) for data availability. These data have been downloaded to U.S. EPA's national STORET and PC-STORET. Data requests are actively filled on a weekly basis to numerous requesters in the form of disks (ASCII or Excel) or hard copy. Roughly six marine water data requests per month are filled for paying clients from the public, private, and academic sectors. Some of the program-wide assessment questions listed below have specific application to the marine water monitoring. Of particular importance is to increase integration between PSAMP components, with respect to sharing data and conclusions, and also with respect to discussing future project questions and planning complementary sampling.

- 6.1a. Are our data high-quality?
 - 6a.1 Assess quality of data in Ecology marine water database (1973 - present) (**Issue #7**).
 - 6a.2 Address problems with DO measurements (**Issue # 5**).
 - 6a.3 Address problems with nutrient analyses.
- 6.1b. Do universities, agencies and public interest groups know about our data?
 - 6b.1 Give lectures.
 - 6b.2 Publish results in journals.
 - 6b.3 Attend regional and national conferences.
- 6.1c. Does management know our major results and understand their significance?
 - 6c.1 Hold 'briefing sessions' with Ecology managers and assistant director.
 - 6c.2 Circulate short written briefs upon completion of report/project.
- 6.1d. Are we conducting relevant and complementary investigations?
 - 6d.1 Participate in PSAMP annual retreat to present and discuss previous year's results and to select foci for focused projects and/or flexible stations.
 - 6d.2 Form PSAMP sub-committees on topics of inter-disciplinary interest.

ISSUES AND RECOMMENDATIONS

Issues have been divided into four categories based on the degree of impact to the Marine Water Monitoring Program: 1) Realities, i.e., areas of high concern that affect the entire program; 2) Refinements, i.e., small refinements to the existing program; 3) Improvements, i.e., substantial changes to facets of the existing program; and 4) Gaps, i.e., development of monitoring avenues currently lacking from the program. The issues discussed in this text have been previously referenced throughout this document. Strength of the recommendations are rated as follows: (+++) = very highly recommended, i.e., needs to occur; (++) = highly recommended, i.e., should occur; (+) = recommended, i.e., beneficial.

An initial recommendation is to adopt the six PSAMP goals and the MW objectives outlined in the previous section. (++)

Realities

Before a more philosophical analysis of the scientific issues and considerations for the program's future direction, a few realities must be acknowledged up front.

Issue #1--Staffing: The Marine Water Monitoring Program of Ecology presently consists of three full-time personnel. Originally funded for four full-time positions, because of agency staffing reductions and hiring restrictions, only three positions are presently filled. The low level of staffing for the Marine Water Monitoring Program severely hampers the amount of monitoring possible, the speed of report completion, and the time available to disseminate Program results. Over the last six years, sampling and data processing/synthesis crises have been filled in with temporary or intern staff. Current state hiring policy and reductions in force makes hiring new temporary staff, who have oceanographic training, difficult. In addition, much time

can be devoted by permanent staff to train short-term (<6 mo.) interns, while long-term data analysis and reports remain unfinished. Completing annual plus seasonal monitoring reports, conducting the long-term and focused sampling programs, maintaining equipment, processing data, maintaining an updated database, and filling data requests for the entire Marine Water Monitoring Program is a large amount of work for a staff of three. There are numerous tasks of various levels of sophistication that need completion. On-going field programs have many unappreciated time requirements. The Marine Water Monitoring Program needs additional oceanographically-trained individuals as well as individuals who will be with the program for more than 6 months.

It must be recognized that undertaking any new directions must be reconciled with an appropriate level of staffing required to do it. In spite of the productivity of the Marine Water Monitoring Program staff under the currently strained conditions, the reality of what three people can cover for a field program of this scope is limited and must be recognized.

Recommendations--

- Increase the level of full-time staffing for the Marine Water Monitoring Program. (+++)
- Pursue an active oceanography student internship program. (+)

Issue #2--Shiptime and access to Strait of Juan de Fuca. Another reality is that while Ecology's use of a float plane for long-term monitoring is efficient and cost-effective for covering the large number of areas sampled, it is, however, unacceptable for sampling the Strait of Juan de Fuca and the northern Strait of Georgia, due to seas that are typically too high for landing and take-off. For focused projects, Ecology's largest vessel is a 20' Boston Whaler with the capability of sending sensors/bottles down to ~35 m. The Hood Canal focused project was conducted using a chartered 60' vessel and with some R/V shiptime donated by Ocean Technical Services at the University of Washington. There is little money in the present budget for shiptime. Lack of shiptime on a decent sized research vessel with covered laboratory space plagues the ability of the Marine Water Monitoring Program to conduct comprehensive monitoring in Puget Sound.

The omission of sampling the Strait of Juan de Fuca in the present program needs to be seriously considered. These waters are the oceanic source water for Puget Sound, yet current long-term sampling in the U.S. Strait of Juan de Fuca waters is not known. The waters at ADM002 have been monitored, but because of its proximity to mixing processes in Admiralty Inlet, this station is not exclusively representative of the Strait. Specific reasons for monitoring the Strait of Juan de Fuca waters include: to detect changes in incoming temperature and salinity of oceanic waters, driven by climate, ENSO, and other forces; to detect changes in nutrient and DO concentrations due to changes in upwelling intensity off the coast; and to detect the influx of exotic and/or harmful species into Puget Sound. *Pseudonitzschia*. and other harmful phytoplankton were recently detected off the Pacific Coast (July, 1995; R. Horner, UW, pers. comm.) yet little is known regarding whether these cells actively flow into Puget Sound through the Strait of Juan de Fuca. The PSAMP needs to evaluate whether resources should be spent to monitor the open waters of the Strait of Juan de Fuca, or it should be dropped from mention as part of the program.

Recommendations--

- Investigate deployment of moored sensors (see also **Issues #11 and 14**). (++)
- Fund shiptime on larger vessels for focused project sampling in Puget Sound (+++) and for monitoring the Strait of Juan de Fuca. (++)
- Address monitoring of the Strait of Juan de Fuca or refine definition of PSAMP geographical area. (+++)

Refinements

Issue #3--Long-term monitoring sampling strategy. The concept of occupying core stations in order to establish long-term conditions and patterns is sound, and has been yielding valuable information. Many of the present core stations have data extending back to the 1970's from Ecology monitoring, and many of these same stations were occupied by UW oceanographers back several decades further. To interrupt this long-term data record would not be wise. This is particularly true, since none of the 16 core stations monitored have similar characteristics or water quality attributes (Tables 5 through 8). The present set of core stations represents many of the key areas in Puget Sound required to address large-scale variation. Evaluation should be made on whether there are additional key areas that may yield valuable information. Examples of stations and reasons for inclusion are: 1) stations, such as the old ADM003 and rotating station EAP001, along the main axis of Puget Sound, that in concert with present stations would allow a better transect view of the Sound. If data is plotted against time and stations in the transect are compared, some information on water mass movement is possible; 2) HCB002 (never visited) in Dabob Bay, source of some of the deepest, oldest water in Puget Sound with information on long-term stability or change; and 3) stations where new development is most severe or where increased loadings are projected, e.g., southern Puget Sound inlets, off the Nisqually and Skagit Rivers, in order to detect changes and to gain baseline data with which to model impacts before they occur.

After such an evaluation, we recommend selecting a set number (~20) of core stations to be monitored monthly. Under the proposed PSAMP format, these will be called "fixed" stations (Prescott, 1995 PSAMP QIR paper). We recommend dropping the strict concept of 3-yr rotating stations and instead adopting "flexible" stations. A number of flexible stations would be identified in areas where water quality problems are suspected or where little information is available. A group of these flexible stations (~5-10) would be occupied as part of the long-term monitoring component for one year. If water quality problems are detected at any of the flexible stations, e.g., as has been noted in Eastsound (EAS001) and Penn Cove (PNN001), the station should be retained and/or the topic of a focused project. If problems are not detected, the station would be dropped. This approach allows more stations to be assessed and places effort on finding problematic areas.

It is obvious from the seasonal monitoring that stations further in the inlets or bays have different water quality attributes than the long-term monitoring stations. Of particular concern is that the low DO concentrations that exist in the inner areas would not be suspected from the long-term station data (Figure 2A). However, low DO concentrations are seasonal in Puget Sound. Thus instead of moving all stations inwards, or increasing the number of flexible stations occupied throughout the year, it is recommended to run transect surveys monthly during August through

October in numerous Puget Sound bays and inlets. If low DO problems are detected, more thorough monitoring to assess spatial and temporal patterns in nutrients, stratification, etc. should be conducted through a focused project.

Recommendations--

- Retain a set number (e.g., 20) of fixed stations for vertical profiling. Make selection criteria based on existence of historical data, representativeness of basins and urban bays, and diagnostic information (e.g., oceanic sources, old Puget Sound water, etc.). (+++)
- Reduce the number of other stations occupied each wateryear; select a cadre of flexible stations to be occupied for one-year intervals. Stations with problems should be retained for further monitoring or a focused project. (+++)
- Conduct transects or otherwise sample inner portions of bays in late summer to early fall in order to investigate presence of low DO concentrations. (++)

Issue #4--Fixed station parameters. Nutrients need to be sampled at depth in order to monitor long-term changes and to trace water masses. The upper water column (≤ 30 m) is involved with biological processes and, thus, is highly variable. If long-term changes in nutrient concentrations in Puget Sound are occurring, these will be seen at depth, where the long-term signal to short-term noise ratio is tempered. Profiles of nutrients (e.g., 6 depths between 0.5 m and the near-bottom) should be taken at selected stations along the main axis of Puget Sound, such that by contouring over time, and along transect, water mass movement can be inferred.

Because diatoms are a major component of Puget Sound phytoplankton and their distribution is influenced by silicate concentrations, understanding phytoplankton populations in Puget Sound requires knowledge of silicate concentrations.

Ecology contracts nutrient analyses to Manchester Environmental Laboratory (MEL). Poor results have been obtained for matrix spikes on marine nutrient samples (spike recoveries of 50% to 160%). The cause for this is unknown; however, their use of freshwater standards for nutrient analyzer calibrations when running marine water nutrient samples is highly suspect. MEL's freshwater matrix spikes show good quality recoveries. This problem needs to be rectified.

Evaluations should be made on sampling for FCB and for phytoplankton species. These topics are developed as **issues #9 and #10**, respectively.

Recommendations--

- Add sampling of nutrients at depth. (+++)
- Evaluate adding silicate as a measured nutrient. (+)
- Secure a way of getting acceptable marine water nutrient analyses. (+++)

Issue #5--Equipment. A significant problem was recently detected regarding the DO sensor data collected by Ecology's Marine Water Monitoring Program. *In situ* membrane DO sensors, as are outfitted on Ecology's Sea-Bird Electronics, Inc., CTD profilers, have an inherent time-lag in their measurement ability. Since the measurement of DO is dependent on temperature as well as DO, the lag is exacerbated when the instrument goes through a thermocline. During recent tests in the low DO near-bottom waters of Hood Canal, the discrepancy between the reading after

a 1-minute soak and a 9-minute soak was 1 mg/L. Up-cast and down-cast data, even after processing by Sea-Bird technicians were substantially different, reflecting the impact of the thermocline gradient. These results were obtained from a 19-m water column, where DO changed from saturation to values below 3 mg/L and temperature changed from 22 °C to 9 °C. *In situ* DO sensors have good accuracy in waters where gradients are smaller or spread over a larger vertical range. In all applications, however, adequate profiles of DO titration samples are required in order to ground-truth DO sensor data. After consultation with Sea-Bird technicians and UW Ocean Technical Services staff, we conclude that the large temperature and DO ranges within the short water columns found at many locations in Puget Sound pushes beyond the capability of DO membrane sensors. This problem is primarily noticeable when DO concentrations are below 3 mg/L.

Thus, it appears that the absolute value of the low DO concentrations <3 mg/L monitored by Ecology since 1990 may be uncertain by 1 mg/L. This is a serious issue, since this amount uncertainty is far too great in data to be used for identifying historical trends. This problem is not a factor of ill-maintained equipment. Sea-Bird technicians have approved of all calibration and processing procedures presently used by Ecology. Ecology maintains annual factory DO sensor calibrations and conducts monthly in-house calibrations. These calibrations, following manufacturer procedures, are 2-point calibrations, at saturation and zero DO concentrations, which does not address accuracy at low DO concentrations.

Because of the attention paid to monthly calibration procedures, the standard operating procedure of Ecology's Marine Water Monitoring had been to take only one or two samples per flight for Winkler titrations. Samples were taken from mid-depth (10 m or 30 m) bottle casts below the thermocline; seldom were these from near-bottom depths and at most only two out of about ten stations per flight were sampled. Because of the high uncertainty in the probe data, more samples for DO titrations are required and should be from several (e.g., 6) depths over the water column and at each station.

Ecology's DO titration procedures for marine waters need evaluation. Ecology has used a sodium-azide modified Winkler titration (APHA et al., 1989) for measuring DO. Because of hazardous materials restrictions on marine flights, powdered reagents have been used (Hach™ powder pillows) for fixing samples. Use of these reagents was informally tested by UW Ocean Technical Services and found to produce results within acceptable ranges (K. Kroglund, UW, pers. comm.). Upon analysis of the DO sample by Ecology staff, a 100-mL subsample is titrated.

A comparison of DO concentrations measured by Ecology's CTD sensor and Winkler titrations from the Sinclair Inlet study is shown in Table 13, along with excerpted text from the report describing sources of variation (Albertson et al., *in press*). The variation is random and is in some cases unacceptable (>1 mg/L). The range of DO concentrations sampled did not include values <6 mg/L. The primary reason for the observed variation in DO results undoubtedly is due to differences in waters sampled by the CTD and via Niskin bottles approximately 10-15 minutes later. Plane/boat drift, water advection, and wire angles all contribute to this uncertainty. A rosette of bottles around the CTD is required. Ecology is presently investigating obtaining such a set-up. A secondary reason for variation is the CTD sensor; however, there is nothing further

that can be done to increase sensor accuracy. Soaking the sensor for several minutes at the near-bottom depth can and should be done, yet this cannot provide a more accurate profile of DO. The third reason for variation is imprecision in titrations. The Carpenter (1965) modification of the Winkler (1888) method is typically recommended for marine waters for improved accuracy. This method uses a smaller volume buret, more concentrated sodium thiosulfate, and eliminates sample transferring, since the titration is conducted in the sample bottle. Ecology presently has two cases of calibrated Carpenter-method bottles recently donated by K. Kroglund. The UW Ocean Technical Services employs an automated Dosimat™ for conducting large numbers of titrations in a rapid and consistent fashion. This allows a high number of samples to be analyzed in a reasonable time.

In order to obtain accurate DO concentration data in Puget Sound, Ecology needs to collect profiles of samples for DO titrations and purchase an automated titration set-up for Carpenter method titrations. The present data cannot be used to assess historical trends nor to accurately assess present-day water quality.

Recommendations--

--The Marine Water Monitoring Program must obtain a rosette for ~6 Niskin bottles to be attached to the CTD for DO and nutrient sampling. (+++)

--Collect profiles of samples to be analyzed for DO using automated Carpenter titrations. (+++)

Issue #6--Focused projects. The underlying principle behind monitoring versus focused project investigations is analogous to taking a patient's pulse at regular intervals, versus putting the patient on a treadmill or a new diet and measuring EKG's or other measures of heart condition before and after. The nutrient-addition experiments (Hood Canal) and the historical (Hood Canal, Whidbey Basin) or before and after (Budd Inlet) comparisons that comprise the focused projects are examples of this latter treatment, whereas long-term monitoring can be considered the pulse rate timeseries. The point of this analogy is that both approaches are necessary and complementary; both approaches are just as applicable to understanding "health". If sources of variation, forcing mechanisms, or estimates of change are not understood, the pulse has much less significance to planning and policy and also to an accurate assessment of condition.

Focused projects should be retained and expanded, when possible. In addition, it is recommended that PSAMP tasks work in a cohesive way on focused projects. For instance, the 1993 Marine Water seasonal monitoring project to assess low DO in Sequim Bay benefited from benthic data collected by Ecology earlier that year (Hannach et al., *in review*). Ecology's Marine Sediment Monitoring Program staff partook in the 1994 Hood Canal cruises to assess low DO concentrations in S. Hood Canal. There are many additional avenues for better integration of the PSAMP data including comparing water transparency with near-shore habitat changes, and relating biological resource distribution to water quality parameters. Discussion of scientific results at PSAMP Steering Committee meetings should be stressed. Topics for focused projects involving two or more tasks should be encouraged. A regular forum for deciding on these projects is necessary, e.g., an annual PSAMP Steering Committee retreat (Prescott, 1995 PSAMP QIR).

Recommendations--

--Continue to use focused projects to answer specific regional water-quality questions (e.g., 1995 projects), that have high relevance to marine water quality and to the PSAMP goals. (+++)
--Recommend and co-ordinate all focused projects with the PSAMP Steering Committee during annual retreat in late January. (++)

Issue #7--Database. The present database (Dbase IV™) has housed discrete (0, 10, 30 m) long-term marine water monitoring data since 1973. The database is easily uploaded to EPA STORET and downloaded to disks in either ASCII or Microsoft Excel™ format. At present, much of Ecology's data manipulations and graphics are done using Excel software. (Contouring has been done using Golden Software Surfer™ and Spyglass Transform™. Both of these software packages have drawbacks). Microsoft Access™ software has been adopted as Ecology's agency standard for databases. Because of its ease in interfacing with Excel, the Marine Water Monitoring Program will investigate use of this database software.

Ecology' Marine Water Monitoring Program presently fills numerous data requests to private, public and academic sector clients. We enclose a letter describing methods and all caveats with the data, as well as engaging in verbal communication regarding the data when requests are received.

More data transferring between PSAMP tasks is important. A standardized file transfer format should be established. The lack of data transference among PSAMP principal investigators has, in our experience, been due to lack of scientific coordination, not to technical limitations. For the most part, recent software advances make data transfers between applications a non-issue.

While a centralized database would have some value, e.g., log-in capability to schools and universities, we have two major concerns. First, data requests are presently filled in a timely and informed manner. We feel it is important to preserve the link between the data collectors and the data users. Second, for the goal of increasing PSAMP synthesis, of primary importance is to have more scientific discussion and better collaboration between PSAMP investigators. Whether data exchange between PSAMP tasks is through standardized file transfer formats or through log-in to a centralized database is of secondary importance. The amount of revenue and personnel required to establish and maintain a centralized database needs to be critically evaluated and weighed against other PSAMP needs.

Recommendations--

--Improve in-house database (e.g., Access™). (++)
--Standardize file transfer formats for PSAMP to facilitate data transfer. (++)

Improvements

Issue #8--Historical/other data. As previously stated for MW objective 4, no monitoring can have significance if the historical record is ignored. The Marine Water Monitoring Program has been placing effort on obtaining historical data from Puget Sound. Many technical reports and archived data from the University of Washington were recently obtained. Our goal is to catalog and house a Puget Sound marine water data repository at Ecology. Numerous scientists have

donated data/reports for this effort already. Due to staffing shortages, most of these data are still in boxes.

Recommendations--

--Continue to act as a repository for historical Puget Sound data. (++)

--Catalog, inventory and enter historical marine water column data into Marine Water Monitoring Program database. (++)

Issue #9--Fecal coliform bacteria monitoring. FCB in seawater are monitored by Health, Metro and Ecology. Different approaches have been taken by each. Better integration and possibly consolidation of these programs should be addressed. A problem with Ecology's FCB sampling is that one monthly sample from the middle of a bay may not be an adequate assessment of sewage contamination. In addition, Ecology's sampling has been at the mid-basin and mid-bay stations, where FCB are likely losing viability rapidly due to saltwater exposure (Lessard and Sieburth, 1983). The Washington Administration Code 173-201A-030 (WAC, 1992) states that FCB "exceedences" shall be based on geometric means of count data but that samples cannot be averaged beyond 30 days. Thus, Ecology's monthly sampling of one sample at one station carries much weight on a particular estimate of a highly variable concentration.

For PSAMP, Health has sampled FCB from seawater at numerous stations at eight bays: Eastsound, Samish Bay, Penn Cove, Port Blakely, Burley Lagoon, Henderson Inlet, Oakland Bay, Quilcene, and Sequim Bay. However, Health also monitors FCB, primarily from intertidal waters, at roughly 80 commercial shellfish growing sites and 50 recreational sites throughout Puget Sound. Their monitoring is largely in response to detecting tainted shellfish beds or unsafe beaches. Metro's monitoring is of the greater Seattle-King County region, and includes beach and water-column samples. The range of their water column sampling is from just north of PSB003 (off Carkeek Park) to just north of EAP003 (N. tip of Vashon Island; Figure 1). Methods of detection vary between agencies also: Health uses the Most Probable Number (MPN) test (APHA, 1984), whereas Ecology and Metro use the Membrane Filter (MF) method (APHA et al., 1989) on seawater samples.

Is the monitoring of FCB by Ecology useful? Is it giving us information that we do not already get from Health and Metro? Are Health and Ecology overlapping sampling areas? Because of Ecology's low sampling frequency, are the data reliable? Are the data meaningful? All of these questions need to be evaluated and all three programs should be addressed in unison. As shown in Table 5, despite the low sampling frequency and variation, definite patterns were observed in the Ecology data and, in many cases, these were consistent between wateryears. In terms of assessing human health concerns from ingesting shellfish, Health covers the issue adequately. Ecology's FCB data are useful in identifying anthropogenic inputs, particularly in concert with high ammonium-N concentrations. The question that remains is are these data of high enough value, at the expense of other data or needs?

Recommendations--

--Assess whether Ecology's monitoring of FCB does or can yield useful information that Health's monitoring does not. If not, discontinue this element and rely on the complete suite of Health's FCB data, if so, refine sampling designs between agencies to better complement each other.
(+++)

Issue #10--Harmful phytoplankton monitoring. Increased monitoring of phytoplankton species should be addressed, particularly with reference to assessing the environmental conditions associated with harmful phytoplankton blooms. The incidence of harmful algal blooms is on the rise in Puget Sound (Taylor and Horner, 1994). Domoic acid poisoning (amnesiac shellfish poisoning; ASP), caused by some diatoms in the *Pseudonitzschia* genus, had not been documented on the West Coast prior to 1991. Its detection caused closures of shellfish beds on the Washington coast during 1991, 1993, and 1994 (Taylor and Horner, 1994). The diatoms which can produce domoic-acid have been found in Puget Sound (Horner, WDE, unpublished data), but documentation of where blooms occur and the associated environmental conditions is severely lacking. Paralytic shellfish poisoning (PSP) from certain dinoflagellate species (most commonly *Alexandrium catenella*) is annually prevalent in Puget Sound. The apparent increased prevalence of these outbreaks may be because of increased awareness, introduction of species (e.g., ballast water), or anthropogenic alteration of macro- and/or micro-nutrients. None of these possible causes have been proven, however. Other harmful phytoplankton observed in Puget Sound include: *Heterosigma carterae*, a small flagellate that can cause fish kills; a few species in the diatom genus *Chaetoceros*, that also can cause fish kills; and four species of the dinoflagellate *Dinophysis*, known to cause diarrhetic shellfish poisoning elsewhere, but as of yet has not been reported here (R. Horner, UW, pers. comm.).

Species succession and what stimulates a bloom of a certain species are notoriously complex issues that are typically not well-understood in natural systems. Nonetheless, some patterns have been noted, e.g., *Ceratium fusus* excels when surface nitrate is deplete (Eisner et al., 1994); *Skeletonema costatum* can dominate in low or variable salinity waters (Spies and Parsons, 1985; Rijstenbil, 1988). In Eisner's (1995b) analysis, patterns of species in three physically distinct environments (Georgia Strait, Puget Sound main basin, Budd Inlet) showed patterns that could be linked to environmental conditions (refer to summary in briefing paper; Newton et al., 1995b). It is probable that much of why blooms of phytoplankton species in natural systems appear to be unpredictable is that often the environmental data used to correlate with species abundance are the conditions at the time of the bloom, not from week or two prior. If progress is to be made on understanding what environmental conditions stimulate harmful phytoplankton blooms, data of this latter type are required. In addition, more phytoplankton samples and data are required to assess spatial and temporal patterns of blooms in Puget Sound. With a larger database in hand, pre-bloom data can be analyzed for patterns in environmental conditions that emerge in association with harmful phytoplankton blooms. Although taxonomic phytoplankton analysis is somewhat expensive in dollars and time, only the phytoplankton samples from periods before and during the blooms need be analyzed to address the objective; the others can be archived or disposed of after time has passed.

Ecology presently takes phytoplankton species samples during focused projects and has been archiving monthly samples from selected long-term stations. We recommend that this sampling

be standardized to involve a set number of specific stations and that samples be analyzed to establish seasonal baseline conditions. Health presently has an extensive phytoplankton sampling program, but the program was funded for one year only. The rest of Health's monitoring for PSP and ASP is from mussel tissue samples, obtained from mussel cages set in various areas. Certainly these two agencies should coordinate sampling designs and exchange data, yet additional sampling coverage in space and time will be necessary to address stimuli of harmful phytoplankton outbreaks. A recommended way to increase sampling coverage must involve more people but in a coordinated fashion with consistent techniques. As mentioned in MW objective 5.1, a database is being presently generated through a Washington Sea Grant/PCOGA project wherein oyster growers are taking weekly water-column data and samples according to a simple protocol devised by Ecology staff (Newton, 1995c). These data should be included in a PSAMP database, and this protocol should be considered as a template that could be repeated with other groups. A good example of additional samplers would be Health mussel cage monitoring staff and established citizen alliance groups. Equipment costs and time investment for this monitoring is relatively low, yet affords weekly temperature, salinity, Secchi, and weather data and preserved phytoplankton and nutrient samples. As described, only samples before and during harmful phytoplankton blooms are analyzed.

Recommendations--

- Continue to collect monthly phytoplankton samples from key long-term stations and fund analysis. (++)
- Assess how Health and Ecology can increase phytoplankton species and environmental parameter sampling. (+++)
- Spread simple water-column monitoring protocol devised for Sea Grant/PCOGA project to Health mussel cage samplers and interested and established citizen groups.
- Coordinate access to all phytoplankton data. (+)

Gaps

Issue #11--Circulation. An important component of water quality, presently not monitored, is quantitative information on circulation. Water circulation and the flushing character of Puget Sound are essential information for environmental planning and policy. How long do contaminants stay in Puget Sound? How is this influenced by local climate, runoff, and land-use practices? Where are the places where loadings of various compounds will have long residence times in the system, and where are the places where this is minimized? This area has been explored by Cokelet and Stewart (1985), Ebbesmeyer et al. (1989), and Cokelet et al. (1991) among others. However, one important set of data upon which to build useful models is lacking: synoptic current meter measurements throughout Puget Sound. Such data have never been obtained. Moored current meters and sensors at 5 stations in Puget Sound would add significantly to our ability to answer these questions. These measurements could be used in existing models (e.g., Cokelet et al., 1991) to calculate the flushing of Puget Sound each year.

The model constructed by Cokelet et al. (1991) inputs current, river flow and salinity data to estimate flushing and residence times. In order to make the model Puget Sound-wide, current meter data from various small-scale studies in various years were used. Because currents vary widely according to freshwater input and weather conditions, the bias introduced by non-

synoptic current data is unknown. The Cokelet et al. (1991) model has high utility, however, because monthly river flow and salinity data can be input and annual flushing volumes calculated and compared. Ecology's data from the Marine Water Monitoring and Freshwater Monitoring Programs can be used directly in the Cokelet et al. (1991) model to derive circulation for each specific wateryear.

Current meters at five stations (2 to 3 depths per station) would adequately describe the circulation of Puget Sound (C. Ebbesmeyer, Evans-Hamilton, pers. comm.) Ecology's Environmental Investigations and Laboratory Services Program (in which the Marine Water Monitoring Program resides) owns several AanderaTM current meters that could be used for this purpose. A static array would be deployed, on which CTD sensors could be mounted. Such continuous records of temperature and salinity as well as current data synoptically in these key areas is unprecedented. The data would contribute valuable information regarding variation on time-scales and events presently un-monitored, such as tidal and diel time-scales and storm impacts. In addition, the current meter data would be used for a more accurate model of flushing in Puget Sound.

Whether old or new current meter data are used, assessment of circulation must be done. Understanding of impacts from human-caused contamination, such as nutrient loading, effects of oil spills, increased anthropogenic input due to an increasing regional population (projected to increase by more than 60%; see Copping et al., 1994), cannot occur if we do not have realistic estimates of flushing within and throughout Puget Sound. Physical oceanographers have expressed interest in jointly working on this project. The Marine Water Monitoring Program has significant physical oceanographic and mathematical modeling expertise (S. Albertson) on board and some equipment in hand. A small investment in this present monitoring gap would result in highly useful and applicable information. Refer to Table 1 regarding how many of the original PSAMP objectives involve water mass movement, contaminant transport and circulation. These have never been addressed by the PSAMP. We strongly recommend that it is time to address this significant gap.

Recommendations--

--At approximately five sites, deploy current meters with CTD sensors to be changed at 3-month intervals for a minimum of 1.25 year. We recommend this be a joint project in cooperation with an established physical oceanographer. (++)

--Use existing models (e.g., Cokelet et al., 1991), historical current meter data and present-day salinity and flow data to calculate each year's flushing rates. (+++)

Issue #12--Chemical contamination in the water column. Chemical contamination in the water column has not been pursued by the PSAMP. Many chemicals are known to adsorb onto particles and sink out of the water column, thus chemical contamination has largely been addressed by the Sediment task (Ecology's Marine Sediment Monitoring Program). However, non-particle reactive chemicals may be found in the water column in biologically significant concentrations; also the residence time of adsorbed contaminants in the water column may be long enough to have deleterious effects on organisms. In addition, some chemicals are hydrophobic and accumulate in the surface micro-layer. Studies have shown quite different chemical concentrations in this layer than in the rest of the water column (e.g., Word et al., 1987;

Cross et al., 1987). The surface micro-layer is an important environment for eggs and larvae; numerous sperm cells were observed in the surface micro-layer of Padilla Bay (Thompson, 1995). If contamination is significant in this layer, exposure could be quite deleterious to developing organisms.

In addition to monitoring chemical contaminants in sediments, the PSAMP has included monitoring contaminants in invertebrates, fish, and birds. Plankton, at the base of the food web and diet for many marine organisms have not been investigated for tissue chemical contamination. Net tows through water columns in areas known to be contaminated could be done, with the entire sample homogenized and analyzed for contaminants. In order to fully assess the health of organisms higher on the food chain, this issue should not be ignored.

Both of these avenues could be pursued in pilot projects at one or two worst-case-scenario sites. Contaminated sites in Puget Sound may be off urban industrialization or off agricultural lands.

Another avenue to exploring chemical contamination in marine waters is to conduct an *in situ* bioassay. A common form is to deploy cages of mussels at sites and monitor growth and tissue concentrations (Salazar and Salazar, 1991). The feasibility and utility of this approach should be evaluated for Puget Sound.

Recommendations--

- Assess water column concentrations of contaminants. (++)
- Investigate surface microlayer contamination in a few selected locations. (++)
- Measure contaminant levels in plankton from contaminated sites. (++)
- Deploy oyster and/or mussel cages in various control and contaminated sites. (+)

Issue #13--Food web characteristics. Some measures of marine food-web characteristics need consideration. Although marine food webs can be complex and seasonally dynamic, planktonic organisms hold much information on water quality since they are exposed throughout their life cycle to the water mass' physical and chemical conditions. Do zooplankton stocks in Puget Sound show long-term changes as they do in other areas (e.g., Roemmich and McGowan, 1995)? Are contaminants, such as tri-butyl tin (TBT), having any effect on planktonic organisms as has been observed in gastropod snails? Can we use organisms or the food-web structure to better indicate water quality? With well-designed projects, many of these questions can be addressed relatively easily.

Zooplankton in Puget Sound could be encountering effects from a variety of sources. Roemmich and McGowan, 1995 recently published an analysis of CALCOFI data illustrating a declining zooplankton population in the California Current correlated with changes in sea temperature and upwelling. A signal from ENSO weather conditions can be detected in Puget Sound sea-surface temperature and salinity (Newton, *in press*); do temperature and salinity shifts influence zooplankton in Puget Sound? Toxics, such as dioxins and TBT, are inputted to Puget Sound waters. TBT has been reported to cause gender shifts and thus reproductive failure in gastropod snails, yet its effect on zooplankton has not been investigated. Little is known regarding long-term conditions of zooplankton in Puget Sound.

Measuring zooplankton can be a challenge due to high variability in their distribution. In Puget Sound, the overwintering standing stock of zooplankton has much less variation than standing stocks measured in other times of the year (B. Frost, UW, pers. comm.). A long-term zooplankton biomass record has never been established for Puget Sound. We propose to begin one, based on sampling the overwintering stock in key locations of Puget Sound. Zooplankton biomass can be patchy, thus necessitating many replicate tows for an accurate assessment. By confining sampling to one focused wintertime period, an adequate number of replicate tows could be made at each of the stations, the scope of the project is feasible. Samples would be archived and settling volumes recorded. Historical samples of zooplankton from various Puget Sound stations are available at UW for several historical periods of time (e.g., 5-10 year periods). Records of overwintering settling volumes could be obtained from these preserved samples.

Students from UW and TESC often look for class projects. Marine Water Monitoring Program staff have been involved to varying degrees at both of these institutions for lectures, project suggestions and shared sampling. Assessing zooplankton species composition, chemical contamination in plankton, or looking for growth abnormalities or gender ratio shifts by comparing present-day vs. the historical UW samples are all possible topics for student projects.

Planktonic food webs can be characterized (e.g., gelatinous zooplankton-chaetognath-small phytoplankton versus copepod-diatom) and have been used to indicate nutrient availability and physical stability (Landry, 1977). The ratio of bacterial to phytoplankton biomass has been found to be affected by eutrophic conditions (e.g., Suttle et al., 1990; Pace and Funke, 1991). Sampling and observations of the food web need to be made, particularly during focused projects. Information from the Sinclair/Dyes Inlets, Sequim Bay, Budd Inlet, and Hood Canal projects would have been stronger if these measurements were made. Effective food-web sampling methods should be further investigated.

Recommendations--

- Begin long-term monitoring of overwintering zooplankton stock. (++++)
- Assess zooplankton stock by comparison with historical samples at UW (suggested student intern project). (+)
- Look for planktonic abnormalities and/or gender ratio abnormalities in plankton from Sinclair Inlet (suggested student intern project). (+)
- Assess food web in areas of water quality concern, including:
 - prevalence of gelatinous organisms;
 - bacterial :phytoplankton abundance. (++)

Issue #14--Temporal variation. Ecology presently samples only during daylight, under relatively calm weather conditions and, for the long-term strategy, only once per month. These "snapshots" do not allow an understanding of the system's dynamics or the impact of events. Also, our sampling is conducted during variable tidal stages. This limits the comparative value of the data, especially for identifying seasonal trends, since many parameters (e.g., DO, salinity, chlorophyll *a*) co-vary with tidal stage at a given station (Figure 2B). Moored sensors would facilitate continuous coverage such that dynamics and trends could be better identified and variation assessed in different areas of Puget Sound. This issue has been developed within issue 11 but is reprised here. A major criticism of Ecology's marine water long-term monitoring is that

tidal stage is not controlled for. The only way to address this in such a dynamic and diverse region as Puget Sound is through moored sensors.

The impacts of diel, tidal and weather processes will be different in S. Budd Inlet than in Dana Passage. Thus, some moored CTD sensors also need to be placed in inner bays. Once variation on temperature and salinity is recorded, progressing to assess variation in chemical and biological parameters can proceed in areas where variation was high.

Recommendations--

--At selected sites, including a few nearer-shore sites, deploy recording CTD sensors. (++)

--Assess impact at various representative locations of:

--night;

--tide shifts;

--storms. (++)

Issue #15--Primary production. Phytoplankton production and particularly the sensitivity of phytoplankton to nutrient supply are important pieces water quality information. Typically, phytoplankton in Puget Sound are considered to be light-limited because the mixing processes in much of the Sound re-supply nutrients to the euphotic zone. However, there are many places in Puget Sound where nutrient concentrations become low (Table 7). Low nutrient concentrations do not imply nutrient-limited growth. Nutrient limitation must be demonstrated by measuring growth with versus without added nutrients. As shown by the ^{14}C uptake experiments conducted in 1994, nutrient-addition stimulates organic production significantly in Hood Canal, but not in the Puget Sound main basin (Figure 3). In Hood Canal, nutrient (N+P) addition stimulated phytoplankton productivity by as much as 300% at a given depth and integrated production was increased by as much as 80% ($1 \text{ g C m}^{-2} \text{ d}^{-1}$). Ecology's Marine Water Monitoring also conducted nutrient-addition experiments at two stations in Budd Inlet. The station nearer the WWTP outfall showed less stimulation of production than did the station farther out in the Inlet.

These data are highly useful for assessing eutrophication and its affects in Puget Sound. Further experiments should be conducted in the other areas identified to be sensitive to eutrophication and also where eutrophication is suspected (Tables 7 and 9).

Solstice monitoring was originally proposed for assessing phytoplankton production. This effort was to use citizen volunteers to intensively sample chlorophyll *a* around the solstices. Such large efforts have not been orchestrated. Although there may be merit to this approach, if assessing primary production is the goal, we recommend direct ^{14}C uptake measurements. This recommendation is because data on nutrient limitation also can be obtained, vertically-resolved production rates are obtained, and production vs. irradiance (P vs. I) information is produced. Radio-isotope expertise was not available in Ecology's Marine Water Monitoring Program at the time original PSAMP guidelines were set (MMC, 1988). Experienced staff are now on board (J. Newton, L. Eisner).

Another method for determining phytoplankton biomass (based on chlorophyll *a*) and inferring production is via remote sensing. This method has been used from satellites, but also can be done using aircraft. Puget Sound is of the scale that would best be served by sensors mounted on planes. The present use of planes by Ecology's Marine Water Monitoring, DNR's Nearshore Habitat Monitoring, and by DFW's Bird Monitoring makes this avenue highly appealing to develop. The sensors and data processing equipment for this method would be a one-time investment and the technology pre-exists. Much of the equipment used by DNR may be suitable for this application as well. An individual with expertise in remote sensing would be required to develop and implement phytoplankton remote sensing procedures. We recommend that this would be an excellent topic for a one-two year cooperative research position.

Phytoplankton data from remote sensing would be advantageous because large scale patterns can be assessed in one day. Repeated flights can measure the degree of variation and meso-scale surface water mass movement.

Recommendations--

--Continue to conduct nutrient-addition experiments at sites where BRL nitrate+nitrite-N concentrations are persistently seen. (++)

--Develop remote sensing of phytoplankton from aircraft through filling a cooperative research position. (+)

SUMMARY

As summarized by its "report card" (Table 12), the Marine Water Monitoring for PSAMP is an adequate program (grade = B) for the original PSAMP directives it was intended to fulfill. It is important to evaluate the program for meeting these directives, as well as to refine the focus and objectives of the Marine Water Monitoring Program. This document contains the proposed objectives for the future that take into account both the original program and the gaps that may be important to monitoring marine water quality in Puget Sound.

Fifteen issues were presented along with recommendations to address them. Most of the issues in the refinement and improvement categories can be addressed with relatively little capital investment. Of more immediate concern are the pragmatic issue of staffing level and the issues regarding monitoring gaps in the current program. These latter issues need evaluation for their importance to Marine Water Monitoring and to the PSAMP. The former issue permeates all issues presented in this QIR paper.

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Appendix B-3. 2005 PSAMP Marine Water Column Review Results

The report and findings from the 2005 PSAMP review can be found at the Puget Sound Partnership's website:

www.psparchives.com/publications/our_work/science/psamp/PSAMP_2005_review.pdf

2008 PSAMP “Lessons Learned” Document

The Executive Summary of the review is also included in the PSAMP document “Lessons Learned”, published in 2008 found in Appendix A., pages A-3, 4:

www.psp.wa.gov/downloads/PSAMP_2008_lessons_learned.pdf

Engrossed Senate Bill 5372 – Formation of the Puget Sound Partnership

<http://apps.leg.wa.gov/documents/billdocs/2007-08/Pdf/Bills/Senate%20Bills/5372-S.E.pdf>

Appendix C. Long-Term Marine Waters Monitoring Strategy

Introduction

The Long-term Marine Waters Monitoring Program 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 spatial-temporal resolution.

The MWM program 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 C-1). The combination of approaches improves the spatial and temporal information in strategically important areas.

Mission of the Marine Waters Monitoring Unit

The Long-Term Marine Monitoring Program 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.

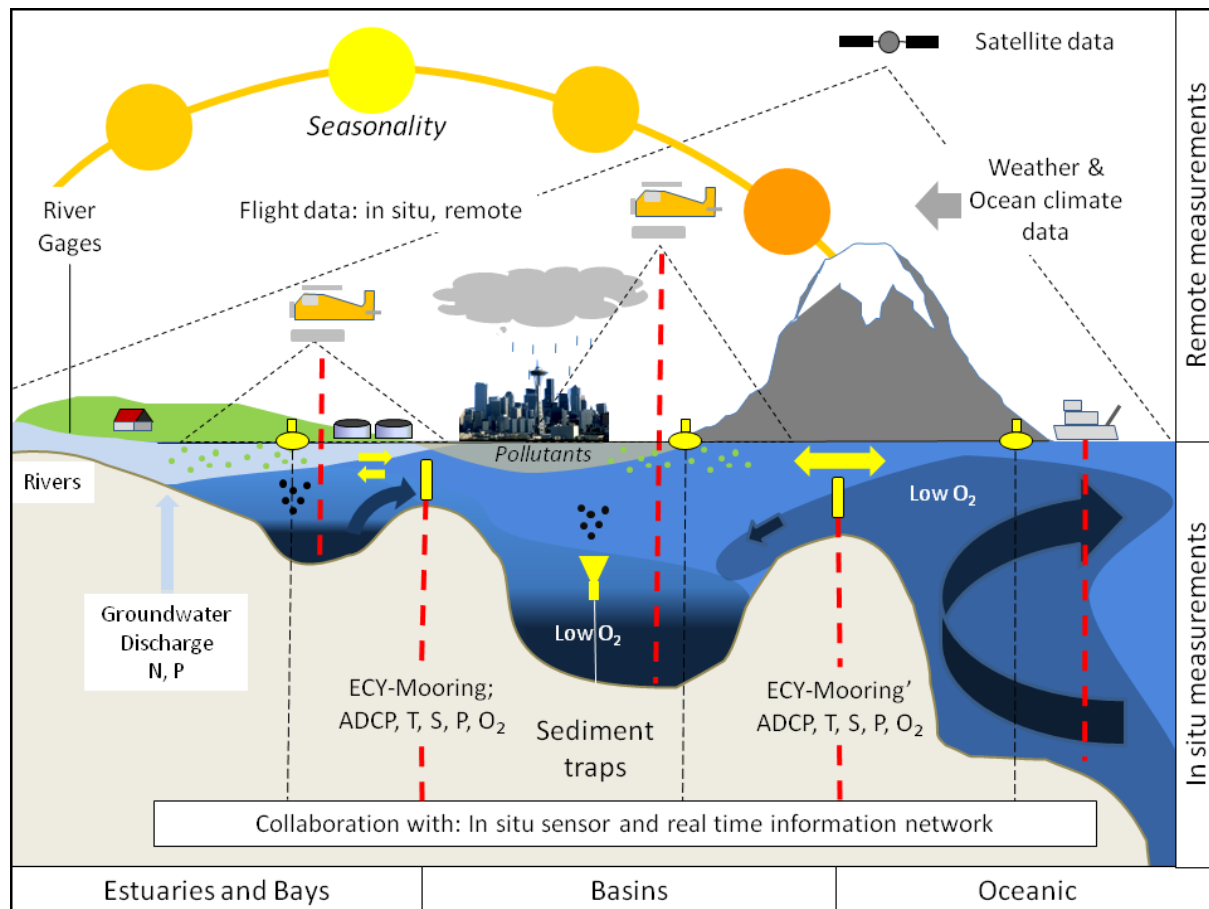


Figure C.1 Ecology's statewide marine monitoring program describes the status and trend of estuarine processes and marine eutrophication in Washington State. The spatially nested program detects changes in estuarine water quality and reports its observations in context of large-scale climatic, oceanographic 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 (Fig. 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 where physical state variables are continuously measured with in situ sensors, Fig. 1)
- B. The near-surface environment (using remote sensing products, Fig. 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), (Fig. 1). Sampling sites that meet the needs of programs are (e.g. Rosario Strait, Admiralty Reach, the Narrows, Mukilteo, Dana Passage, Squaxin Passage, Manchester etc.)

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 publically 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 D. Example Field and Lab Sample Forms, Logs, Lists, and other coordinating documents

Table D.1. Annual Planning Checklist for Long-Term Marine Waters Monitoring Flights.

- ☐ 1 - Solicit monitoring requests (Sep-Nov)-
- ☐ 2 - Determine stations (core/rotational/seasonal) to monitor based on monitoring requests, last year sampled & water quality data (early Nov)-
- ☐ 3 - Lay out flight/profile sampling itineraries & justifications (yyyyStations.xlsx)-
- ☐ 4 - Determine flight plan/sampling order/flight duration (yyyyFlightPlans.xlsx)-
- ☐ 5 - Determine parameters to sample at each station (Marine Flight Samples.xlsx)-
- ☐ 6 - Create maps w/ station depths & sampling notes-
- ☐ 7 - Create pilot (navigational) charts w/ lat & longs-
 - ☐ Verify station order with Kenmore
- ☐ 8 - Update field log templates (digital) & forms (PrintLogs.xlsx) -
- ☐ 9 - Update field notification forms (FORM MF Field Work Plan.xls)-
- ☐ 10 - Update Navy & Coast Guard/Seattle traffic notifications as needed-
- ☐ 11 - Verify nutrient & salinity analyses with contract lab(s)-
 - ☐ Generate PPRs, COCs, sample tracking sheets as needed
- ☐ 12 - Update CTD operations, safety plan and other tech notes or procedures as needed, including updated screen shots-
- ☐ 13 - Update monthly prep, pre- & post- flight/survey checklists as needed-
- ☐ 14 - Add all new paperwork, forms, lists, maps to field notebooks-
- ☐ 15 - Update forms and software on field laptops & data processing computers-

Table D.2. Example of Marine Flight itineraries for Puget Sound and coastal bays stations.

Flight	Station ID	Location	WQMA	Depth (m)	Record	Justification
Marine Flight 1:	GYS004	Chehalis R.	Western Olympic	12	1974 to present	represents inner Grays Harbor near Chehalis R.
	GYS008	Mid-S. Channel	Western Olympic	5	1974 to present	represents mid Grays Harbor, south
	GYS016	Damon Point	Western Olympic	9	1982 to present	represents outer Grays Harbor, north
	WPA004	Toke Point	Lower Columbia	15-20	1973 to present	represents north Willapa Bay
	WPA113	Bay Center	Lower Columbia	10-15	1997 to present	represents mouth of (NW) Willapa Bay
	WPA006	Nahcotta Channel	Lower Columbia	10-15	1991 to present	represents central Willapa Bay
	WPA003	Willapa R., John. Slough	Lower Columbia	10	1973 to present	represents north Willapa Bay, off Willapa R.
	WPA001	Willapa R., Raymond	Lower Columbia	5	1973 to present	represents inner Willapa Bay in Willapa R.
Marine Flight 2:	ADM001	Admiralty Inlet	Kitsap & Cedar/Green	110-120	1975 to present	represents waters within Admiralty Inlet
	PTH005	Port Townsend	Eastern Olympic	33	1977 to present	represents waters off city of Port Townsend
	ADM002	N. of Admiralty Inlet	Island & E. Olympic	80-90	1980 to present	represents waters entering Admiralty Inlet
	RSR837	Rosario Strait	Nooksack/San Juan	54	2009 to present	represents waters in Rosario Strait
	GRG002	Strait of Georgia	Nooksack/San Juan	200	1988 to present	represents Strait of Georgia end member
	BLL009	Bellingham Bay	Nooksack/San Juan	6-10	1977 to present	represents waters off city of Bellingham
	SKG003	Skagit Bay	Island/Snohomish	25	1990 to present	represents Whidbey Basin
	SAR003	Saratoga Passage	Island/Snohomish	100-140	1977 to present	represents Whidbey Basin
Marine Flight 3:	PSS019	Possession Sound	Island/Snohomish	100	1980 to present	represents waters off city of Everett
	CMB003	Commencement Bay	South Puget Sound	140-160	1976 to present	represents waters off city of Tacoma
	EAP001	East Passage	Kitsap & Cedar/Green	220	1988 to present	represents S. Puget Sound main axis
	ELB015	Elliott Bay	Cedar/Green	70	1991 to present	represents waters off city of Seattle
	PSB003	Puget Snd. Main Basin	Kitsap & Cedar/Green	20-40	1976 to present	represents Puget Sound Main Basin
	ADM003	S. of Admiralty Inlet	Kitsap & Cedar/Green	200-230	1988 to present	represents waters S. of Admiralty sills
	PGA001	Inner Port Gamble Harbor	Eastern Olympic	22	1998 to present	reports of poor WQ, eutrophication, HABs
	PMA001	Port Madison	Eastern Olympic	52	1992 to present	reports of poor WQ, eutrophication
	EAG001	Eagle Harbor	Eastern Olympic	20	1998 to present	reports of poor WQ, eutrophication
	SIN001	Sinclair Inlet	Kitsap	10	1973 to present	represents waters off city of Bremerton
Marine Flight 4:	GOR001	Gordon Point	E. Oly & Kitsap & SPS	180	1996 to present	represents S. Puget Sound south of Narrows
	BUD005	Budd Inlet	Eastern Olympic	12	1973 to present	represents waters off city of Olympia
	DNA001	Dana Passage	Eastern Olympic	35-40	1984 to present	represents south reach of Southern Puget Sound
	NSQ002	Devil's Head	E. Oly & Kitsap & SPS	100	1984 to present	represents S. Puget Sound near Nisqually
	CSE001	Case Inlet	Eastern Olympic	50	1978 to present	represents waters within Case Inlet
	CRR001	Carr Inlet	Eastern Olympic	86	1977 to present	represents waters within Carr Inlet
	HCB010	Hood Canal, S of Bangor	Kitsap & E. Olympic	60-91	2005 to present	represents northern Hood Canal
	HCB003	Hood Canal, Eldon	Kitsap & E. Olympic	120	1976 to present	very low DO, assess duration & coverage
	HCB004	Hood Canal, Sisters Pt.	Kitsap & E. Olympic	40-50	1975 to present	represents southern Hood Canal
	HCB007	Hood Canal, Lynch Cv.	Kitsap & E. Olympic	20	1990 to present	very low DO, assess duration & coverage
	OAK004	Oakland Bay	Eastern Olympic	24	1974 to present	represents waters off city of Shelton
Denotes rotational stations to sample						

Table D.3. Variables, Methods and Labs Used for Marine Water Column Data Collection.

Variable	Start Date	End Date	Unit	Method	Collection	Lab
Attenuation	10/9/01	Present	m ⁻¹	WET Labs C-Star	Calculated	
Chlorophyll <i>a</i>	7/1/99	Present	µg/L	EPA 445.0; LORENZEN, 1966	Sample	ECOLOGY MARINE LAB
Conductivity	10/9/01	Present	S/m	Sea-Bird Electronics SBE4	Measurement	
Density	11/1/89	Present	sigma-t	UNESCO, 1983	Calculated	
Depth	10/9/01	Present	db	UNESCO, 1983	Calculated	
Dissolved Oxygen	10/9/01	Present	mg/L	Sea-Bird Electronics SBE43	Measurement	
Dissolved Oxygen	1/1/02	Present	mg/L	Carpenter; Winkler	Sample	ECOLOGY MARINE LAB
Dissolved Oxygen Saturation	1/1/99	Present	%	Gordon & Garcia, 1992	Calculated	
Fluorescence	3/1/09	Present	µg/L	WET Labs ECONTU	Measurement	
Ammonium - NH ₄ (uM)D	2/1/99	Present	µM	SLAWYK & MACISAAC	Sample	MARINE CHEMISTRY
Nitrite - NO ₂ (uM)D	2/19/99	Present	µM	UNESCO, 1994	Sample	MARINE CHEMISTRY
Nitrate - NO ₃ (uM)D	2/19/99	Present	µM	UNESCO, 1994	Sample	MARINE CHEMISTRY
Radiation)	2/1/11	Present	µEinsteins/m ² /sec	Biospherical Instruments QSP-2200	Measurement	
pH	11/1/89	Present	pH	Sea-Bird Electronics SBE18	Measurement	
Pheopigments	7/1/99	Present	µg/L	EPA 445.0; LORENZEN, 1966	Sample	ECOLOGY MARINE LAB
Ortho-phosphate - PO ₄ (uM)D	2/19/99	Present	µM	UNESCO, 1994	Sample	MARINE CHEMISTRY
Pressure	10/9/01	Present	db	Sea-Bird Electronics SBE29	Measurement	
Salinity	10/9/01	Present	PSU	UNESCO, 1983	Calculated	
Secchi	10/1/92	Present	m	SECCHIO	Measurement	
Silicate - SiOH ₄ (uM)D	2/19/99	Present	µM	UNESCO, 1994	Sample	MARINE CHEMISTRY
Temperature	10/9/01	Present	deg C	Sea-Bird Electronics SBE3	Measurement	
Turbidity	3/1/09	Present	NTU	WET Labs ECONTU	Measurement	
Transmission (Light)	10/9/01	Present	%	WET Labs C-Star	Measurement	

Table D.4. Example of Lab Sample Collection List by flight.

Y2013 Marine Flight Samples

*Table lists depths sampled for each parameter

*Note: for any flight, samples may be dropped due to time and/or weather constraints

	nutrients	chlorophyll	dissolved oxygen	salinity	Depth (m)
Marine Flight 1					
GYS004	0, 10			10	12
GYS008	0	0	NB*		5
GYS016	0, 10	0, 10	NB*, NB*		9
WPA004	0, 0, 10	0, 0, 0, 10	NB	10	15-20
WPA113	0, 10	0, 10	NB*, NB*		10-15
WPA006	0, 10	0, 10	NB*		10-15
WPA003	0, 10	0, 10	NB*		10
WPA001	0, 10		NB*, NB*	10	8
Total Samples:	16	13	10	3	
<i>*take replicate samples where possible, minimum of 10 winklers total</i>					
	nutrients	chlorophyll	dissolved oxygen	salinity	
Marine Flight 2					
PTH005	0, 10, 30	0, 10, 30	NB*		25
ADM002	0, 10, 30	0, 10, 30	NB*, NB*	30	80-90
RSR837	0, 10, 30	0, 10, 30			54
GRG002	0, 10, 30	0, 10, 30	NB*		200
BLL009	0, 0, 10	0, 0, 0, 10			6-10
SKG003	0, 10	0, 10	NB*, NB*	10	21
SAR003	0, 10, 30	0, 10, 30	NB*, NB*		100-140
PSS019	0, 10, 30	0, 10, 30	NB*, NB*		100
Total Samples:	23	24	10	2	
<i>*take replicate samples where possible, minimum of 10 winklers total</i>					
	nutrients	chlorophyll	dissolved oxygen	salinity	
Marine Flight 3					
HCB004	0, 10, 30	0, 10, 30	NB*, NB*		40-50
HCB007	0, 10	0, 10	NB*		20
HCB003	0, 10, 30	0, 10, 30	NB*		120
HCB010	0, 10, 30	0, 10, 30	NB*	30	60-91
ADM001	0, 10, 30	0, 10, 30	NB*		110-120
ADM003	0, 10, 30	0, 10, 30	NB*, NB*		200-230
ELB015	0, 10, 30	0, 10, 30	NB*	10	70
PSB003	0, 10, 30	0, 10, 30	NB*		20-40
SIN001	0, 0, 10	0, 0, 0, 10			10
Total Samples:	26	27	10	2	
<i>*take replicate samples where possible, minimum of 10 winklers total</i>					
	nutrients	chlorophyll	dissolved oxygen	salinity	
Marine Flight 4					
BUD005	0, 0, 10	0, 0, 0, 10	NB*, NB*	10	13
DNA001	0, 10, 30	0, 10, 30	NB*		35-40
NSQ002	0, 10, 30	0, 10, 30			100
GOR001	0, 10, 30	0, 10, 30	NB*		180
CMB003	0, 10, 30	0, 10, 30	NB*	30	140-160
EAP001	0, 10, 30	0, 10, 30	NB*		220
CRR001	0, 10, 30	0, 10, 30	NB*		86
CSE001	0, 10, 30	0, 10, 30	NB*, NB*		50
OAK004	0, 10	0, 10			20
Total Samples:	26	27	10	2	
<i>*take replicate samples where possible, minimum of 10 winklers total</i>					
Monthly Totals:	91	91	40	9	
Annual Total:	1092	1092	480	108	

Table D.5. Marine Flights Monthly Flight Prep Checklist.

PAPERWORK & FORMS

- ☐ **PRINT or copy** station logs
- ☐ **SET UP** flights for Yuma on Desktop application
- ☐ **CHECK** flight/field notebooks for completeness (station logs, forms, maps, SOPS, pencils, tags, etc.)
- ☐ **Call** Kenmore Air to schedule flights 800-543-9595 x92210

Flight Equipment

- ☐ CTD/AFM batteries have been changed, instrument is calibrated & working
- ☐ Winch, frame, blocks, control switch are clean, undamaged & in working order
- ☐ Desk & toolbag are clean & stocked w/ supplies
- ☐ Secchi disk line is well-marked
- ☐ 12 volt batteries (wooden case #1 & #2) are charged

Marine Lab

- ☐ 5 racks of clean chlorophyll tubes are available
- ☐ 1-2L of 90% acetone is prepped & available (in addition to acetone for other projects)
- ☐ Sample tote is stocked w/
 - *Chlorophyll a* bottles
 - Nutrient filters & syringes
 - 3 Salinity bottles
 - Phytoplankton bottle
 - DO sampling tubes, pipettes, extra pipette tips
 - Extra Ziploc bags, absorbent towels, garbage bags, gloves, dry towels, leather glove
- ☐ DO bottle box is stocked w/ 10 DO bottles
- ☐ DO chemical box and pipette tips
- ☐ Nutrient bottles, make sure nutrient standard bottles have been removed

Electronics Cabinet

- ☐ Yuma is charged
- ☐ Panasonic CF-29 laptop is charged
- ☐ Current .CON file is on both laptops and Yuma
- ☐ Cables to connect to CTD are in plastic bin on top of cabinet
- ☐ Cell phone (**360-701-0322**) is charged
- ☐ VHF radio is charged
- ☐ Camera is charged and memory card is empty

Table D.6. List of required field equipment.

Sampling Gear

CTD Package
Winch and frame apparatus
Charged marine 12V batteries
CTD adapter cable
Spare dummy plug
Tool kit
Field packer
Sample cooler
Nutrient bottles, filters and syringes
Dissolved oxygen kit
Deionized water
Secchi disk
Field binder with maps, SOPs and paper logs

Personal Gear

Gloves
Camera
Lunch
Drinking water
Sunglasses
Ear protection
Life vests

Electronics

Toughbook laptop
Yuma
GoPro camera
VHF radio
Cell phone

Other

Dock cart and desk
Towels
Trash bags
Cart lock

Table D.7. Example of Marine Flights Pre-flight Checklist.

Notifications

- ☐ **Email** Manchester Lab, Long-Term Marine Staff, and Olympia Rowing Club staff:
- ☐ **Post** Field Sampling Notification Form on EAP SharePoint website → Field Schedules
[/EAP/FieldSchedules/Forms/](#)
- ☐ **Email** Coast Guard watch supervisor, Seattle Traffic and WA state Ferry security. Forms are at: Y:\Seabird\LONGTERM\Y2012\Maps & Plans\Current Requests & Notifications

Marine Flight Van

- ☐ Cart and lock
- ☐ Frame for CTD/winch
- ☐ Winch with line and control switch
- ☐ Gray collar for protecting plane from CTD
- ☐ Desk with Leatherman, timer, extra dummy plug and pH cap etc.
- ☐ Fecal coliform bottle holder
- ☐ Secchi disk
- ☐ Blue tool bag w/ gloves, lifejackets, tools, laptop adapter, etc.
- ☐ Headsets
- ☐ Kneeling pads
- ☐ Orange buoy

Boatshed

- ☐ 12 volt batteries (wooden case #1 & #2)

Marine Lab

- ☐ CTD w/rosette (remove syringe/tubing, fluorometer cap, pH storage solution, PAR cover)
- ☐ pH 8 buffer
- ☐ Sample/bottle and supplies packer
- ☐ Cooler with ice, DI water squirt bottle, empty bottle for filtered seawater
- ☐ Chlorophyll bottles
- ☐ Nutrient filters & syringes
- ☐ Salinity bottles
- ☐ DO sampling tubes, chemicals, pipetters, pipette tips
- ☐ Extra Ziploc bags, gloves, absorbent towels, trash bags
- ☐ Nutrient bottle flat
- ☐ DO bottle box w/ 10 DO bottles, tygon tube

Electronics Cabinet

- ☐ Notebook with data sheets, labels, lab analysis (fecals) form, station maps
- ☐ Panasonic CF-29 laptop with DC power cord adaptor (in laptop bag)
- ☐ Yuma
- ☐ Cable to connect to CTD + spare cable
- ☐ Spare dummy plug
- ☐ Marine Flight Cell Phone (**360-701-0322**)
- ☐ VHF radio
- ☐ Camera
- ☐ Hearing Protector (Peltor Headsets)
- ☐ MF van logbook

Table D.8. Example of Marine Flight Station Operations Guidelines

For the MF-25 Ctd. These instructions assume that the CTD and AFM are already programmed.

- Remove pH 8 buffer vial from pH sensor.
- Set Niskin bottles – use AFM arm positions 3, 9, 11 and 12. Ensure vents & spigots are closed & turned inside to prevent damage.
- Turn on CTD
- Lower CTD – Hold just below surface for at least 60 seconds.
- Take fecal sample
- Raise CTD to first aluminum tier. Hold for 6 seconds, then lower CTD to 1-2 meters above bottom. (When CTD reaches bottom and line goes slack, raise so CTD does not drag on bottom.)
- Hold for 120 seconds.
- Take secchi reading to closest half meter. Each line marking is equal to 0.5 m.
- Raise CTD until it just breaks the surface, hold until surface bottle fires, then bring on board.
- Turn CTD off and check bottles for leaking.
- Rinse pH probe and return pH 8 buffer vial to pH sensor.
- Take DO sample and preserve.
- Take salinity sample (if needed).
- Take nutrient samples.
- Take chl-a samples.
- Drain and reset Niskin bottles.
- Close hatch and secure CTD.
- Proceed to next station.
- Attach computer cable to CTD.
- Download data
- Capture ~12 voltage readings (VRs) and ~10 frequency readings (FRs).
- Plot data with Seasave while capturing VRs and FRs from sensors.
- Reprogram CTD en route to next station.
- Just before deploying the next cast, ARM the AFM.

Table D.9. Example of Marine Flights Post-flight Checklist.

Boatshed

- ☐ Store & re-charge 12 volt batteries (wooden cases #1 & #2)
- ☐ Rinse CTD, AFM, tubing & sensors with copious amounts of fresh water (paying special attention to cable connections, transmissometer lenses, etc.). Rinse niskins at least 2x, and leave nipples & valves open for storage.
- ☐ Flush the tubing with fresh water. Flush the sensor for 1 minute with *1% solution of Triton X-100*. Next flush the tubing with *50:1 bleach solution* for 1 minute. After the flush, drain and flush with D.I. water for 5 minutes. Leave syringe on the CTD with DI water in it.

Marine Lab

CTD:

- ☐ Re-set CTD memory ("IL'd", "QS'd") and ensure AFM is not armed! (*done at end of flight*)
- ☐ Fill *conductivity cell, tubing, & DO sensor* with syringe filled with DI water (*done after cleaning*)
- ☐ Place cap on fluorometer
- ☐ Place pH 4.0 buffer solution bottle on pH sensor
- ☐ Place cap on PAR meter
- ☐ Change batteries in *CTD* after every flight, and *AFM* (at least 1x/month)
- ☐ Ensure spigots & valves of niskins are open for storage

Samples:

- ☐ Filter chlorophylls and wash sample bottles
- ☐ Place nutrients in marine lab freezer
- ☐ Shake dissolved oxygen samples, place a cap of DI water over the stopper, place in DO containers, and place in marine lab refrigerator
- ☐ Place salinity samples in designated sample box in marine lab
- ☐ Replenish black MF carrier & DO box (gloves, chemicals, filters, etc.)

Chain of Custody:

- ☐ Enter number of samples, sample numbers, expiration date, etc. for chlorophyll, nutrient, dissolved oxygen, & salinity samples in COC sheet in marine lab.

Electronics

- ☐ Download pictures from camera onto the Y drive Y:\Seabird\PHOTOS\MarineFlights\A MF_2012 PHOTOS. Charge battery if necessary.
- ☐ Plug in CF-29 laptop, cell phone, VHF radio, cell phone, Yuma, and camera in electronics cabinet to recharge

Office

- ☐ Download CTD/AFM data directly to Y drive Y:\Seabird\LONGTERM\Y2012\CTD\Unprocessed
- ☐ Download VR data directly to Y drive Y:\Seabird\LONGTERM\Y2012\CTD\Voltage Readings
- ☐ Download digital logs from Yuma to Y:\Seabird\LONGTERM\Y2012\CTD\Unprocessed
- ☐ Enter field data into appropriate flight log data entry form in Y:\Seabird\Longterm\Y2012\FlightLogs_DataEntry\
- ☐ Place original field log sheets in a folder labeled with flight number and date. Put in flight folder in-box in Julia's cube
- ☐ Email coworkers/co-fliers to inform of any equipment/schedule/flight issues. ☺

Other

- ☐ Enter mileage in MF van logbook.

Figure D.1. Example of the digital field log used on the Yuma.

MW Monitoring - Flight Forms

HomeFlight SetupFlightPost Flight

North_121116PilotSampler 1Sampler 2CTD

Station: ADM001Add stationLaptop:Flight Comment:

ObservationsCasts

Sampled?no entry

Latitude 4

Longitude 12

Secchi (m)

Wave H (in)

Wind Spd (kts)

Wind Dir (o)

Water Color

Sea Surf

Cloud Type

% Cloud

Bloom Presence

River Discharge

Debris Islands

Direct Sun

Algal Mats

Field Comment

Lab Comment

CTD Comment

CTD Comment 2

>Nutrient ranges: Start 11428End 11450Start 21698End 21800Start E0End E0

MW Monitoring - Flight Forms

HomeFlight SetupFlightPost Flight

North_121116PilotSampler 1Sampler 2CTD

Station: ADM001Add stationLaptop:Flight Comment:

ObservationsCasts

CAST

Cast #1CTD HitCTD Time DownCast Comment

	Paramete	Nisk	Bottle	Depth	Rep	Comment
+ Click here to add new item						
x	DO			NB	1	
x	Nutrients			30	1	
x	Nutrients			10	1	
x	Nutrients			0	1	
x	Chla			30	1	
x	Chla			10	1	
x	Chla			0	1	

>Nutrient ranges: Start 11428End 11450Start 21698End 21800Start E0End E0

Figure D.2. Example summary of all samples collected per flight.

MW Monitoring - Flight Forms
Home
Flight Setup
Flight
Post Flight
X

Central_120911

save data

Casts

Nutrients

DO

Chla

Fecal

Standard

Flight Summary

Generate Flight Summary

Save Summary to PDF

Save Flight to EAPMW database

Save Flight to XML file

		2585 2586 2587	MF20 MF21 MF22
DO Bottles Count=9 LT1006 LT1008 LT1005 LT1004 LT1001 LT1011 LT1002 LT1013 LT1016	Salinity Bottles Count=2 E43 E05	Fecal Bottles Count=4 01 02 04 08	

MW Monitoring - Flight Forms
Home
Flight Setup
Flight
Post Flight
X

Central_120911

save data

Casts

Nutrients

DO

Chla

Fecal

Standard

Flight Summary

Generate Flight Summary

Save Summary to PDF

Save Flight to EAPMW database

Save Flight to XML file

Figure D.3. Chain of custody form for marine nutrients and chlorophyll *a*.

LONGTERM - MF / Moorings
Marine Waters Monitoring - Chain of Custody

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

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		

Figure D.4. Chain of custody form for dissolved oxygen and salinity.

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	

CTD Calibration Log MFA 25 - pH							
CTD:						Prepared by:	
S/N:						Date data was entered	
Calibration Date:							
			Date	Slope	Offset	Filename	
		**Previous					
		*New					
Buffer	Scan #	CTD Temp. (°C)	V _{out} = V _I (volt)	pH	Pressure (dBar)	Ref. Temp (°C)	*Residuals
7.0							
7.4							
8.0							
9.0							
10.0							
					Mean Ref. Temp (°C)	#DIV/0!	
Name of new Configuration files:							
Location of new Configuration files:		Seabird\Calibration\CTD					
Comments:							
*Calculated after calibration							
*pHfit will ask for the S/N and mean Ref. temperature, followed by successive pH and V _{out} values for each solution tested. The program will determine a new slope and offset. Compare with factory calibrations and see if they should							
**Record prior to calibration							
File location: Y:\SEABIRD\Calibration\CTD\Bi-Monthly Calibration\MFA							

[illegible]

Table D.10. VHF Marine Radio Channels & Frequencies.

U.S. VHF Marine Radio Channels and Frequencies			
Channel Number	Ship Transmit MHz	Ship Receive MHz	Use
01A	156.050	156.050	Port Operations and Commercial, VTS. Available only in New Orleans/Lower Mississippi area.
05A	156.250	156.250	Port Operations or VTS in the Houston, New Orleans and Seattle areas.
6	156.300	156.300	Intership Safety
07A	156.350	156.350	Commercial
8	156.400	156.400	Commercial (Intership only)
9	156.450	156.450	Boater Calling. Commercial and Non-Commercial.
10	156.500	156.500	Commercial
11	156.550	156.550	Commercial. VTS in selected areas.
12	156.600	156.600	Port Operations. VTS in selected areas.
13	156.650	156.650	Intership Navigation Safety (Bridge-to-bridge). Ships >20m length maintain a listening watch on this channel in US waters.
14	156.700	156.700	Port Operations. VTS in selected areas.
15	--	156.750	Environmental (Receive only). Used by Class C EPIRBs.
16	156.800	156.800	International Distress, Safety and Calling. Ships required to carry radio, USCG, and most coast stations maintain a listening watch on this channel.
17	156.850	156.850	State Control
18A	156.900	156.900	Commercial
19A	156.950	156.950	Commercial
20	157.000	161.600	Port Operations (duplex)
20A	157.000	157.000	Port Operations
21A	157.050	157.050	U.S. Coast Guard only
22A	157.100	157.100	Coast Guard Liaison and Maritime Safety Information Broadcasts. Broadcasts announced on channel 16.
23A	157.150	157.150	U.S. Coast Guard only
24	157.200	161.800	Public Correspondence (Marine Operator)
25	157.250	161.850	Public Correspondence (Marine Operator)
26	157.300	161.900	Public Correspondence (Marine Operator)
27	157.350	161.950	Public Correspondence (Marine Operator)
28	157.400	162.000	Public Correspondence (Marine Operator)
63A	156.175	156.175	Port Operations and Commercial, VTS. Available only in New Orleans/Lower Mississippi area.
65A	156.275	156.275	Port Operations
66A	156.325	156.325	Port Operations
67	156.375	156.375	Commercial. Used for Bridge-to-bridge communications in lower Mississippi River. Intership only.
68	156.425	156.425	Non-Commercial
69	156.475	156.475	Non-Commercial
70	156.525	156.525	Digital Selective Calling (voice communications not allowed)
71	156.575	156.575	Non-Commercial
72	156.625	156.625	Non-Commercial (Intership only)
73	156.675	156.675	Port Operations
74	156.725	156.725	Port Operations
77	156.875	156.875	Port Operations (Intership only)
78A	156.925	156.925	Non-Commercial
79A	156.975	156.975	Commercial. Non-Commercial in Great Lakes only
80A	157.025	157.025	Commercial. Non-Commercial in Great Lakes only
81A	157.075	157.075	U.S. Government only - Environmental protection operations.
82A	157.125	157.125	U.S. Government only
83A	157.175	157.175	U.S. Coast Guard only
84	157.225	161.825	Public Correspondence (Marine Operator)
85	157.275	161.875	Public Correspondence (Marine Operator)
86	157.325	161.925	Public Correspondence (Marine Operator)
AIS 1	161.975	161.975	Automatic Identification System (AIS)
AIS 2	162.025	162.025	Automatic Identification System (AIS)
88A	157.425	157.425	Commercial, Intership only.

Table D.11. Hospitals near Marine Flight stations by County

CLALLAM

Pt. Angeles	OLYMPIC MEMORIAL HOSPITAL 939 Caroline Street Port Angeles 98362 Tel: (206) 457-8513
-------------	---

GRAYS HARBOR

Aberdeen	GRAYS HARBOR COMMUNITY HOSPITAL 915 Anderson Drive Aberdeen 98520 Tel: (206) 532-8330
----------	--

McCleary	MARK REED HOSPITAL P.O. Box 28 322 So. Birch Street McCleary 98557 Tel: (206) 495-3244
----------	--

ISLAND

Coupeville	WHIDBEY GENERAL HOSPITAL Main Street, P.O. Box 400 Coupeville 98239 Tel: (206) 678-5151
------------	--

JEFFERSON

Pt. Townsend	JEFFERSON GENERAL HOSPITAL 834 Sheridan Port Townsend 98368 Tel: (206) 385-2200
--------------	--

KING

Seattle	BALLARD COMMUNITY HOSPITAL P.O. Box C-70707, Seattle NW Market and Barnes Seattle 98107-1507 Tel: (206) 782-2700
---------	--

Kirkland	EVERGREEN HOSPITAL MEDICAL CENTER 12040 NE 128th Street Kirkland 98033 Tel: (206) 821-1111
----------	---

Seattle	HARBORVIEW MEDICAL CENTER 325 Ninth Avenue Seattle 98104 Tel: (206) 223-3036 (206) 223-3000
---------	---

Federal Way	ST. FRANCIS COMMUNITY HOSPITAL 34515 - 9th Avenue South
-------------	--

Federal Way 98003
Tel: (206) 838-9700

Seattle

SWEDISH HOSPITAL MEDICAL CENTER
747 Summit Avenue
Seattle 98104
Tel: (206) 386-6000

Seattle

UNIVERSITY OF WASHINGTON MEDICAL CENTER
1959 NE Pacific Street
Seattle 98195
Tel: (206) 548-3300

KITSAP

Bremerton

HARRISON MEMORIAL HOSPITAL
2520 Cherry Avenue
Bremerton 98310
Tel: (206) 377-3911

MASON

Shelton

MASON GENERAL HOSPITAL
2100 Sherwood Lane
Shelton 98584
Tel: (206) 426-1611

PACIFIC

Ilwaco

OCEAN BEACH HOSPITAL
First and Fir
Drawer H
Ilwaco 98624

Tel: (206) 642-3181

South Bend

WILLAPA HARBOR HOSPITAL
P.O. Box 438
South Bend 98586
Tel: (206) 875-5526

PIERCE

Tacoma

ALLENMORE HOSPITAL
P.O. Box 11414, Tacoma 98411
South 19th and Union
Tacoma 98405
Tel: (206) 572-2323

Tacoma

ST. CLARE HOSPITAL
11315 Bridgeport Way S.W.
Tacoma 98499
Tel: (206) 588-6422

Tacoma

ST. JOSEPH HOSPITAL & HEALTH CARE CENTER
1718 South I Street
Tacoma 98405
Tel: (206) 627-4101

Tacoma	TACOMA GENERAL HOSPITAL P.O. Box 5299 315 South K Street Tacoma 98405 Tel: (206) 594-1000
SKAGIT	
Anacortes	ISLAND HOSPITAL 1211 - 24th Street Anacortes 98221 Tel: (206) 293-3181
Mt. Vernon/	SKAGIT VALLEY & UNITED GENERAL HOSPITAL 1415 Kincaid Street Mt. Vernon 98273
SNOHOMISH	
Everett	GENERAL HOSPITAL MEDICAL CENTER P.O. Box 1147 Everett 98206 1321 Colby Avenue Everett 98201 Tel: (206) 258-6300
Everett	PROVIDENCE HOSPITAL P.O. Box 1067 916 Pacific Avenue Everett 98201 Tel: (206) 258-7123
Edmonds	STEVENS MEMORIAL HOSPITAL 21600 - 76th Avenue W Edmonds 98020 Tel: (206) 774-4000
THURSTON	
Olympia	CAPITAL MEDICAL CENTER P.O. Box 19002 3900 Capital Mall Dr. SW Olympia 98507-0013 Tel: (206) 754-5858
Olympia	ST. PETER HOSPITAL 413 North Lilly Road Olympia 98506 Tel: (206) 491-9480 (206) 456-7204 (Admin. Office)
WHATCOM	
Bellingham	ST. JOSEPH HOSPITAL - MAIN CAMPUS 2901 Squalicum Parkway Bellingham 98225-1898 Tel: (206) 734-5400

County: Whatcom

Appendix E. Standard Operating Procedures and Reference Manuals

Table E.1. Official Ecology Standard Operating Procedures.

EAP025 Standard Operating Procedure for Seawater Sampling

www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_SeawaterSampling_v_2_0EAP025.pdf

EAP026 Standard Operating Procedure for Chlorophyll *a* Analysis

www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_ChlorophyllAnalysis_v_3_0EAP026.pdf

EAP027 Standard Operating Procedure for Seawater Dissolved Oxygen Analysis

www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_SeawaterDissolvedOxygenAnalysis_v2_1EAP027.pdf

EAP028 Standard Operating Procedure for Reagent Preparation

www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_Reagent%20Preparation_v2_2EAP028.pdf

Table E.2. Sea-Bird Application Notes.

www.seabird.com/application_notes/AN02d.htm	Instructions for Care and Cleaning of Conductivity Cells
www.seabird.com/application_notes/AN15.htm	TC Duct Assembly & Plumbing Installation
www.seabird.com/application_notes/AN18_1.htm	SBE 18, 27, and 30, & AMT pH Sensor Calibration (PHFIT Version 2.0)
www.seabird.com/application_notes/AN18_2.htm	SBE 18, 22, 27, and 30 pH Sensor Storage, Maintenance, & Calibration
www.seabird.com/application_notes/AN64-1.htm	Plumbing Installation -- SBE 43 DO Sensor and Pump on a CTD
www.seabird.com/application_notes/AN66.htm	Routine Maintenance for the SBE 32 Carousel Water Sampler
www.seabird.com/application_notes/AN75.htm	Maintenance of SBE 5T, 5P, and 5M Pumps
www.seabird.com/application_notes/AN64.htm	SBE 43 Dissolved Oxygen Sensor-Background Information, Deployment recommendations, and Cleaning and Storage

Table E.3. Sea-Bird Manuals.

www.seabird.com/products/spec_sheets/3Fdata.htm	CTD Temperature Sensor SBE3F
www.seabird.com/products/spec_sheets/4data.htm	Conductivity Sensor SBE4
www.seabird.com/products/spec_sheets/18data.htm	pH Sensor SBE 18
www.seabird.com/pdf_documents/manuals/23_000.pdf	SBE 43 Manual
www.seabird.com/pdf_documents/manuals/32_020.pdf	SBE 32 Manual
www.seabird.com/pdf_documents/manuals/25_017.pdf	SBE 25 Manual
www.seabird.com/pdf_documents/manuals/SBEDataProcessing_7.21k.pdf	SBE Data Processing Manual
www.seabird.com/pdf_documents/manuals/AFM_015.pdf	SBE AFM Manual

Table E.4. Biospherical Instruments Inc. and WET-Labs Information.

www.biospherical.com/index.php?option=com_content&view=article&id=52:single-channel-sensors&catid=35&Itemid=65	QSP-2200PD
www.wetlabs.com/eco-flntu	FLNTU
www.wetlabs.com/cstar	C-STAR

Table E.5. Ecology Technical Notes.

Technical Note Marine Flight Troubleshooting 2012
Technical Note Marine Flight Recording Weather revised 2012
Technical Note Marine Flight SBE 25 operations v 2012b
Technical note Marine Flight Safety

Technical Note. Recording Weather, Wind and Wave Conditions 2012

For consistency please record as follows.

Record winds as a degree:

Wind direction is given a compass designation (i.e. N, NW, E, etc.) from direction of origin.

If winds are recorded as an angle, convert to compass direction.

North = 0°

East = 90°

South = 180°

West = 270°

Record wind speed in knots.

Record atmospheric conditions:

Clear / Overcast (clear = completely cloudless sky)

Sun (direct sunlight) / No Sun (direct sun = no clouds in front of sun)

Rain / Fog (rain=precipitation, fog=low lying clouds/precipitation)

Overcast skies should be described as follows:

% of coverage or angle of coverage:

- if clouds are dispersed throughout sky, estimate % coverage of clouds (roughly).
- If clouds are along the horizon “monk hairdo” conditions, determine angle *from the horizon*, that the clouds are covering and use the following table to estimate % of coverage. % coverage = $\sin \theta$

θ	% Coverage	Comments
90°	100%	Completely cloudy sky
60°	85%	Probably not realistic
45°	70%	Probably not realistic
30°	50%	Probably not realistic
20°	35%	Probably not realistic
15°	25%	Band of clouds around horizon
10°	17%	Thin band of clouds around horizon
5°	9%	Very thin band of clouds
0°	0%	Completely clear sky

Record cloud cover as follows:

Give brief description of cloud type:



Stratus clouds are a uniform gray and usually cover most of the sky.



Stratocumulus clouds are lumpy, layered clouds often following a cold front, and they can produce rain or drizzle.



Cirrus clouds are thin and high in the sky.



Cumulus clouds are lumpy and can stretch high into the sky.



A nimbus cloud comes in the form of dark precipitous cloud. Nimbus is known as cloud or rain storm in the Latin language.

Mixed cloud type, a mix of all the above mentioned cloud types.

Record sea surface state, wind wave or swell height as follows:

Flat / Choppy / Whitecaps / Strong current / Eddy or Tidal Rip / Upwelling / Unremarkable.

Estimate wave height using the following guideline & table:

Wave height is a measure of the distance between the trough and the crest of a wave; record in inches.

Beaufort Scale of wind force and probable wave height:

Beaufort number	Description term		Wind speeds		Wave height (m)	
	Wind	Wave	knots	m/s	probable	maximum
0	Calm	-	< 1	0 - 0.2	-	-
1	Light air	Ripples	1 - 3	0.3 - 1.5	0.1	0.1
2	Light breeze	Small wavelets	4 - 6	1.6 - 3.3	0.2	0.3
3	Gentle breeze	Large wavelets	7 - 10	3.4 - 5.4	0.6	1.0
4	Moderate breeze	Small waves	11 - 16	5.5 - 7.9	1.0	1.5
5	Fresh breeze	Moderate waves	17 - 21	8.0 - 10.7	2.0	2.5
6	Strong breeze	Large waves	22 - 27	10.8 - 13.8	3.0	4.0
7	Near gale	Large waves	28 - 33	13.9 - 17.1	4.0	5.5
8	Gale	Moderately high waves	34 - 40	17.2 - 20.7	6.0	7.5
9	Strong gale	High waves	41 - 47	20.8 - 24.4	7.0	10.0
10	Storm	Very high waves	48 - 55	24.5 - 28.4	9.0	12.5
11	Violent storm	Exceptionally high waves	56 - 63	28.5 - 32.6	11.5	16.0
12	Hurricane	Exceptionally high waves	64 - 71	32.7 - 36.9	14.0	> 16
13	Hurricane	Exceptionally high waves	72 - 80	37.0 - 41.4	> 14	> 16
14	Hurricane	Exceptionally high waves	81 - 89	41.5 - 46.1	> 14	> 16
15	Hurricane	Exceptionally high waves	90 - 99	46.2 - 50.9	> 14	> 16
16	Hurricane	Exceptionally high waves	100 - 109	51.0 - 56.0	> 14	> 16
17	Hurricane	Exceptionally high waves	109 - 118	56.1 - 61.2	> 14	> 16

Monthly Tide Phase

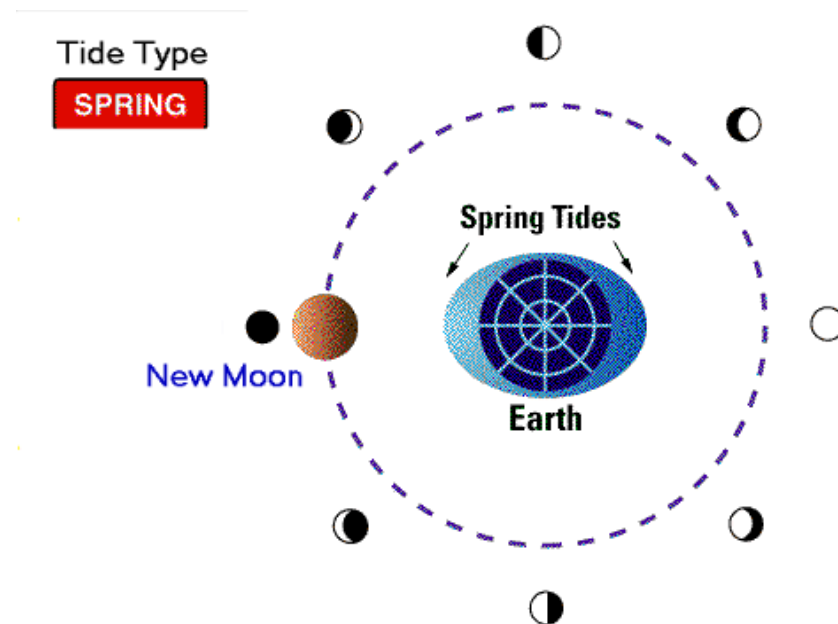
Spring Tides

When the moon is full or new, the gravitational pull of the moon and sun are combined. At these times, the high tides are very high and the low tides are very low. This is known as a spring high tide. Spring tides are especially strong tides (they do not have anything to do with the season Spring). They occur when the Earth, the Sun, and the Moon are in a line. The gravitational forces of the Moon and the Sun both contribute to the tides. *Spring tides occur during the full moon and the new moon.*

Neap Tides

During the moon's quarter phases the sun and moon work at right angles, causing the bulges to cancel each other. The result is a smaller difference between high and low tides and is known as a neap tide. Neap tides are especially weak tides. They occur when the gravitational forces of the Moon and the Sun are perpendicular to one another (with respect to the Earth). *Neap tides occur during quarter moons.*

The Proxigean Spring Tide is a rare, unusually high tide. This very high tide occurs when the moon is both unusually close to the Earth (at its closest perigee, called the proxigee) and in the New Moon phase (when the Moon is between the Sun and the Earth). The proxigean spring tide occurs at most once every 1.5 years.



home.hiwaay.net/~krcool/Astro/moon/moontides/

General Weather Conditions Look-up Lists

General Weather Condition	Cloud Type	Monthly Tide Phase	Tide Stage	Surface Condition	Water Color	Presence/Absence	Daylight savings time ?
Rain	Cumulus	Spring	Flood	Flat	Blue	Yes	0
Fog	Stratus	Neap	Ebb	Choppy	Blue-Green	No	1
Overcast	Strato-cumulus		Low Slack	Wavelets	Dark Green	NA	
Clear	Nimbus		High Slack	Whitecaps	Green	See Comments	
Partly Cloudy	Cirrus				Brown-green		
	Mixed				Brown		
					Red		
					Red-brown		
					Olive		
					Glacial Blue		
					Other (describe)		

Tide Stage

Slack water, or **slack tide**, is the period during which no appreciable [tidal current](#) flows in a body of [water](#). Slack water usually happens near [high tide](#) and [low tide](#), and occurs when the direction of the tidal current reverses.^[1] [Tide tables](#) indicate the time of high and low water at ports and other locations. Slack water can be accurately calculated in most regions using a tide table or current table combined with either a [tidal atlas](#) or the [tidal diamond](#) information on a [nautical chart](#).^[2]

Ebb

- the flowing back of the tide from high to low water or the period in which this takes place
- (as modifier): the ebb tide

<http://encyclopedia2.thefreedictionary.com/ebb>

Tide Height

Use “Tides” program at office to estimate height at nearest tide station

Water color

Blue, Blue-green, Dark green, Green, Brown-green, Brown, Other (describe).

Presence/Absence: Yes, No, NA, See comments

Bloom Presence

Indicate presence/absence of plankton blooms. If more detail is available, add to comment field.

River Discharge

Indicate presence/absence of observable river discharge. If more detail is available, add to comment field.

Debris Island

Indicate presence/absence of wood, debris, terrestrial matter. If more detail is available, add to comment field.

Algal Mats

Indicate presence/absence of algal mats (primarily seaweed/marine species). If more detail is available, add to comment field.

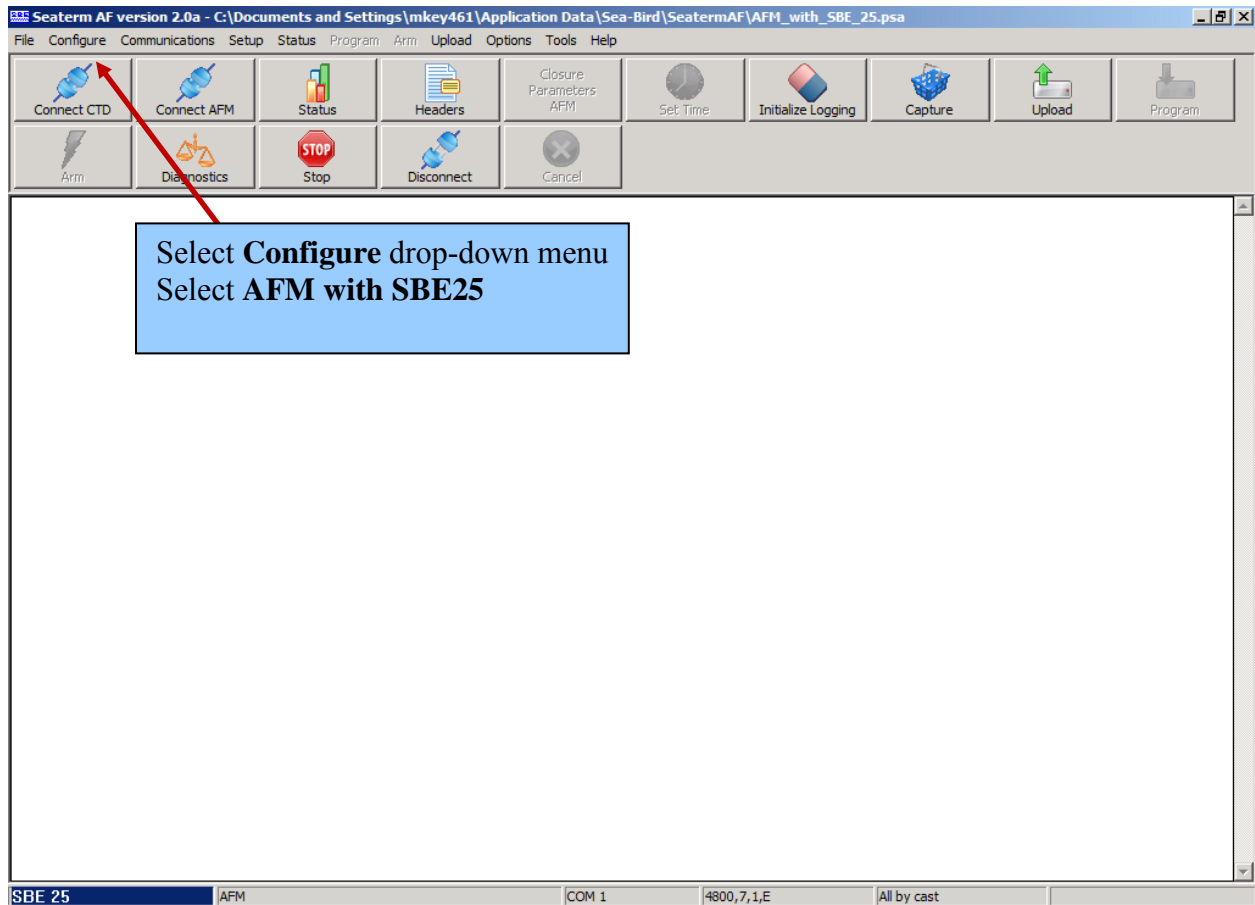
Technical Note. Marine Flight SBE25 operations V2 2012

Program CTD & AFM

Open SeaTermAFV2 software program on desktop

Configure choose SBE25

Configure CTD



Check configuration settings in each window

- You can keep the same Program Setup File and save over the last one or rename and save the days settings.

AFM with SBE 25 Configuration Options

Bottle Closure Pressures/Times | Upload / Header options | AFM Battery

Setup File | Communications | Bottle Closure Logic

Program Setup File

d Settings\mkey461\Application Data\Sea-Bird\SeatemAF\AFM_with_SBE_25.psa

Save Save As...

Instrument Configuration File (.XMLCON or .CON) file

C:\Data\Flights\Current MFA-25\MFA_May12Cal.con

Browse... Modify... Create...

Strain gauge pressure sensor serial number = 0444

Coefficients:

A0 = 1.610152e+002
A1 = -4.147523e-002
A2 = 4.260316e-008
Offset = 0

SBE 3 temperature sensor serial number = 2969

SBE 4 conductivity sensor serial number = 2581

☐ SBE 25 firmware version less than 3.0

☒ SBE 25 firmware version 3.0 or greater

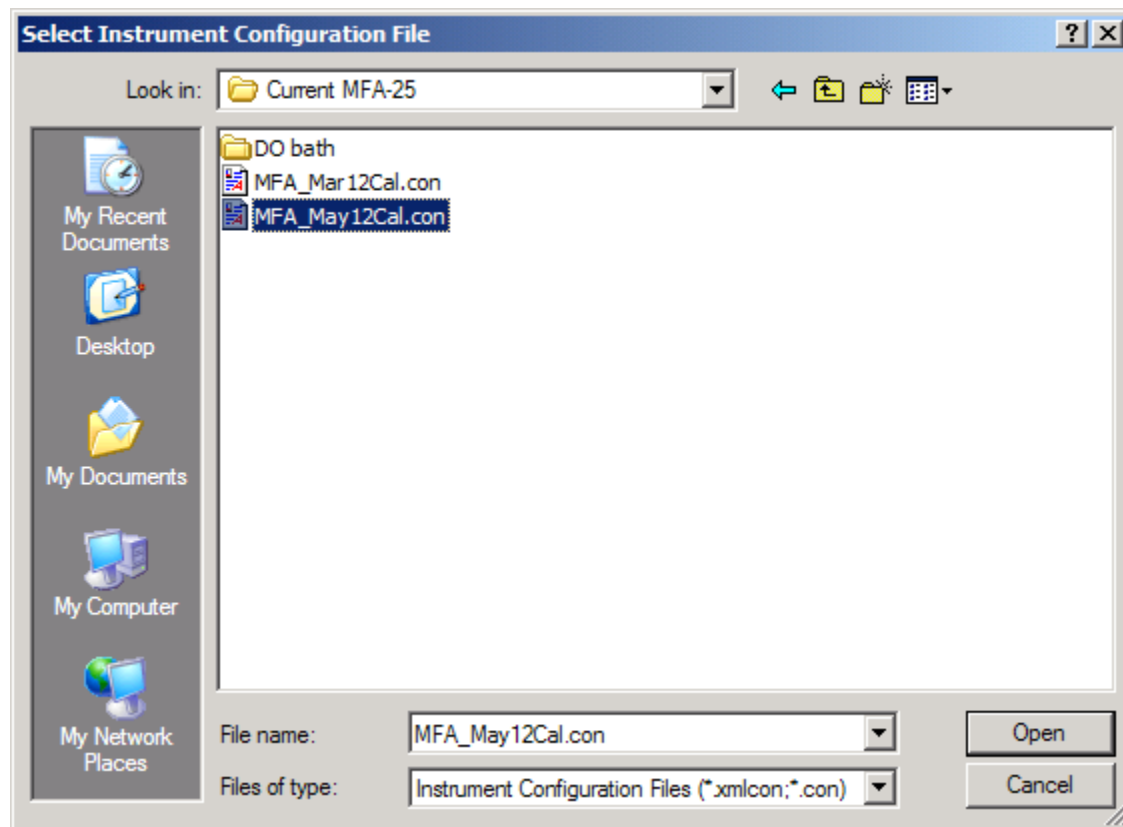
Report Default Help OK Cancel

Select most current **Con File** specific to CTD in use
The **temperature** and **conductivity** sensor serial numbers are now pulled from the configuration file.
Confirm they are the correct numbers.
Check **SBE 25** firmware version **3.0** or greater.

Instrument Package	Sensor	Serial #	.ini Filename
MFA	SBE3 (Temp)	2969	<i>MFAStd.ini</i>
	SBE4 (Cond)	2581	
MFB	SBE3 (Temp)	4501	<i>MFBSStd.ini</i>
	SBE4 (Cond)	3096	
SeaLogger (SBE25)	SBE3 (Temp)	1329	<i>SBESStd.ini</i>
	SBE4 (Cond)	1068	

Table 1. CTD Configurations

Example of current configuration file name and location.



AFM with SBE 25 Configuration Options

Bottle Closure Pressures/Times Upload / Header options AFM Battery

Setup File Communications Bottle Closure Logic

Communications between computer and AFM

Serial port: **COM 1** Data bits: **7**

Baud rate: **4800** Parity: **Even**

Communications between computer and CTD through AFM

Baud rate: **4800** Data bits: **7**

Upload baud rate: **19200** Parity: **Even**

Upload baud rate not applicable if 'SBE 25 firmware version less than 3.0' selected on 'Setup File' tab.

Communication of pressure data from CTD to AFM

Real-time baud rate: **4800**

Not applicable if 'Close on elapsed time, do not record CTD data' selected on 'AFM Bottle Closure Logic' tab.

Report **Default** **Help** **OK** **Cancel**

Check **Communication Logic**
Serial Port **COM 1**
Baud rate **4800**
Data bits **7**
Upload baud rate **19200**
Parity **Even**
Real-time baud rate **4800**

Puget Sound Scenario: Have a longer stationary time on bottom-2mins and only soak at the surface for 1min so you can try to avoid the bottles firing during soak.

AFM with SBE 25 Configuration Options

Bottle Closure Pressures/Times | Upload / Header options | AFM Battery

Setup File | Communications | Bottle Closure Logic

Bottle closure options

☒ Close on upcast ☐ Close on elapsed time, record CTD data

☐ Close on downcast ☐ Close on elapsed time, do not record CTD data

☐ Close when stationary

Upcast / downcast logic

☒ Bottom bottle closure enabled

Pressure to enable bottom bottle [db] 25

Pressure decrease to determine upcast [db] 2

Stationary time on bottom, 1 - 12 minutes 2

Bottom pressure window, 1 - 25 db 1

Stationary logic

Time to hold in pressure window [min]

Pressure window size [db]

Minimum change between bottles [db]

Enable pressure for first bottle

Check Bottle Closure Logic
- Check **Close on upcast**
then check **Bottom bottle closure enabled**
Pressure to Enable Upcast = to 1/2 depth of station being sampled.

Report Default Help OK Cancel

Coast Scenario: The Coast stations are so shallow you need to use a different strategy. Stationary time on bottom-1min and bottom pressure window 1db.

AFM with SBE 25 Configuration Options

Bottle Closure Pressures/Times | Upload / Header options | AFM Battery

Setup File | Communications | Bottle Closure Logic

Bottle closure options

☒ Close on upcast ☐ Close on elapsed time, record CTD data
☐ Close on downcast ☐ Close on elapsed time, do not record CTD data
☐ Close when stationary

Upcast / downcast logic

☒ Bottom bottle closure enabled
Pressure to enable bottom bottle [db] 25
Pressure decrease to determine upcast [db] 2
Stationary time on bottom, 1 - 12 minutes 1
Bottom pressure window, 1 - 25 db 1

Stationary logic

Time to hold in pressure window [min]
Pressure window size [db]
Minimum change between bottles [db]
Enable pressure for first bottle

Report Default Help OK Cancel

Check Bottle Closure Logic
- Check **Close on upcast**
then check **Bottom bottle closure enabled**
Pressure to Enable Upcast = to ½ depth of station
being sampled.

Set up when you don't need a near bottom bottle (no DO sample needed).

AFM with SBE 25 Configuration Options

Bottle Closure Pressures/Times | Upload / Header options | AFM Battery

Setup File | Communications | Bottle Closure Logic

Bottle closure options

☒ Close on upcast ☐ Close on elapsed time, record CTD data

☐ Close on downcast ☐ Close on elapsed time, do not record CTD data

☐ Close when stationary

Upcast / downcast logic

☐ Bottom bottle closure enabled

Minimum pressure to determine upcast [db] 25

Pressure decrease to determine upcast [db] 2

Stationary time on bottom, 1 - 12 minutes 1

Bottom pressure window, 1 - 25 db 11

Stationary logic

Time to hold in pressure window [min] 10

Pressure window size [db] 10

Minimum change between bottles [db] 10

Enable pressure for first bottle 500

Report Default Help OK Cancel

Check Bottle Closure Logic

- Check **Close on upcast**

- If you don't need a NB bottle **uncheck the bottom closure enabled**.

Pressure to Enable Upcast = to $\frac{1}{2}$ depth of station being sampled.

AFM with SBE 25 Configuration Options

Setup File | Communications | Bottle Closure Logic

Bottle Closure Pressures/Times | Upload / Header options | AFM Battery

Number of Bottles to Close: 4

Closure order	Bottle position	Closure pressure[db]	Closure order	Bottle position	Closure pressure[db]
Bottom bottle	3	stationary	18		
2	8	30.5	20		
3	10	10.5	21		
4	12	0.75	22		
5			23		
6			24		
7					
8					
9					
10					
11					
12					

Closure pressures must decrease from closure 1 to last bottle.

Report Default Help OK Cancel

Change number of bottles to 4
 Check **bottle firing position**
 Set **bottles** to fire 0.5 m deeper than desired depth
30.5, 10.5, 1.0 or 0.75 m. At 0.75 you will see the
 bottles fire.

AFM with SBE 25 Configuration Options

Setup File | Communications | Bottle Closure Logic

Bottle Closure Pressures/Times | Upload / Header options | AFM Battery

Upload options for CTD data upload (.hex) file

☒ All data separated by cast ☐ All data as a single file

☐ Single cast ☐ By scan number range

☐ By cast number range

Header options for CTD data upload (.hex) file

☐ Prompt for header information

☐ Include default header information

☒ Do not include header information

Header options for AFM data upload (.afm) file

☐ Prompt for header information

☐ Include default header information

☒ Do not include header information

Scans per block for CTD upload

300

Report Default Help OK Cancel

Check AFM communication logic

- **All data separated by cast**
- **Do not include header information**
- **Do not include header information**
- **Scans per block use default 300**

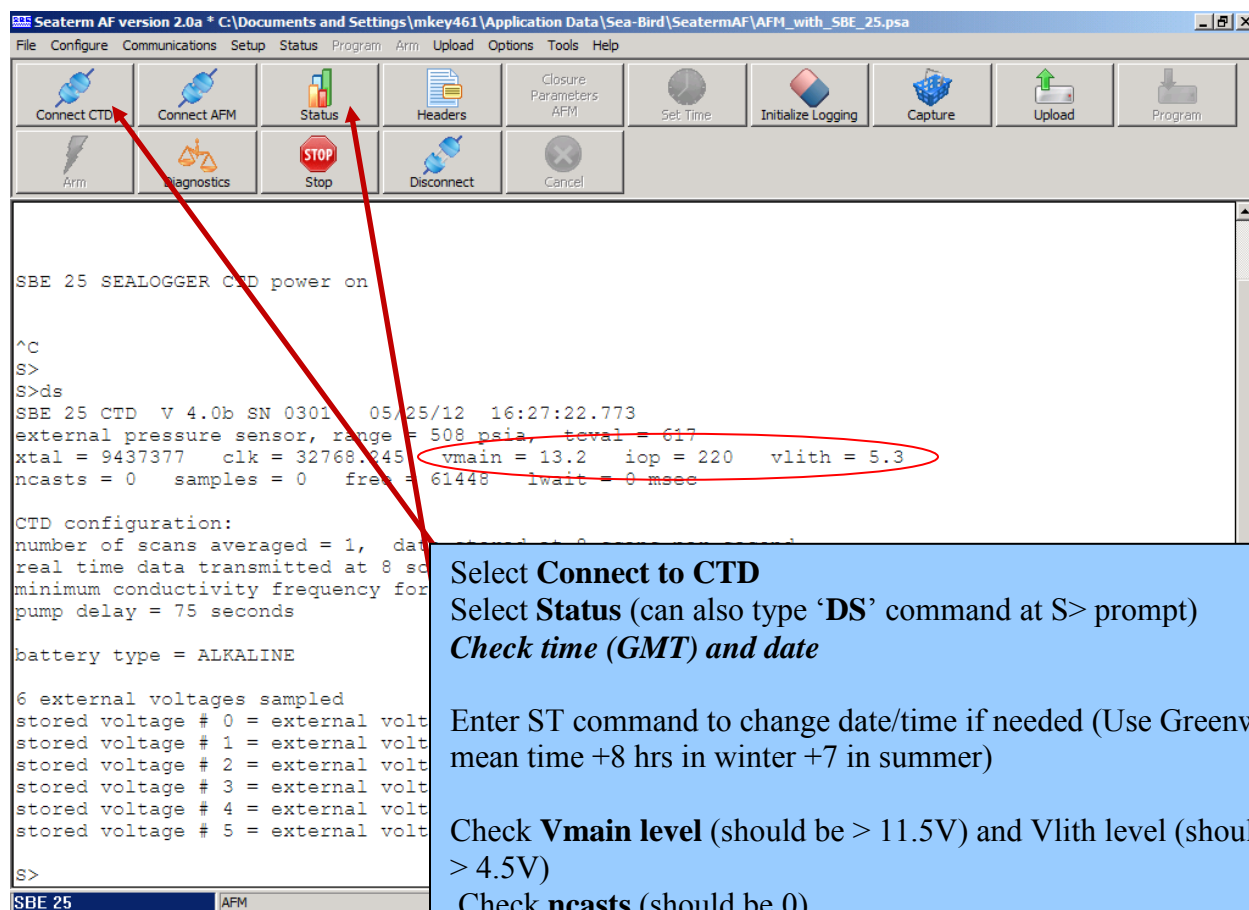
AFM with SBE 25 Configuration Options [X]

Setup File	Communications	Bottle Closure Logic
Bottle Closure Pressures/Times	Upload / Header options	AFM Battery

☒ Alkaline
☐ Nickel metal hydride (NiMH)
☐ Nickel-cadmium (Ni-Cad)

**Check AFM communication logic
Select **battery type** as Alkaline**

Report Default Help OK Cancel



Select **Connect to CTD**

Select **Status** (can also type 'DS' command at S> prompt)

Check time (GMT) and date

Enter ST command to change date/time if needed (Use Greenwich mean time +8 hrs in winter +7 in summer)

Check **Vmain level** (should be > 11.5V) and **Vlith level** (should be > 4.5V)

Check **ncasts** (should be 0)

Seaterm AF version 2.0a * C:\Documents and Settings\mkey461\Application Data\Sea-Bird\SeatermAF\AFM_with_SBE_25.psa

File Configure Communications Setup Status Program Arm Upload Options Tools Help

Connect CTD Connect AFM Status Headers Closure Parameters AFM Set Time Initialize Logging Capture Upload Program

Arm Diagnostics Stop Disconnect Cancel

A>
A>
A>

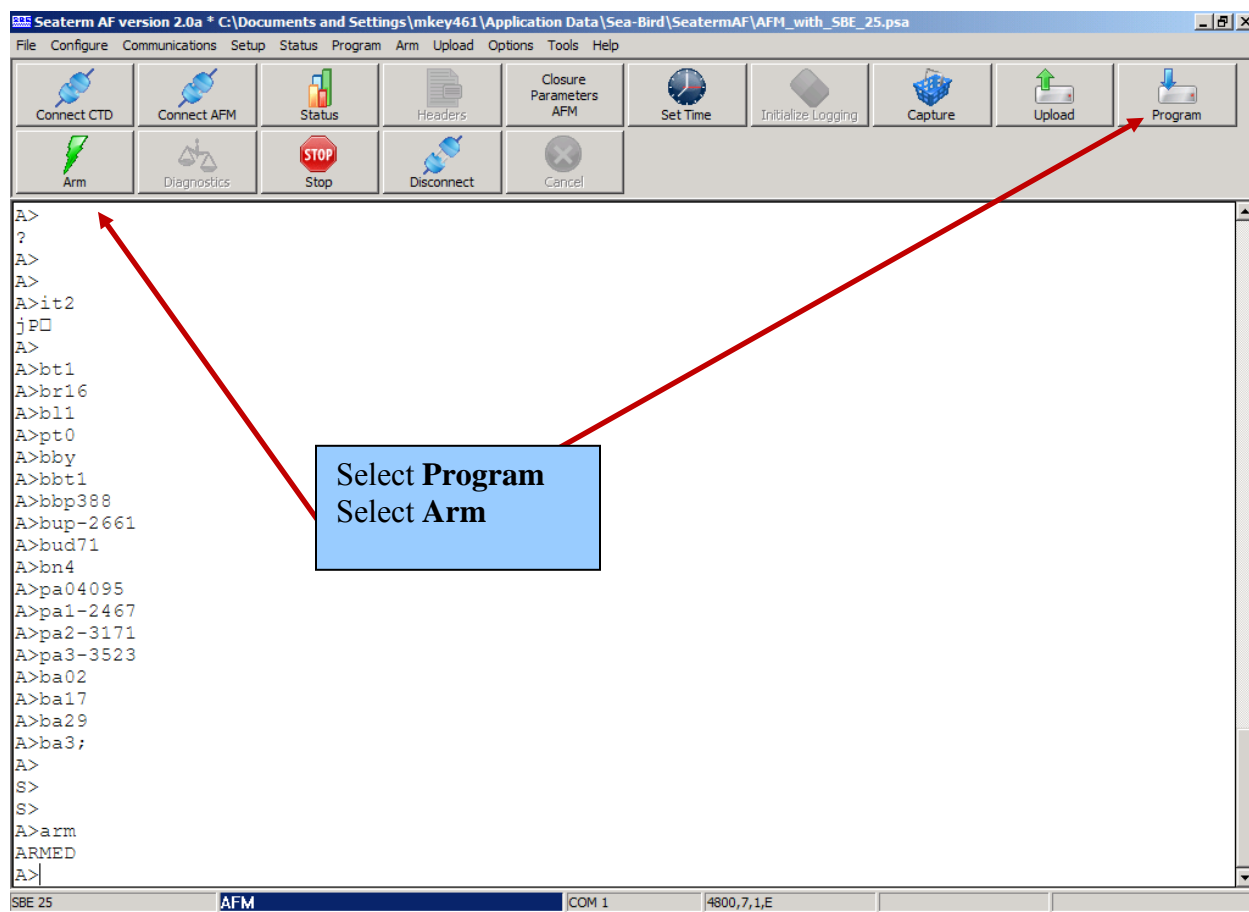
Select **Connect AFM**
Select **Status** (can also type 'DS' command at S> prompt)
Check time (GMT) and date

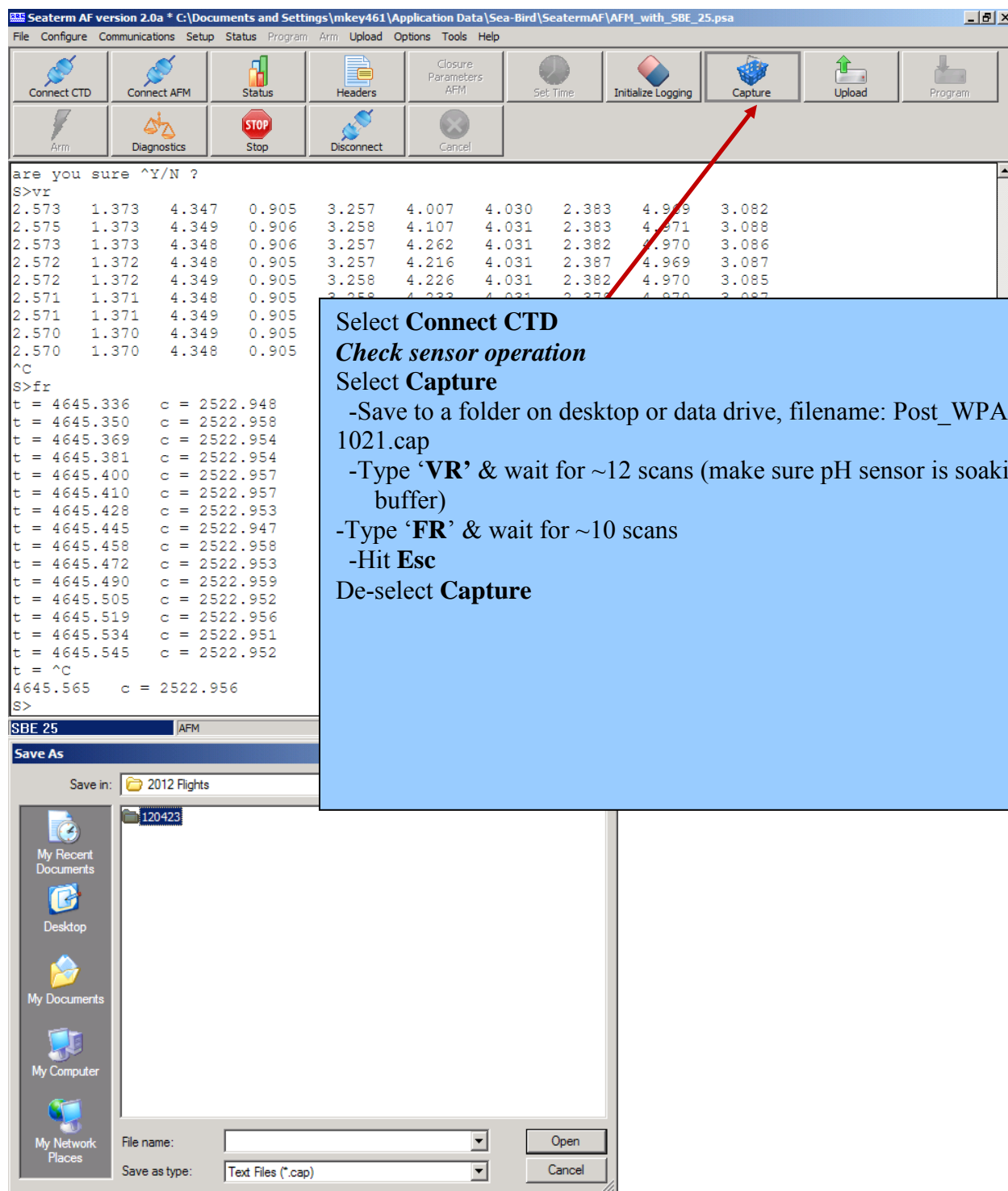
Enter ST command to change date/time if needed (Use Greenwich mean time +8 hrs in winter +7 in summer)

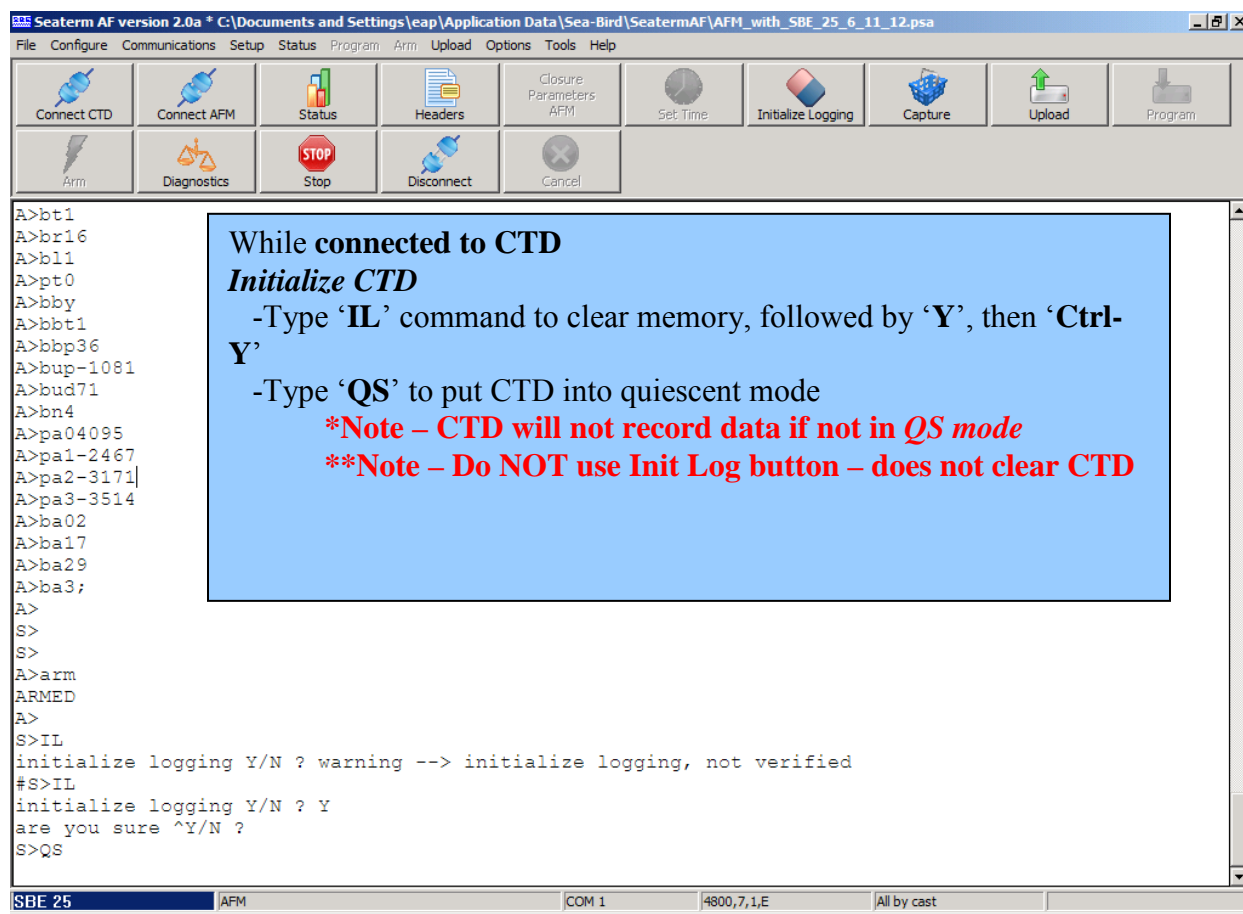
Check **Vmain level** (should be > 11.5V) and **Vlith level** (should be > 4.5V)

A>
A>
A>
A>
A>
A>ds
SBE 90208 Auto Fire Module V 1.1 05/25/12 23:29:57.2
vmain = 13.0 , vlith = 5.0
Auto Fire Module is NOT ARMED
A>

SBE 25 AFM COM 1 4800,7,1,E







Remove pH buffer 8 from pH sensor.

Prep CTD for deployment (PREFERRED METHOD):

- Turn magnetic CTD switch '**On**' while the comm cable is still plugged in.
- Watch for **data to scroll** across the screen, indicating CTD is logging data.
- Select **Disconnect**, then put laptop into **Standby mode**.
- Disconnect the **comm cable** from CTD.
- Replace dummy plug.

*Alternatively

- Disconnect **communication cable** from CTD.
- Replace dummy plug.
- Wait **2 minutes** then turn magnetic switch '**On**', **slowly & firmly**.
- *Note – 2 minute wait is necessary to allow the comm channel to clear signal from unplugging the comm cable. CTD will **not** log data if channel not cleared

Deploy CTD

- Lower **CTD** into water until top of frame is 1 meter under the surface.
- Soak for at least **90 seconds**.
- Raise **CTD** back up until lower frame piece is at the surface.
- Hold for **6 seconds**, taking care not to lose prime on pump.
- Lower to **depth**, taking care not to drag on bottom or do a "mud plant".
- Hold 1-2 m off bottom for **60 seconds**.
- Bring back to **surface**.

- Turn **CTD 'Off'** when brought back onboard.

If QA station:

- ***For bottom bottles***, do regular cast.
- Hold CTD at bottom for 2 – 3 minutes to allow all bottles to trip.
- Bring to surface
- ***For surface bottles***: Program bottles to fire at surface. Follow CTD deployment procedures.
- Raise CTD to surface until top of frame is just under water. Allow all bottles to close.

Upload CTD & AFM

****Note – CTD & AFM must both be uploaded on every data upload.***

- Put **pH buffer 8 back** on pH sensor.
- Plug **communication cable** into CTD.
- Open **SeaTermAF**.
- Select **Connect CTD**.
- Select **Upload**.
- Enter filename according to Table 2.

****Note - File should be saved to C:\Data\Seabird\Flights for newer CF-29b***

*****Note - The software will automatically append a cast # (000, 001, etc.) to the end of the filename.***

******Note - If one or more CTD-only stations (no bottle samples) follow a station where water bottles were tripped, and the CTD has not been uploaded, give the filename the normal sequential letter (a,b,c, etc). The software will append 000 to the 1st cast, 001 to the 2nd cast, 002 for the 3rd cast, etc.***

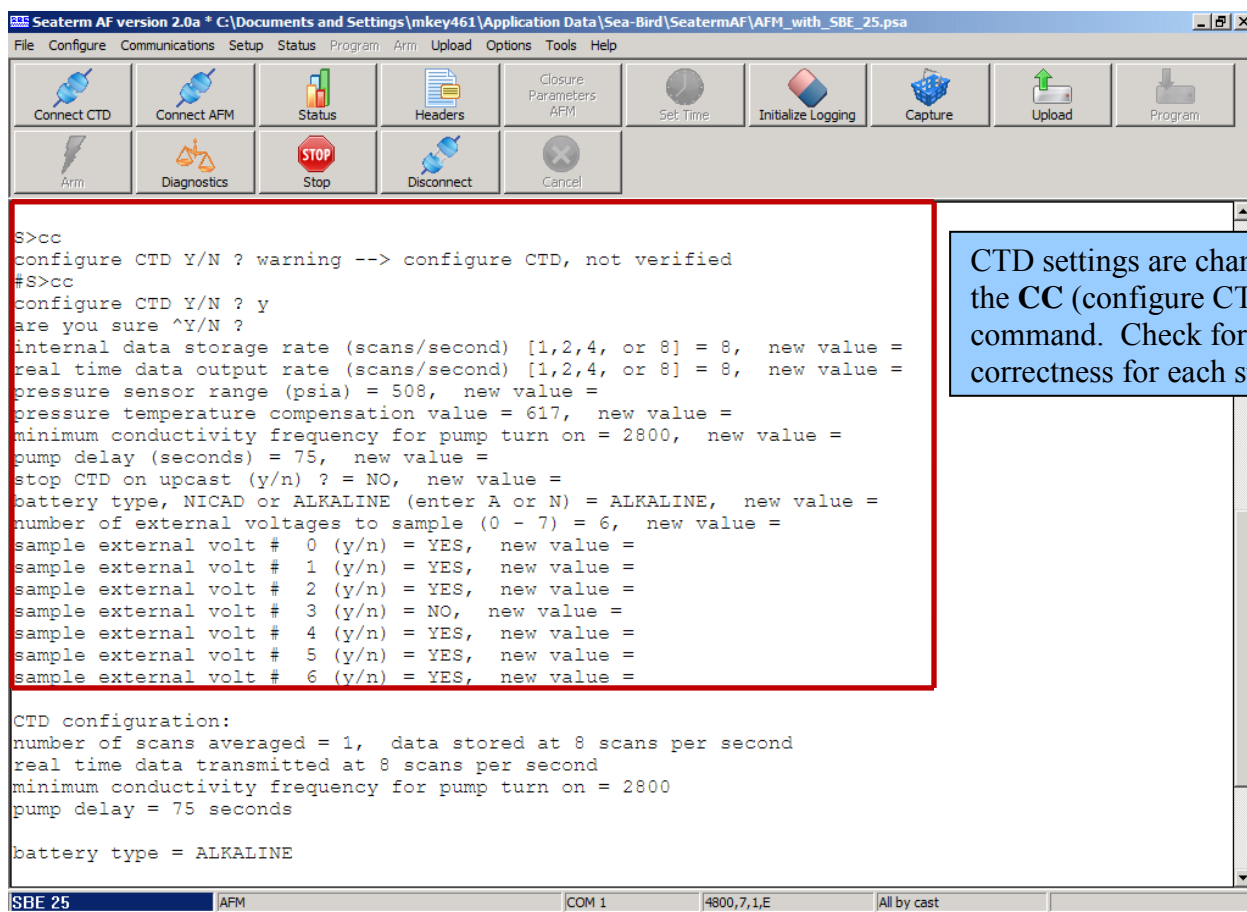
- Select **Connect AFM**.
- Select **Upload**.
- Name **AFM file** to ***match*** the CTD hex file.

****Note - The AFM file will always have the same cast # as the ***last*** cast of each CTD upload (000 for 1 cast, 001 for 2 casts, etc).***

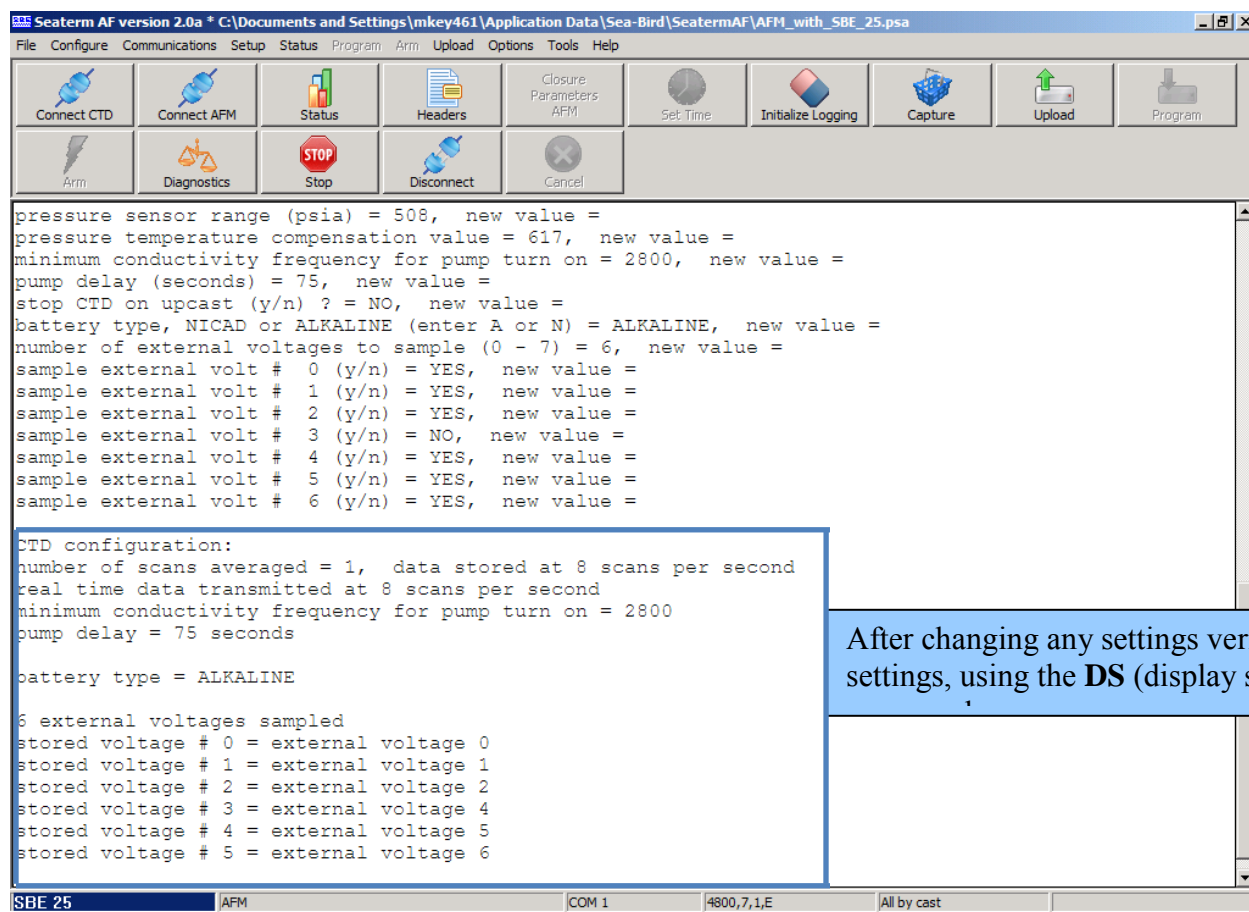
Reprogram **CTD & AFM** for next station.

Table 2. CTD File Naming Convention

Marine Waters Monitoring - CTD File Name Convention				
(by project)				
Project:	Naming Convention:	Example:	Types of Files:	
Long-Term	<i>yymmdd_stationname000.hex</i>	120103_BUD005000.hex	hex (CTD)	
Marine Flights/Profiles	<i>yymmdd_stationname000.afm</i>	120103_BUD005000.afm	rosette (afm)	
	x = consecutive letter starting with "a"			
	00# = cast number that software appends to file			
South Sound (SPSMEM)	<i>yymmddxx##00#.hex</i>		hex (CTD)	
Skookum voyages	<i>yymmddxx##00#.afm</i>		rosette (afm)	
	xx## = Station number			
	00# = cast number that software appends			
South Sound (SPSMEM)	<i>mmddy0##01.dat</i>		dat (CTD)	
Barnes voyages	<i>mmddy0##01.bl</i>		rosette	
	0## = Station number			
	01 = cast number that software appends			
Willapa Bay moorings	<i>WPA##yymmdd.hex</i>		hex (CTD)	
	WPA## = Station number			
Puget Sound moorings	<i>XXX##yymmdd.hex</i>		hex (CTD)	
	XXX## = Station designation:			
	X = letter, ## = station number			



CTD settings are changed using the CC (configure CTD) command. Check for correctness for each specific



After changing any settings verify settings, using the **DS** (display status)

Environmental Assessment Program Safety Manual - 2012

Chapter 2. Specialized Work: Marine Flights

Purpose

To describe safety precautions for marine flights.

Application

For EAP staff conducting marine flights.

Requirements

Field sampling notification

A *Field Sampling Notification* form must be completed by staff prior to the flight. The form must be turned into the EAP section secretary.

Notification of the US Coast Guard (USCG) on flight days

On the morning of a flight, notification of flight activities must be sent in the form of an email cover letter and flight map for the applicable flight to the U.S. Coast Guard at:

hlswatch@pacnorwest.uscg.mil

Flight operations near naval bases and vessels

Two of the Marine Monitoring Unit's long-term marine flight stations are located near Naval Operations Areas including the Bremerton Naval Shipyard (Sinclair Inlet) and the Indian Island Munitions Depot, Pt. Townsend. Due to the Navy's sensitivity regarding the security of these areas, it is advisable to use judiciousness and exercise cautious behavior when sampling in the vicinity of these bases. One of the long-term marine flight stations is now located in a no-fly (total security restriction) zone, near the submarine base at Bangor (Hood Canal). Access to this station is not allowed. Flight personnel must familiarize themselves with the boundaries of this area and avoid entering this air space.

Naval vessels must not be approached. All vessels must maintain a distance of at least 500 yards from any Navy vessel. When in the vicinity of a naval vessel, contact the vessel on [VHF16](#) and contact the USCG senior watch officer at [206-217-6002](tel:206-217-6002) and notify them of flight activities.

Lifting hazards

Staff must be aware of the lifting hazards involved in loading and unloading the van and plane. Follow the lifting safety procedures recommended in the [Ecology Safety Program Manual](#).

Safety in the air

Staff must familiarize themselves with the location and use of the emergency equipment (life preservers, life raft, first aid kit, radio, exits, etc). The pilot will provide this information to all staff and observers before take-off. Earplugs, seat belts, and life vests (stormy seas) must be worn while in the air and during take-offs and landings.

Safety on the water

The float plane is considered a watercraft while on the water and must follow all boating safety rules that apply to boats and other motorized watercraft. The pilot is responsible for the safe operation of the float plane. Staff must be aware that the float plane cannot maneuver as quickly, and is more affected by the wind than a boat of the same size. Paddles are located on the pontoons to help maneuver in an emergency situation.

Winch operation

Due to the close proximity to rotating equipment, the winch operator must wear proper clothing and avoid loose hair to prevent entanglement. Crew members must be instructed not to distract or have conversations with the winch operator while the winch is in operation, except during an emergency. The winch operator must never leave the winch unattended while it is in operation.

The winch operator must make every effort to safely guide the Vectran line evenly onto the winch drum while the winch is re-spooling. This assures balanced distribution of the line, as well as preventing the line from jumping off the drum and entangling in the spindle and creating snarls and weaknesses in the line.

Snagging the Conductivity, Temperature, and Depth (CTD) Instrument

If the CTD becomes permanently snagged on the bottom, the line must be released and a buoy attached to mark the spot (allow sufficient extra line to account for tidal fluctuations and current set). Get a position (dead reckoning, GPS, pilot's fix) as soon as possible. Staff must not attempt to use the plane nor the marine flight winch and winch frame to free the instrument as this could lead to extremely unsafe situations or equipment failure or both. Staff must return by boat ASAP to retrieve the equipment.

Chemical use

Powdered or liquid chemicals for fixing dissolved oxygen as well as chemicals for preservation of phytoplankton samples are used on the flights. Staff must be familiar with the applicable Material Safety Data Sheets and wear appropriate protective gear such as eye protection and gloves. Staff must also follow safety guidelines in the [Ecology Headquarters Chemical Hygiene Plan](#). The pilot and air crew must be made aware of the hazards of these chemicals and how they are to be employed during marine flight operations. The MSDSs must be made available for review by the flight crew.

Chapter 2. Specialized Work: Operating Winches on Small Boats, Trailers, and Vehicles

Purpose

To ensure EAP staff operating winches receive adequate on-the-job training to prevent personal injury and also loss/damage to expensive field sampling equipment.

Application

For EAP staff operating an electrically operated or mechanically operated winch on an Ecology-owned or -leased boat, boat trailer, winches, vehicle winches, portable winches, and marine float plane winches. This policy presents operating and safety considerations primarily for winches on boats, but for other winches as well.

Requirements

EAP boat operators must comply with all provisions of the [EA Boating Plan](#) and Ecology policy [Operating Ecology Boats](#) (Chapter 3 of this manual) by briefing the crew on all safety-related items on board an Ecology boat or a boat leased to Ecology. This includes the winch system, as installed, for raising and lowering scientific equipment, anchors, and grabs.

The staff assigned to operate the winch controls must be instructed on proper winch boom positioning and locking, lowering control and cable pay-off considerations, raising control, and need for proper cable winding on the cable drum. Also, the need to restrict boom swing and the boom's load effect on boat stability must be demonstrated within

safety limits. Staff assigned to operate other types of winches, e.g., boat trailer, will receive similar safe-operating instructions.

Due to the close proximity to rotating equipment, the winch operator must avoid loose clothing and hair to prevent entanglement. He/she must wear gloves to prevent being hooked by broken cable strands ("fish hooks") as the cable is fed back on the cable drum.

Before actual winch operations, the operator must inspect the winch to ensure all mechanical and electrical components are in serviceable condition.

Equipment failure of the winch system requires an [Equipment Problem Report](#) be given to the Operations Center technician. Any injury sustained in operating the winch that is treated beyond first aid must be reported to the Ecology safety officer by the winch operator within 24 hours.

The winch operator needs to stay focused on operating the winch. The operator must not engage in eating or drinking, and crew members must be instructed not to distract the winch operator while the winch is in operation.

Staff must always wear hard hats when overhead pipes, beams, sampling equipment, and other overhead objects are within the work area.

Chapter 3. Boating: EAP Boating Plan

Purpose

To ensure EAP staff safety while operating watercraft.

Application

For EAP staff operating Ecology-owned or leased boats.

Requirements for Vessel Use

EAP staff who desire to become boat operators must:

- Attend a U.S. Coast Guard Auxiliary or U.S. Power Squadron boating safety course or possess a U.S. Coast Guard license. Upon satisfactory completion of an approved boating safety course, the EAP employee will send a copy of the course completion certificate to their immediate supervisor and to the Ecology safety officer to be kept on file.
- Attend the following EAP-sponsored class as soon as practical: EAP Boating Course arranged through the Ecology Training Office.
- Act as crew members for on-the-job training before being the boat operator for each Ecology boat. This will allow for training on boat-specific equipment and unique boat handling characteristics.

Responsibilities of the EAP boat operator:

- The boat operator must be accompanied by a crew member, and both must have current First Aid/CPR certification.
- Oversee the safe and proper operation of the boat when trailering and while on the water. As the designated boat operator, you may delegate duties, but the overall responsibility remains with you.
- Select from EAP's boat fleet the proper boat for your purposes, based on size, engine power, engine type, load limits, and standard and unique onboard equipment. Refer to "Boat Information for the EAP" located in this *Safety Manual*.

- Consider the boat's normal and special equipment needs while operating the boat. If the needed equipment is not normally available for the selected boat, contact the Operation Center's technical staff for assistance in fabricating/purchasing the needed equipment or the proper exchange of equipment from another EAP boat. You must not remove equipment from another boat without the knowledge of the Operation Center's technical staff.
- Reserve the selected boat using the EAP's web site for "[Boat Reservations](#)" If you anticipate heavy use of a vessel for an extended period of time (e.g., every other week for two months), you must notify the other unit supervisors at least two weeks in advance of first use. This will allow everyone time to manage schedule conflicts.
- Select the proper towing vehicle for size, power, and braking ability. While towing, take into consideration the weather, road conditions, and traffic; expect the unexpected. You are responsible for the safe driving of the combined tow vehicle/boat trailer even if a co-driver is behind the wheel.
- File an [Ecology Field Plan](#) and designate a primary contact person to close the plan. If operations are covering multiple days, you must make contact on a daily basis to close the field plan and prevent an unnecessary search operation by the U.S. Coast Guard or other rescue agencies. You must also instruct the primary contact person to contact EAP supervisors when a search for an overdue boat is underway.
- Use the "[Boat Check List](#)" during pre-use inspections, departure from the Operation Center, at the launch site, and upon return of the boat to the Operation Center, clean and ready for the next person's use. Take every opportunity to inspect (1) trailer wheel bearings for overheating while towing and (2) trailer suspension/boat support rollers when the boat is off the trailer.
- While on the water, (1) follow established U.S. Coast Guard Navigation Rules for International and Inland boat operations and (2) display good seamanship and courtesy at all times.
- Oversee the well-being of crew members and their actions while aboard an Ecology boat. Brief the crew on emergency procedures and location/operation of emergency equipment prior to getting underway. Require boat crew to wear Personal Flotation Devices (PFDs) at all times when crew could fall into the water, and always during boat operations.
- Be aware of conditions that could affect the health and safety of the crew. Driving too far or spending too long on rough water may lead to fatigue and accidents. Schedule adequate time for each part of the boating operations, including lunch breaks and crew rest breaks. Watch for signs of crew stress, especially during weather extremes. No circumstances justify risking harm to staff or property.
- Decide whether to begin or continue any boating activity. If small craft advisories, gale warnings, or other weather notices have been posted by the U.S. Weather Service, you must exercise additional caution and good judgment in deciding whether to conduct boating activities. If in doubt, do not go.
- Check weather forecasts for the area you will be operating in. The National Weather Service forecasts can be accessed at:
 - Their web site: www.wrh.noaa.gov/Seattle/
 - NOAA weather radio at 162.475 MHz (most vessel VHF-FM radios access this weather channel).

-- If operating on lakes or rivers, you may also wish to check local telephone directories for information about local weather forecasts.

- Oversee all staff and equipment when trailering a boat and during boating operations. Do not be persuaded to deviate from known safe boat or vehicle operations at the request of others.
- Report deficiencies or usage of any boating safety equipment as well as problems with engines, electrical systems (lighting, pumps, navigation, radios), or boat trailer components. Reporting will be on a standard EAP [*Equipment Problem Report*](#) and left with the Operations Center technical staff. The forms are available in printed form at the Operation Center manager's desk. The Equipment Problem Report will be maintained in the boat's maintenance file located in the Operations Center's office filing cabinet's top drawer.
- Report all water-related or boat trailering-related accidents that require attention beyond first aid, to the Ecology safety officer within 24 hours of the incident. If an [*Injury/Accident report*](#) is required, provide copies to the Operations Center manager as well as his/her unit, section, and program manager.

Appendix F. Quality Assurance Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Examples of data types commonly validated would be:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Method Detection Limit (MDL): This definition for detection was first formally advanced in 40CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of

an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero. (Federal Register, October 26, 1984)

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

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

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

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

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

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

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

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

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

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

$$[\text{Abs}(a-b)/((a + b)/2)] * 100$$

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

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

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

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

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

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

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

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

Split Sample: The term split sample denotes when a discrete sample is further subdivided into portions, usually duplicates. (Kammin, 2010)

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

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

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

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